# MINERAL RESOURCES OF THE LOWER OWYHEE CANYON WILDERNESS STUDY AREA MALHEUR COUNTY, OREGON

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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 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 Lower Owyhee Canyon Wilderness Study Area, (OR-003-110) Malheur County, Oregon

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## SUMMARY

### Abstract

At the request of the U.S. Bureau of Land Management, the Lower Owyhee Canyon Wilderness Study Area, comprising approximately 73,010 acres, was evaluated for mineral resources and mineral resource potential. Throughout this report, "wilderness study area" and "study area" refer to the 73,010 acres for which mineral surveys were requested. The U.S. Geological Survey and the U.S. Bureau of Mines conducted geologic, geochemical, and geophysical surveys in 1986 and 1987 to assess the identified mineral resources (known) and mineral resource potential (undiscovered) of the study area. The study area contains an inferred subeconomic resource of 7.7 million short tons (st) of zeolite-bearing rock and less than 2,000 st of decorative stone. Sand and gravel covers approximately 6 mi². The entire study area has low mineral resource potential for gold, silver, lead, zinc, antimony, and mercury. Northern and central parts of the study area have low mineral resource potential for barite. The southern two-thirds of the study area has low energy resource potential for oil and gas. Central and southern parts of the study area have low potential for geothermal energy resources.

### Character and Setting

The Lower Owyhee Canyon Wilderness Study Area is about 30 mi west of Jordan Valley, Oreg. (fig. 1). The study area is part of the Owyhee Plateau where a 32-mi-long segment of the Owyhee River has cut a canyon into a broad plateau that includes low hills, mesas, and buttes. The canyon is incised as much as 1,960 ft into the plateau. The study area is underlain by Miocene, Pliocene, and Quaternary sedimentary, volcanic, and volcaniclastic rocks and deposits (fig. 2; see "Appendixes" for geologic time chart). A few steep faults cut the rocks of the study area.

### Identified Resources

The study area contains approximately 7.7 million short tons (st) of zeolite (clinoptilolite) resources having an ammonia-ion exchange capacity (AEC) as high as 2.00 milliequivalents per gram (meq/g) and less than 100 ft of overburden in the Chalk Basin–Lambert Rocks area. Decorative stone occurs in Chalk Basin. Sand and gravel covers approximately 6 mi² on the canyon rims. None of these high-volume, low-unit-value commodities are economically exploitable at present because the same commodities are available closer to existing markets or railways.

### Mineral Resource Potential

The entire study area has low mineral resource potential for gold, silver, lead, zinc, antimony, and mercury. Two smaller areas in the northern and the central parts of the study area have low mineral resource potential for barite. The southern two-thirds of the study area has low energy resource potential for oil and gas. Two small areas in the central and southern parts of the study area have low potential for geothermal energy resources.

## INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is the result of a cooperative effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to a system that is a modification of that described by McKelvey (1972) and the U.S. Bureau of Mines and U.S. Geological Survey (1980). U.S. Geological Survey studies are designed to provide a scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. See "Appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

## Area Description

The Lower Owyhee Canyon Wilderness Study Area (OR–003–110) covers 73,010 acres along the Owyhee River

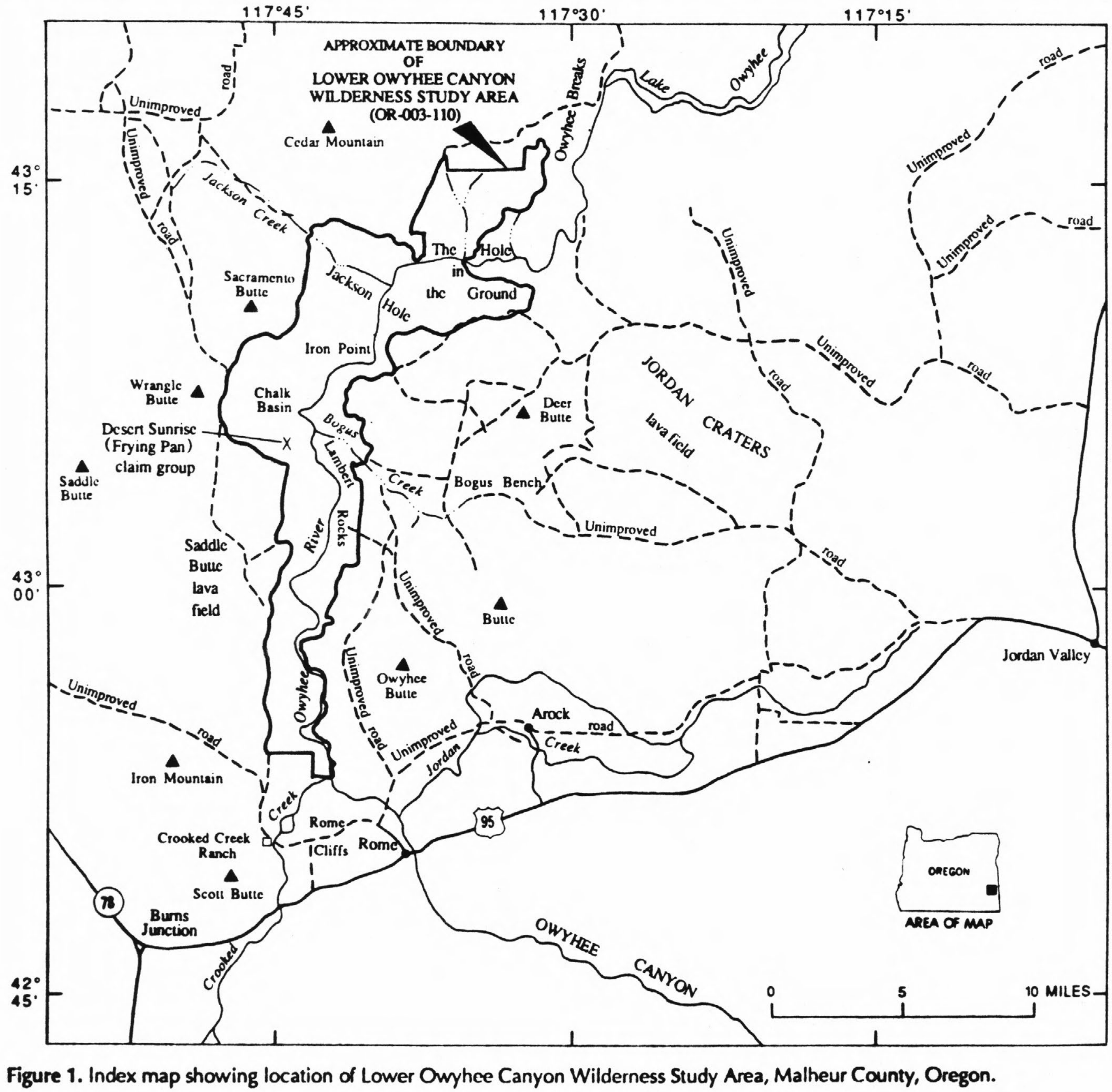

Figure 1. Index map showing location of Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon.

and adjacent parts of the Owyhee Plateau. The terrain is flat to hilly away from the canyon. The plateau rises gradually from 3,780 ft at the southern end north of Rome, Oreg., to 4,800 ft at the northern end north of The Hole in the Ground. Over this same distance, the Owyhee River drops from 3,360 ft at the southern end to 2,840 ft at the northern end. Maximum relief is 1,960 ft at the northern end where the canyon is 5 mi wide. The canyon is most spectacular, however, at Iron Point, where the gorge is one-half mile wide and 1,400 ft deep. Sedimentary rocks along the canyon wall consist of alternating white, green, and red beds in the Chalk Basin and Jackson Hole areas. Most tributaries of the Owyhee River are incised as much as several hundred feet. Bogus Creek, however, flows over the very young basalt flows of Lambert Rocks and descends to the Owyhee River over a 200-ft-high waterfall. The arid climate supports sagebrush, rabbit brush, and sparse native grasses. Riparian areas support mostly grasses, rushes, and sedges. Parts of the study area are used for cattle grazing and also support mule deer, pronghorn antelope, wild horses, coyotes, and numerous species of birds, small mammals, and reptiles, including the western diamondback rattlesnake.

Dirt roads and jeep trails follow much of the study area boundary. Access to most of the study area is best from Rome on U.S. Highway 95. The east side of the study area is accessible by crossing the Owyhee River at a ranch 2 mi north of Rome. The west side of the study area is accessible from the gravel road through Rome Cliffs and Crooked Creek Ranch. The Hole in the Ground area at the northern end can also be reached by dirt roads from U.S. Highway 95, 27 mi east of the study area, and by dirt roads that intersect the paved highway 14 mi north of Jordan Valley and pass through the Jordan Craters area.

### Previous and Present Investigations

Reconnaissance geologic mapping of the southern part of the study area was published by Walker and Repenning (1966) at the scale of 1:250,000, and later, a geologic map that included all of the study area was published by Walker (1977) at the scale of 1:500,000. Other workers (Hart, 1982; Hart and Mertzman, 1983; Hart and others, 1983) studied the stratigraphy and chemistry of the volcanic rocks of southeastern Oregon and adjacent regions, including part of the Lower Owyhee Canyon Wilderness Study Area. Plumley (1986) studied the volcanic stratigraphy and chemistry of The Hole in the Ground area. A small part of the geology mapped by Plumley was used in preparing figure 2.

Other studies that cover part or all of the study area include an evaluation of uranium resources in the southernmost 8 mi of the study area in the Jordan Valley 1° by 2° quadrangle (Berry and others, 1981), regional studies of the geology and mineral resources (Gray and others, 1983; Bukofski and others, 1984), a description of nitrate deposits (Williams, 1918; Mansfield and Boardman, 1932), and an investigation of the ground-water hydrology (Newcomb, 1961). Zeolite tuffs near Rome (the informal Rome beds) immediately south and southwest of the study area and contemporaneous with part of the Miocene sedimentary rock section in the study area, were examined by Regis (1967), Ellison (1968), Sheppard and Gude (1969, 1974), Munson and Sheppard (1974), Sheppard (1976), Campion (1979), Sand and Regis (1979), Santini and LeBaron (1982), and Mumpton (1983). The mineral resources and geology of the Owyhee Breaks Wilderness Study Area, which adjoins the Lower Owyhee Canyon Wilderness Study Area on the northeast, were studied by Causey (1989b) and Vander Meulen and others (1990).

The U.S. Geological Survey carried out field investigations in the study area during 1986 and 1987. This work included geologic mapping at the scale of 1:24,000 for later compilation at 1:48,000, geochemical sampling, geophysical surveys (gravity and aeromagnetic and gamma-ray spectrometer), and remote sensing. Geochemical data were obtained from 58 stream-sediment and 58 heavy-mineral-concentrate samples, and from 68 rock samples (R.L. Turner, unpub. data, 1989); 71 rock samples were collected for petrographic analysis.

The U.S. Bureau of Mines conducted field studies and examined records of Malheur County, the U.S. Bureau of Land Management, and the U.S. Bureau of Mines during 1986 and 1987. They collected 5 alluvial, 64 rock-chip, and 7 clay samples.

## APPRAISAL OF IDENTIFIED RESOURCES

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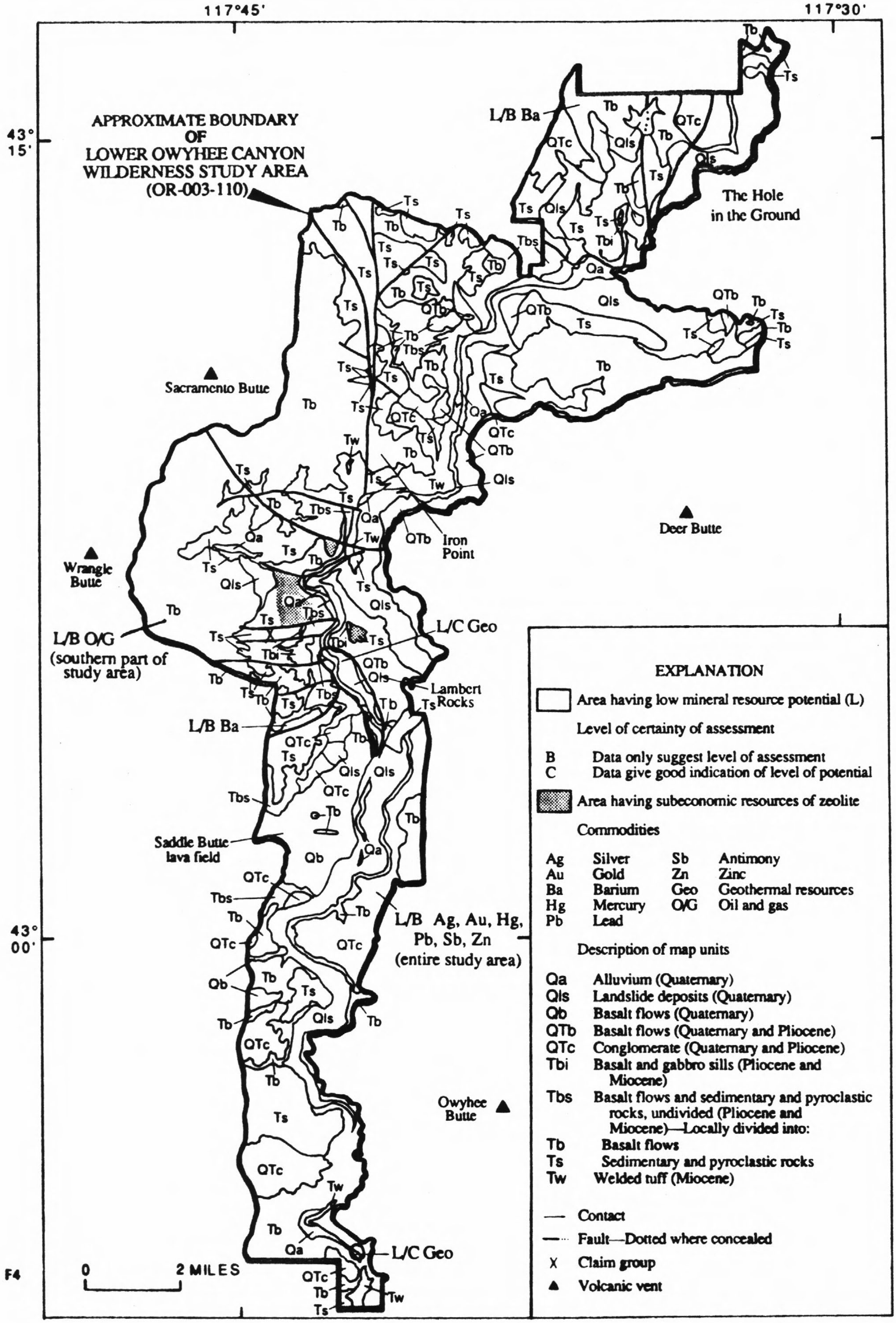
### Methods

The U.S. Bureau of Mines examined Malheur County claim records, and U.S. Bureau of Land Management records of mining claim locations, land status, and use. Additional information was obtained from the U.S. Bureau of Mines library and Mineral Industry Location System.

Five alluvial and bench gravel deposits were sampled. The samples consisted of one or two 14-in. level pans full of material. Samples were panned to about one-third of their initial volume in the field. In the laboratory of the U.S. Bureau of Mines, Western Field Operations Center, Spokane, Wash., the samples were weighed, wet-sieved to −14 mesh, and concentrated on a Wilfley table. Gold was recovered by handpicking and (or) barrel amalgamation, then weighed. Concentrates were dried, weighed, and checked for radioactivity and fluorescence. The magnetic fraction was collected and weighed. Concentrates were examined under a binocular microscope to determine if the heavy


117°45'
117°30'
43° 15'
43° 00'
APPROXIMATE BOUNDARY OF LOWER OWYHEE CANYON WILDERNESS STUDY AREA (OR-003-110)
The Hole in the Ground
Sacramento Butte
Deer Butte
Wrangle Butte
Iron Point
Lambert Rocks
L/B Ba
L/B O/G (southern part of study area)
L/C Geo
Saddle Butte lava field
L/B Ag, Au, Hg, Pb, Sb, Zn (entire study area)
Owyhee Butte
0 2 MILES
EXPLANATION
Area having low mineral resource potential (L)
Level of certainty of assessment
B Data only suggest level of assessment
C Data give good indication of level of potential
Area having subeconomic resources of zeolite
Commodities
Ag Silver
Au Gold
Ba Barium
Hg Mercury
Pb Lead
Sb Antimony
Zn Zinc
Geo Geothermal resources
O/G Oil and gas
Description of map units
Qa Alluvium (Quaternary)
Qls Landslide deposits (Quaternary)
Qb Basalt flows (Quaternary)
QTb Basalt flows (Quaternary and Pliocene)
QTc Conglomerate (Quaternary and Pliocene)
Tbi Basalt and gabbro sills (Pliocene and Miocene)
Tbs Basalt flows and sedimentary and pyroclastic rocks, undivided (Pliocene and Miocene)—Locally divided into:
Tb Basalt flows
Ts Sedimentary and pyroclastic rocks
Tw Welded tuff (Miocene)
Contact
Fault—Dotted where concealed
X Claim group
▲ Volcanic vent

F4

minerals ilmenite, garnet, rutile, zircon, or apatite were present.

A total of 64 rock and 7 clay samples were collected. All samples were checked for radioactivity and fluorescence. Of these samples, 45 from unsilicified or slightly silicified tuff and 6 from clay were subjected to a preliminary zeolite test (Helfferich, 1964). The 30 tuff and the 6 clay samples that tested positive for the presence of zeolite minerals were sent to Cominco American, Spokane, Wash., for X-ray diffraction analysis and to Chemex, Sparks, Nev., for fluorine analysis. Ten of the tuff samples that contain zeolite minerals were tested for ammonium-ion exchange capacity (AEC) by Rocky Mountain Geochemical Corp., West Jordan, Utah. The 19 rock samples that were not tested for zeolites and the 15 samples of tuff that did not test positive for zeolite were crushed, pulverized, and split at the U.S. Bureau of Mines office in Spokane, Wash., and analyzed by Geochemical Service, Inc., Sparks, Nev., for 18 elements.

The six clay samples that contained zeolites have high bloating characteristics and white color. These samples were examined through X-ray diffraction patterns resulting from glycolating and heating them to 300 °C for 1 hr. A clay sample that had undergone no other tests was subjected to a slow firing and preliminary bloating test performed by the University of Alabama, Tuscaloosa, Ala.

## Mining History

Most mining and prospecting occurred just south and southwest of the study area in the Rome beds, which are well exposed near the intersection of the Crooked Creek Ranch road and U.S. Highway 95. These rocks have been extensively explored and evaluated for fluorite and zeolite minerals (mordenite, erionite, clinoptilolite, chabazite, and phillipsite) by Kennedy Minerals Co., Union Carbide Corp., Shell Development Co., Norton Co., Alcoa Corp., Ernst K. Lehman and Associates, Occidental Minerals, Phelps Dodge, Northern Minerals Exploration, and Anaconda Minerals Co. Some horizons contain more than 90 percent zeolite minerals and others contain more than 16 percent fluorite (Mumpton, 1983, p. 43, 46). The U.S. Bureau of Mines, Spokane, Wash., has examined these deposits, and the U.S. Bureau of Mines, Salt Lake City Research Center, Utah, has tested various fluorite-extraction techniques on these tuffs.

Mining in the study area between 1961 and 1964 was limited to decorative stone at the Frying Pan claim group in Chalk Basin. Multicolored silicified tuff was removed at that time, but no production was recorded. In 1980 the Desert Sunrise claim group, covering essentially the same area as the Frying Pan claims, was located by William Lovan, Sr., and William Lovan, Jr., who mined 1- to 3-in.-thick multicolored tuff from a small pit. There is no record of the amount of rock mined from these claims, although a few tons of stone were reportedly extracted during 1984 and 1985 (William Lovan, Jr., oral commun., 1986). Evidence of additional mining activity was noted when the mine was visited in September 1987. It is estimated that less than 200 st of rock has been mined from these claims.

Natural nitrate salts, which were the main source of fixed nitrogen for use in making fertilizer and explosives prior to the development of the Haber-Bosch process in 1913 (Harre and Young, 1983) were reported by Williams (1918, p. 286) on the Hercules claim in Owyhee Canyon. Claims on an occurrence of soluble nitrate salts about 1 mi southwest of Iron Point, near the west end of Bogus Creek, were held until 1967 (Malheur County mining claim records). In 1943, the U.S. Bureau of Mines examined these nitrates and took 10 samples of crystals lining cavities in a flow-banded rhyolite (welded tuff?). Analyses of these samples show 0.33 to 3.07 percent water-soluble salts, predominantly sodium nitrate (U.S. Bureau of Mines, unpub. data, 1943).

## Appraisal of Commodities Examined

### Zeolite minerals

Samples of tuff, tuffaceous sedimentary rock, and clay were collected in the study area to assess the quality of the zeolite minerals in them. X-ray diffraction patterns from these samples, when compared with patterns published by Deer and others (1963, p. 412) and Sheppard and Gude (1973, p. 3), show that 29 of the samples contain clinoptilolite. Clinoptilolite is used mainly in ion exchange applications in aquaculture, agriculture, horticulture, and water treatment and for cesium and strontium extraction from solutions. It can be used to selectively absorb ammonia from animal wastes, including fish, sewage effluent, and gas streams. No other zeolite minerals were identified on X-ray diffractometer scans from these samples. Microscopic examination indicates that more than 60 percent of some samples is a zeolite (James A. Canwell, oral commun., 1988), and one sample contains chabazite. The AEC in 10 samples containing zeolite ranges from 0.10 to 2.00 milliequivalents per gram (meq/g), although there may be an error of as much as 20 percent (Causey, unpub. data, 1988).

Of four zones in the study area that were found to contain zeolite minerals, only one had been prospected (figs. 1, 2). The lowest zone is about 2 ft thick, covered by 200 to 300 ft of overburden, and is poorly exposed. The next higher zone is also about 2 ft thick, covered by about 300 ft of overburden, and is exposed over a distance of about 1,300

◄ **Figure 2.** Mineral resource potential, identified resources, and generalized geology of Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon.

ft south of Chalk Basin. The third zone is as thick as 25 ft and generally covered by less than 100 ft of overburden. In the uppermost fourth zone, one of two samples 300 ft apart contains zeolite (Causey, 1989a, fig. 3).

The 25-ft-thick zone is an altered, white to yellow-orange tuff that contains clinoptilolite. This zone is exposed in four outcrops on both sides of the Owyhee River at and north of Lambert Rocks. An inferred subeconomic resource of 7.7 million short tons (st) of zeolite-bearing rock was calculated for three of the outcrops (fig. 2); the fourth outcrop is overlain by more than 100 ft of overburden and is not considered a resource. The following assumptions were used in estimating the tonnage: the thickness of the tuff varies uniformly, clinoptilolite is the only zeolite present, the AEC is uniform and exceeds 1.00 meq/g, and the specific gravity averages 1.45. A specific gravity of 1.45 is equivalent to a tonnage factor of 30 cubic feet per st ($ft^3$/st) and is within the normal range of 20 to 40 $ft^3$/st for zeolite beds (Eyde, 1981, p. 651). A maximum of 100 ft of overburden was used as an upper limit of burial for a resource. Planimetric measurements were done on the contour lines on the Lambert Rocks 7.5-minute topographic map. The volume of overburden was determined by using an approximate integration formula (Simpson's rule; see Selby, 1968, p.14) on the results of planimeter measurements.

An estimated near-surface natural zeolite resource of 6.7 million st at the largest of these outcrops of zeolite-bearing rock was subjected to an economic analysis, using the U.S. Bureau of Mines preliminary cost-estimating system (Luis Coppa, written commun., 1988). This analysis, using 1987 costs, shows that mine operating costs could be less than $113 per st for a 1,000-st-per-day surface mining operation at a stripping ratio of 3 to 1. The U.S. Bureau of Mines cost-estimating system considers 1,000 st per day to be the minimum acceptable mining rate for surface mines. Lower mining rates are expected to result in higher per-short-ton mining costs. These costs do not include the costs of capital, milling, and marketing industrial minerals. This deposit is considered subeconomic because of the remote location, varying degree of alteration, lack of information on alteration of the tuff below the overburden, color variation (not uniformly white), larger more readily available identified tonnage of clinoptilolite resources elsewhere in the Western United States, and low demand for this zeolite mineral. Present information does not indicate any unique character that would result in the material from this deposit being worth more than, or even as much as, the $125 per st price for clinoptilolite reported by Clifton (1987, p. 16). Because the deposit is remote and has no known special properties, it is not expected to be able to compete with developed deposits in the foreseeable future.

A zeolite-bearing clay zone near the Owyhee River in Chalk Basin is 2.4 ft thick and is dominantly white bentonite showing less than 5 percent yellow-gray clay bands. Dioctahedral smectite (montmorillonite group) and heulandite-group zeolite were identified by using X-ray diffraction. One sample from this zone has an AEC of 2.00 meq/g, the highest of any of the samples tested. The clay zone is believed to be continuous between two exposures 2,300 ft apart. About 300 ft of poorly lithified tuff, tuffaceous sediment, and basalt overlie this clay zone. The deposit would be valuable if it were not remote and deeply buried. The clay is not amenable to surface mining because of the overburden. Underground mining of a 2-ft-thick, horizontal bed would not be feasible using current or foreseeable technology. The waste-to-ore ratio would be at least 1 to 1. The overlying tuff beds would require extensive support, assuming that the ground could be supported at all. Access and haul roads would have to cut through incompetent rocks, requiring very frequent maintenance of the roads.

#### Clay

Another clay zone of unknown thickness is near the Desert Sunrise claim group in Chalk Basin. This clay is thixotropic and shows popcorn texture on weathered surfaces. Tests of bloating and firing characteristics show that the clay could be used for bricks. Firing temperature in the range of 1,000 to 1,050 °C produced a brick having Moh's hardness of 5 to 6.5, bulk density of 125 lbs per cubic foot, linear shrinkage of 12.5 to 15.0 percent, and porosity of 13.14 to 22.9 percent. However, bricks are a low-unit-value product and the study area is remote from population centers and low-cost transportation. It is not expected that mining of this clay will be feasible.

#### Decorative Stone

The Desert Sunrise claim group in Chalk Basin has small inferred resources of a decorative stone called "picture rock," a white chert showing brown hematitic bands. Several tons of the platy rock (sheets 1 to 3 in. thick) are exposed in a pit 4 ft deep. An unknown amount of this rock, estimated to be less than 2,000 st, probably occurs beneath the overburden around the pit. On the basis of nearby outcrops, the thickness of the decorative stone is estimated to be less than 10 ft. Mining on a limited basis (intermittent, small tonnage) can be expected to continue at these claims because of their high unit value; 1989 retail prices range from $1.25 to $1.75 per square foot for thin decorative stone. The amount of rock mined will depend on activity in the construction industry and successful marketing in population centers.

Colored rock less than 500 ft from the Desert Sunrise claim group appears to be at the same stratigraphic level as the rock at the claims. It differs from the decorative rock at the claims in being more massive, breaking less readily into thin sheets, and showing dark orange, brown, red, and gray colors. The rock may be cut or shaped with hand tools into brick-like pieces. Cost of this processing, however, may be excessive for most uses.

### Metallic Minerals

No lode gold was found in the study area. There is no indication that the study area has deposits of other precious or base metals.

A minor amount of gold was found in four of five samples of bench gravel and active stream gravel. Estimated value of the gold, in dollars per cubic yard ($\$/yd^3$) at a gold price of $400 per ounce and a factor of 250 standard 14-in. pans per cubic yard, is $0.09 to $\$0.14/yd^3$. These data do not suggest that economic deposits of placer gold occur in the study area.

### Sand and Gravel

Sand and gravel occurs on small benches along the Owyhee River canyon and on plateau rims south of Lambert Rocks and at the northern end of the study area. The rim deposits, volumetrically the most significant ones, underlie about 6 $mi^2$; 4 $mi^2$ of this area is 4 mi south of Lambert Rocks where it attains a maximum thickness of 100 ft. No mining of the sand and gravel is expected because the deposits are distant from markets. The plateau gravels were not tested for gold content; however, because they were probably deposited by an ancestral Owyhee River, they are not expected to contain any more gold than the samples from the active stream and bench gravels.

### Other Commodities

The U.S. Bureau of Mines examined nitrate occurrences in the study area in 1943 and found no resources. That finding was confirmed during this study. Although the present study attempted to locate fluorite in the samples, no resources were found.

## ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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## Geology

The study area is underlain by flat-lying and gently dipping volcanic, pyroclastic, and sedimentary rocks and deposits of late Miocene to Holocene age (fig. 2). The oldest rock unit of the study area is an unnamed upper Miocene, densely welded rhyolitic ash-flow tuff and lithic ash-flow tuff. It consists of two cooling units at Iron Point where the maximum exposed thickness is 1,200 ft. Much less of it is exposed along the Owyhee River to the south in the Chalk Basin area and at the south end of the study area. The late Miocene age is inferred from the interfingering of the upper cooling unit at Iron Point with upper Miocene sedimentary and pyroclastic rocks north of Chalk Basin. On the basis of its age and petrographic characteristics, the welded tuff does not appear to be related to the middle Miocene Swisher Mountain Tuff exposed along the Owyhee River south of Rome (Evans, 1987). The thick section of welded tuff at Iron Point lies within the deep gravity low (fig. 3) that covers most of the northern part of the study area and that may reflect a largely buried caldera. This relation suggests that the welded tuff at and near Iron Point might be an intracaldera facies and that welded tuff south of Iron Point is an outflow facies.

Poorly to moderately lithified upper Miocene and lower Pliocene sedimentary and pyroclastic rocks interfinger with the welded tuff and with basalt flows. This unit includes white, pale-gray, and light-brown siltstone, sandstone, conglomerate, bentonitic clays, tuff, welded tuff, chert, limestone, and cherty limestone. A maximum uninterrupted thickness of 500 ft occurs at Chalk Basin. A lacustrine environment during deposition of most of the unit is indicated by the presence of chert and limestone, oolites in the limestone, diatom frustules, pelecypod shell fragments, ripple marks, and thin cross-bedded horizons. Shrinkage cracks in clay-rich siltstone suggest that parts of the basin were subject to periodic desiccation. Vertebrate fossils (horse, beaver, and Leparctine) from the unit in and south of Chalk Basin are tentatively dated as early Hemphillian or very late Clarendonian (9 million years before the present, Ma), or late Miocene (C.A. Repenning, written commun., 1987). At The Hole in the Ground at the northern end of the study area, the unit interfingers with basalt that has yielded an early Pliocene age. The distribution of ages suggests that the unit south of Iron Point is late Miocene and that much of the unit north of Iron Point is early Pliocene. The distribution of sedimentary and pyroclastic rock with respect to the possible caldera outlined in figure 3 suggests that the thick section exposed in the Chalk Basin area represents moat fill around the edge of a caldera and that the thick section exposed northeast of Iron Point represents caldera fill.

Upper Miocene and lower Pliocene basalt flows overlie and interfinger with the sedimentary and pyroclastic rock unit. Uninterrupted outcrops of basalt are as much as 400 ft thick. The basalt is thickest toward probable volcano sources, such as Owyhee Butte, Deer Butte, Wrangle Butte, Sacramento Butte, and Iron Mountain that are outside the study area (figs. 1, 2). Cedar Mountain, which is a few miles north of the study area, also contributed some thin flows. The basalts that interfinger with the upper Miocene sedimentary and pyroclastic rocks in and south of Chalk Basin are also presumably of late Miocene age. Other basalts at The Hole in the Ground yielded early Pliocene ages of 4.06±0.41 Ma, 4.09±0.34 Ma, and 4.49±0.38 Ma (Hart, 1982; Hart and Mertzman, 1983).

Basalt and gabbro sills and dikes occur in and near Chalk Basin and at The Hole in the Ground. These intrusions may have also fed minor basalt flows. Hydrothermal systems associated with the sills and dikes resulted in oxidation of basalt, deposition of hematite in porous sedimentary and pyroclastic rocks, deposition of fluorite veins, and widespread recrystallization and silicification of limestone. The silicification may have involved redistribution of available silica from abundant chert that was already present. The chert may have formed when silica was introduced into the lacustrine environment during basaltic or rhyolitic volcanism. Studies by the U.S. Bureau of Mines in the vicinity of the sills and dikes of the Chalk Basin area indicate widespread alteration of volcanic glass to clinoptilolite and to a clay that has commercial properties; the rock samples contain elevated concentrations of arsenic (107–178 parts per million, ppm), fluorine (130–1,600 ppm), and molybdenum (18–231 ppm). These findings might also be the result of hydrothermal systems associated with the sills and dikes.

Pliocene and Quaternary conglomerate as thick as 100 ft is most abundant on the plateau rims on both sides of the Owyhee River in the southern half of the study area. Distribution of the conglomerate reflects the pre-Owyhee canyon paleovalley, which the present drainage closely follows. The clasts are mostly of basalt and welded tuff but also minor chert and quartzite. Chert and quartzite clasts most likely came from outside the Oregon segment of the Owyhee drainage because chert in upper Miocene sedimentary rocks in the study area was not exposed to erosion at the time the conglomerate was deposited. Conglomerate that covers benches 100 to 200 ft above the present canyon bottom were laid down during excavation of the canyon and must be younger than the conglomerate on the rims.

Pliocene and Quaternary basalt flows as thick as 300 ft filled parts of the Owyhee paleocanyon in the north part of the study area. A possible source of the basalt is an unnamed butte that rises on the north side of Bogus Bench, 6 mi east of the study area (fig. 1). The flows must have dammed the Owyhee paleocanyon as they crossed it, and flow remnants indicate the basalt reached at least 6 mi south of Lambert Rocks and into The Hole in the Ground area.

Large Quaternary basalt flows cover much of the region of the study area. Within the study area they occur in the Saddle Butte lava field and at Lambert Rocks; three areas of flow remnants, too small to map on fig. 2, occur just above the low-water level of the Owyhee River north of Lambert Rocks. Basalt tongues that descend existing drainages show that these basalt flows are very young. The three minor flow remnants north of Lambert Rocks may be part of one flow, possibly the youngest in the study area, that may have dammed the river briefly. The large lava flows at Lambert Rocks flowed northwestward down the Bogus Creek drainage from a butte north of Arock and 6 mi southeast of the study area (fig. 1). No clearly defined vent was found for the Saddle Butte lava field. This basalt may have extruded from one or more fissures that are now buried beneath the flows. The minor flow along the Owyhee River must have had one or more local dike sources, but none were found. Both the Lambert Rocks and Saddle Butte flows reached the Owyhee River canyon, but it is not clear if the basalt was voluminous enough to dam the river. Three warm springs along the canyon at river level in the Lambert Rocks area suggest a Quaternary age for this basalt.

Holocene deposits include landslide deposits mostly along the Owyhee River canyon below the basalt cliffs and alluvium mostly along the Owyhee River.

The few faults in the study area are vertical, strike predominantly north and west, and have vertical displacements as much as 300 ft. If all the conglomerate on the plateau rims had been deposited at approximately the same time, the elevation changes of the rim from about 3,700 ft to 4,800 ft suggest a relative uplift of at least 1,000 ft of the northern part of the study area since Pliocene or early Quaternary time.

## Geochemical Studies

A reconnaissance geochemical survey was conducted in the Lower Owyhee Canyon Wilderness Study Area in the summer of 1985 and the fall of 1988. Reconnaissance surveys allow the scientist to evaluate large areas for indications of mineralization but are not designed to find individual deposits. The spacing of samples, however, allows large areas to be subdivided rapidly at low cost into zones of favorable geochemical provinces and mineralized districts. Minus-80-mesh stream sediments, heavy-mineral concentrates derived from stream sediments and rocks were selected as the sample media in this study. Stream sediments were sampled at 58 sites, and heavy-mineral concentrates were prepared from them; 68 rocks were sampled at 61 sites.

Stream-sediment samples were collected from the active alluvium in the stream channel. Each sample was composited from several localities along a channel length of approximately 50 ft. The stream sediments were sieved through an 80-mesh screen and pulverized to a fine powder before analysis. The heavy-mineral concentrates were sieved through a 10-mesh screen and then panned until most of the quartz, feldspar, clay-sized material, and organic matter were removed. The remaining light minerals were separated from the heavy minerals by using a heavy liquid (bromoform, specific gravity 2.8). The magnetite and ilmenite were then removed by an electro-magnet at a setting of 0.2 amperes, and the remainder was separated into nonmagnetic and slightly magnetic fractions using an amperage setting that approximates a setting of 0.6 amperes at a side tilt of 10 degrees and a forward slope of 15 degrees. The nonmagnetic fractions of the concentrates were ground to a fine powder before analysis for this study. Stream sediments represent a composite of the rock and soil exposed upstream from the sample site. The heavy-mineral concentrate represents the heavy-mineral components of the rocks exposed in the drainage basin and permits determination of some elements that are not easily detected in bulk stream sediments. Minerals in the nonmagnetic fraction of the heavy-mineral concentrates could include ore-forming and ore-related minerals if ore-mineralization has occurred in the drainage basin. Rocks were taken from mineralized and unmineralized outcrops and from stream float. Samples that appeared fresh and unaltered were collected to provide information on geochemical background values. Altered or mineralized samples were collected to determine the suite of elements associated with the observed alteration or mineralization. The rocks were crushed and pulverized to a fine powder before analysis.

The heavy-mineral concentrates, stream sediments, and rocks were analyzed for 31 elements by direct-current arc semiquantitative emission spectrographic analysis (Grimes and Marranzino, 1968; Crock and others, 1983). The rocks and the minus-80-mesh stream sediments were also analyzed for certain elements by more sensitive methods: for antimony, arsenic, bismuth, cadmium, and zinc by the method described by O'Leary and Viets (1986), for gold by the method described by Thompson and others (1986), and for mercury by the method described by Koirtyohann and Khalil (1976). Analytical data on which the following account is based is available in Adrian and others (1990).

Stream-sediment samples from several drainages in the study area have anomalous concentrations of one or more of the following elements: arsenic, barium, bismuth, lead, mercury, silver, and tin. Panned concentrates from the northern part of the study area and west of Lambert Rocks (fig. 2) have high concentrations of barium (more than 10,000 ppm). The barium probably comes from the mineral barite, although barite was not identified in outcrops. Some of the barium sources may be outside the north boundary of the study area.

Some panned concentrates also contain high concentrations of bismuth (200 ppm, one sample), lead (2,000 ppm, one sample), and tin (1,000–2,000 ppm, three samples). Most of these samples are from small drainages (less than 2 $mi^2$). However, one sample containing 1,500 ppm tin was from a large drainage (about 18 $mi^2$) on the flank of Iron Mountain (fig. 1); most of this drainage is outside the study area. The presence of large concentrations of bismuth, lead, and tin in panned concentrates could be due to local mineralization related to volcanic processes. In addition, some of the tin in two samples from north of Chalk Basin may have been reconcentrated from altered tuffaceous sedimentary rock.

A stream-sediment sample from a small drainage west of Lambert Rocks (fig. 2) has an anomalous concentration of silver (0.5 ppm).

Anomalous concentrations of arsenic (9–24 ppm) in stream sediments from drainages north of Lambert Rocks are especially widespread in the study area near Wrangle Butte and in the area containing high values of barium near The Hole in the Ground. In the Wrangle Butte area and near Lambert Rocks, the arsenic is associated with 5 to 50 ppm molybdenum in some stream sediments.

Anomalous concentrations of mercury (0.04–0.14 ppm) were found in 12 stream sediment samples scattered the length of the study area, mostly in the southern half. Mercury occurs with molydenum in one sample from the southern half and with arsenic in two samples from near The Hole in the Ground.

About one-third of the rock samples contain anomalous concentrations of one or more of the following elements: antimony (3–6 ppm), arsenic (10–700 ppm), mercury (0.26–0.36 ppm), molybdenum (5–200 ppm), silver (0.5 ppm), tin (10 ppm), and zinc (200–500 ppm). The silver is in two samples (silicified sedimentary rock and amygdular quartz) from southern Chalk Basin near the drainage that yielded a stream-sediment sample having 0.5 ppm silver. Arsenic, molybdenum, and zinc occur in rocks near the basalt sill in Chalk Basin and at Lambert Rocks. Tin is in samples of altered conglomerate and welded tuff from west of Iron Point. Mercury is in a sample from south of Lambert Rocks and in one from near The Hole in the Ground.

The high concentrations of barium, bismuth, lead, and tin in some panned concentrates, the anomalous concentrations of arsenic, mercury, molybdenum, and silver in some stream sediments, and the anomalous concentrations of antimony, arsenic, mercury, molybdenum, silver, tin, and zinc in some rocks indicate widespread epithermal mineralization in the study area and are consistent with the Miocene to Holocene basaltic and rhyolitic volcanism and the hot springs in the study area. The Hole in the Ground, Chalk Basin, and Lambert Rocks areas, where argillic alteration and moderate silicification are seen, appear to have been more affected by hydrothermal processes than other parts of the study area.

Bukofski and others (1984) found gold (5–135 parts per billion, ppb) in 13 of 120 stream-sediment samples collected from a region that includes the Lower Owyhee Canyon Wilderness Study Area. The gold-bearing samples from tributaries to the Owyhee River are scattered throughout the region and do not show a clear geographic concentration. Gold-bearing samples come from drainages from Owyhee Butte, the Saddle Butte lava field, Wrangle Butte through Chalk Basin, Cedar Mountain, and Deer Butte (fig. 2). These data, in addition to the widespread minor-element anomalies mentioned above and the volcanism, hot springs, argillic alteration, and silicification, suggest widespread gold mineralization in the study area.

## Geophysical Studies

A regional aeromagnetic survey was flown over the study area in 1972 (U.S. Geological Survey, 1972). Data were collected along parallel east-west flightlines spaced at an interval of 2 mi and flown at a constant barometric elevation of 9,000 ft above sea level. The Earth's main field was subtracted from the data, which were then plotted and hand contoured at a scale of 1:250,000. Additional aeromagnetic data for the Boise quadrangle (geoMetrics Inc., 1979) and the Jordan Valley quadrangle (Geodata International, Inc., 1980) were published for the Department of Energy, both at a scale of 1:500,000. These data consist of east-west profiles spaced at intervals of 3 mi and flown by helicopter at an average height of 400 ft above the ground surface.

Magnetic minerals, where locally concentrated or depleted, may cause a high or low magnetic anomaly that can be a guide to mineral occurrences or deposits. Boundaries between magnetic and relatively less magnetic rock units are located approximately at the steepest gradient on the flanks of the magnetic anomaly. The majority of the anomalies in the study area are probably caused by the preponderance of lava flows and other volcanic rocks. Survey aircraft maintained an altitude of 4,000 to 6,000 ft above the ground surface, a distance sufficient to suppress most of the short-wavelength anomalies generated by the smaller rock units at or near the surface. These short-wavelength anomalies may be seen on the low-level profiles across the study area (geoMetrics Inc., 1979; Geodata International, Inc., 1980). The aeromagnetic map (U.S. Geological Survey, 1972) shows that the study area lies in an area of linear, north- to northeast-trending regional magnetic lows (contour values of 2,400–2,600 gammas) bordered by highs that have similar trends but lie a few miles outside the study area. The highs are associated with structurally uplifted areas that expose thick sequences of Tertiary volcanic rocks near the center parts, and these rocks may be the source of the regional magnetic highs. A north-trending boundary that approximately follows long 117°30' W. near the east border of the study area appears to separate two areas of differing magnetic patterns. This boundary appears to be caused by a major fault that is not well expressed in the exposed geology and is discussed in the paragraph on gravity interpretation. The weak magnetic anomalies within the study area may be due in part to the edges of magnetic volcanic rock units that are exposed along the Owyhee River canyon. In summary, the magnetic data appear to reflect outcrops of magnetic volcanic rocks and provide no evidence indicating the presence of any mineral resources in the study area.

A gravity survey of this area was conducted by the U.S. Geological Survey in 1986 and 1987 to supplement data already available from the National Geophysical Data Center, Boulder, CO 80303. Station spacing ranges from about 3 to 5 mi, and about 80 stations are situated within or near the border of the study area. The gravity field of the study area south of lat 43°05' N. is relatively featureless (fig. 3). The study area north of this latitude lies within a subcircular gravity low having a maximum amplitude of 17 milligals and a width of about 15 mi. The east side of this low is marked by a steep gravity gradient sloping down to the west toward the study area. The gradient is interpreted as caused by a fault (fig. 3), probably concealed, striking north at about long 117°30' W., nearly coincident to the magnetic boundary previously mentioned. On the basis of the gravity interpretation, this fault appears to be the southernmost end of a major fault extending at least 70 mi north of the study area (Lillie, 1977). The subcircular gravity low west of this fault does not have an easily identified source. The low extends 15 mi northwest across the Owyhee River canyon. The nadir of the low is about 2 mi northwest of the Iron Point area, where the exposed section of silicic welded tuff is thickest. Explanations for a gravity low of this kind include (1) a small concealed granitic batholith, (2) a concealed sedimentary basin filled with low-density sediments,

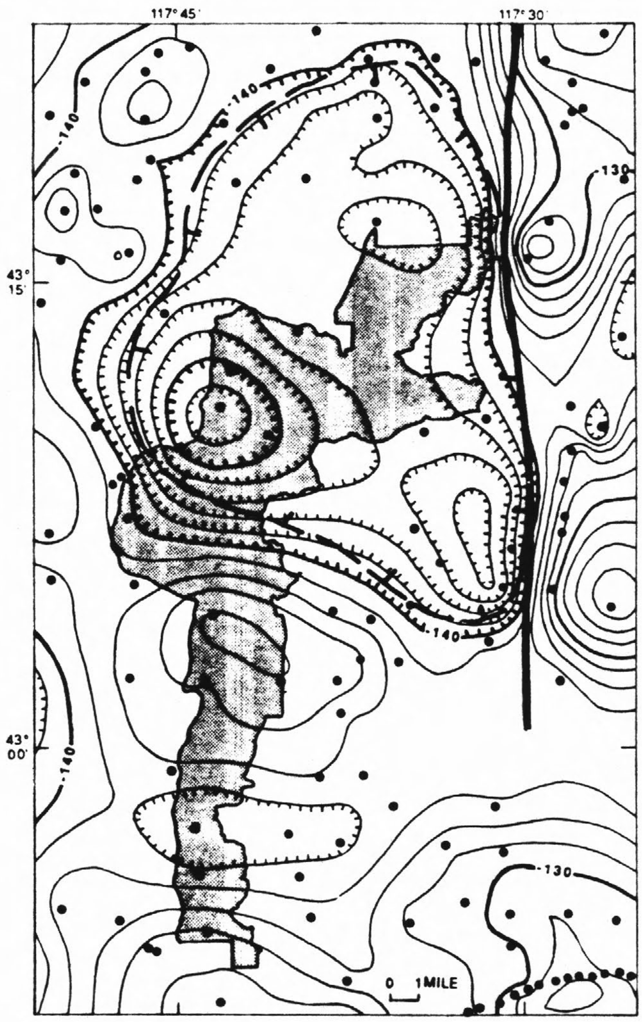

**Figure 3.** Complete Bouguer gravity anomaly map of Lower Owyhee Canyon Wilderness Study Area (shaded area) and vicinity, Malheur County, Oregon. Contour interval 2 milligals; hachures indicate direction of lower gravity value; dots represent gravity stations. Bold solid line, fault probably concealed. Bold dashed outline, possible caldera discussed in text.

or (3) a concealed older caldera complex containing low-density fill. The third explanation appears to be the most likely on the basis of geologic mapping and thickness of the volcanic and sedimentary units. It also offers a possible source for some of the nearby Tertiary rhyolites and welded tuffs that are exposed to the south as well as in the canyon floor within the gravity low. Mineralization might be associated with such a caldera.

Aerial gamma-ray spectrometer measurements are available along the 3-mi-spaced east-west profiles illustrated by geoMetrics Inc. (1979), and by Geodata International, Inc. (1980). Statistically significant anomalies for uranium (designated as anomalies 106 and 118 by geoMetrics Inc., 1979) were found within the boundaries of the study area in the Boise quadrangle (north of lat 43° N.). The anomalies are not large in amplitude, are associated with moderate potassium anomalies, and are located over broad areas of Tertiary sedimentary rocks (mostly lake beds) in the lower parts of Owyhee River canyon. These associations suggest that the anomalies are caused by the relatively normal amounts of uranium and potassium to be expected in many sedimentary rocks of this sort and that the anomalies probably have no economic significance.

Linear features in Landsat multispectral scanner (MSS) images at a scale of 1:800,000 were mapped by photogeologic interpretation for the region of southeastern Oregon, and trend concentration maps were made. Linear features are the topographic and spectral expression of rock fracture patterns and other structural and lithologic lineaments. This expression can be enhanced or subdued by scanner resolution, sun orientation, atmospheric phenomena, and vegetation. Analysis of linear features in conjuction with geologic and geophysical maps may reveal new relations such as fracture control of mineralization.

Linear features of every orientation are well expressed on the surface in southeastern Oregon except in terrains underlain by volcanic rocks. This study area is underlain mostly by volcanic rocks that do not show well-developed linear features at the scale of 1:800,000.

## Mineral and Energy Resource Potential

Geologic and geochemical data indicate that the entire Lower Owyhee Canyon Wilderness Study Area has low mineral resource potential for gold, silver, lead, zinc, antimony, and mercury with a certainty level B. The potential is indicated by widespread samples showing anomalous amounts of gold, and silver; anomalous amounts of arsenic, barium, bismuth, lead, and tin commonly occur with gold and silver mineralization in the region, and anomalous lead, zinc, tin, molybdenum, antimony, mercury, and molybdenum are found in scattered locations in the study area. The geology of the study area is a result of abundant silicic and basaltic volcanism as recently as Holocene; several hot springs occur in the study area, and broad areas of argillic alteration and silicification occur in The Hole in the Ground, Chalk Basin, and Lambert Rocks areas. These data only suggest that the study area exposes the outer parts of a complex zone of hydrothermal alteration that involved precious- and base-metals mineralization.

The mineral resource potential for barite is low in two areas in the northern and west-central parts of the study area (fig. 2). This potential is indicated by high concentrations of barium in panned-concentrate samples. The high concentrations of barium, probably in the mineral barite, may be a result of stream transport dynamics rather than a definitive criterion of significant barite deposits upstream from the sample sites. Some of the barite sources may be outside the boundary of the wilderness study area. A certainty level B is assigned because no veins or bedded deposits of barite were found and because the geologic setting is not clearly indicative of barite deposits.

Wells were drilled for oil and gas 95 mi northeast of the study area in the western Snake River basin of Oregon and Idaho. Study of these wells and the regional geology led Newton and Corcoran (1963) to conclude that the depositional environments of the Snake River basin resemble other nonmarine basins that produce oil and gas and that hydrocarbons formed there during the late Miocene and early Pliocene. The Late Miocene and early Pliocene, however, was a time period characterized by volcanism in the study area. Warner (1980) suggested that southeastern Oregon is underlain by Mesozoic and Tertiary rocks that contain potential source material for petroleum. However, pre-Tertiary rocks exposed about 40 mi southeast of the study area at South Mountain in Idaho and about 80 mi to the southwest in the the Pueblo Mountains in Nevada and Oregon are metasedimentary and metavolcanic rocks that would not be good potential petroleum sources. During this study no surficial evidence was found that indicates the presence of hydrocarbons at depth. Any potential hydrocarbon reservoirs that might be present beneath the rocks exposed in the study area probably would have to be located by seismic surveys. Although it is likely that heat from volcanism in the area would have driven off any hydrocarbons, hydrocarbon concentrations below the rocks exposed in the southern part of the study area cannot be ruled out. The possibility that a caldera underlies the northern part of the study area suggests that the resource potential for oil and gas is remote for that part of the study area because hydrocarbon reservoirs would be unlikely to survive at the site of a caldera. Fouch (1983) estimated the oil and gas potential of the study area to be low. However, available geological and geophysical information indicates that the likelihood for occurrence of oil and gas within the study area is very low to remote; for the purpose of this study the energy resource potential for oil and gas is considered low, certainty level B, for the southern two-thirds of the study area (fig. 2).

Four hot springs were found along the Owyhee River in the study area. Three of them are between the Quaternary basalt of the Saddle Butte lava field on the west and the Lambert Rocks basalt flows on the east. One hot spring is near the south end of the study area, about 2 mi southwest of a small basalt vent on the south flank of Owyhee Butte. The study area is on the west flank of a broad zone of high heat flow defined by Muffler (1979) and is near the 100-milliwatts-per-square-meter contour of regional heat flow. The warm springs in the study area may be a result of young basaltic volcanism or of deep circulation in a region of slightly elevated heat flow. The relatively small basalt vents, most likely extending from great depth, are poor targets for geothermal heat production. For these reasons the two small areas containing hot springs in the study area have a low potential for geothermal energy resource with a certainty level C (fig. 2).

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# APPENDIXES

# DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

## LEVELS OF RESOURCE POTENTIAL

H **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.

M **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 reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L **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 permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.

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

U **UNKNOWN** mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

## LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.
B Available information only 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.

| A | B | C | D |
|---|---|---|---|
| U/A<br>UNKNOWN POTENTIAL | H/B<br>HIGH POTENTIAL | H/C<br>HIGH POTENTIAL | H/D<br>HIGH POTENTIAL |
| | M/B<br>MODERATE POTENTIAL | M/C<br>MODERATE POTENTIAL | M/D<br>MODERATE POTENTIAL |
| | L/B<br>LOW POTENTIAL | L/C<br>LOW POTENTIAL | L/D<br>LOW POTENTIAL |
| | | | N/D<br>NO POTENTIAL |

LEVEL OF RESOURCE POTENTIAL →

LEVEL OF CERTAINTY →

**Abstracted with minor modifications from:**

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.

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## RESOURCE/RESERVE CLASSIFICATION

| | IDENTIFIED RESOURCES | | | UNDISCOVERED RESOURCES | |
|---|---|---|---|---|---|
| | Demonstrated | | Inferred | Probability Range | |
| | 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, V.E., 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 by the U.S. Geological Survey in this report

| EON | ERA | PERIOD | | EPOCH | AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma) |
|---|---|---|---|---|---|
| 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<br>Middle<br>Early | 205 |
| | | Triassic | | Late<br>Middle<br>Early | ~240 |
| | Paleozoic | Permian | | Late<br>Early | 290 |
| | | Carboniferous Periods | Pennsylvanian | Late<br>Middle<br>Early | ~330 |
| | | | Mississippian | Late<br>Early | 360 |
| | | Devonian | | Late<br>Middle<br>Early | 410 |
| | | Silurian | | Late<br>Middle<br>Early | 435 |
| | | Ordovician | | Late<br>Middle<br>Early | 500 |
| | | Cambrian | | Late<br>Middle<br>Early | [1]~570 |
| 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 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.