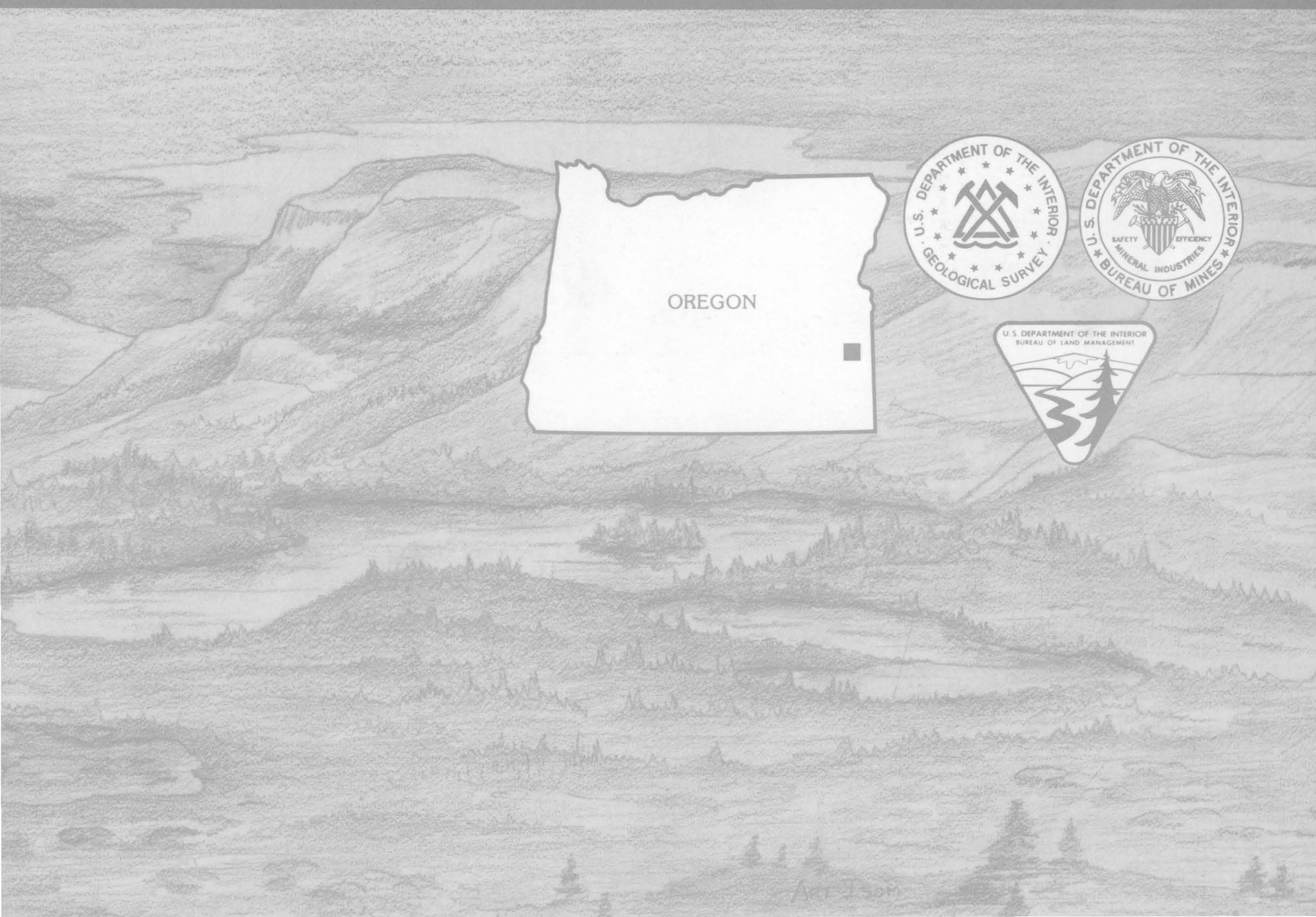
Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon

U.S. GEOLOGICAL SURVEY BULLETIN 1741-G



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Bulletin 1741-G

Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Area, Malheur County, Oregon

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. . . extension of the DeLamar-Duck Valley structural trend and . . .

Chapter G

Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon

By DEAN B. VANDER MEULEN, VINCENT E. BARLOCK, PATRICK S. PLUMLEY, JAMES G. FRISKEN, and ANDREW GRISCOM
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U.S. GEOLOGICAL SURVEY BULLETIN 1741

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
EAST-CENTRAL OREGON

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., 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 Blue Canyon (OR-003-073) and Owyhee Breaks (OR-003-059) Wilderness Study Areas Malheur County, Oregon.

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Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon

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SUMMARY

Abstract

At the request of the U.S. Bureau of Land Management, the U.S. Geological Survey and the U.S. Bureau of Mines conducted field studies of 12,700 acres and 13,100 acres, respectively, in the contiguous Blue Canyon (OR–003–073) and Owyhee Breaks (OR–003–059) Wilderness Study Areas; the areas are adjacent to and include part of the Owyhee River in eastern Oregon. In this report, the areas studied for mineral resources are referred to, individually or collectively, as the "wilderness study area" or simply the "study area." Fieldwork was conducted by the U.S. Geological Survey during 1985 and 1988 and by the U.S. Bureau of Mines during 1988 to appraise the identified mineral resources (known) and assess the mineral resource potential (undiscovered) of the study area.

The southern part of the Blue Canyon Wilderness Study Area contains identified resources of jasper and perlite and occurrences of bentonite. The Owyhee Breaks Wilderness Study Area contains occurrences of bentonite, jasper, and zeolite minerals. Both study areas have sand and gravel deposits that are far removed from transportation routes and existing markets. No energy resources were identified in either study area. In the northern part of the study area, an area underlain by silicified lithic tuff has high mineral resource potential for gold, silver, mercury, and molybdenum. Silicified and brecciated tuffs exposed along two north-trending fault zones in the east-central part of the study area have high mineral resource potential for gold, mercury, and molybdenum. Rocks exposed along the west side of the Owyhee River in the western part of the study area have high mineral resource potential for gold in volcanic- and sediment-hosted hot-spring deposits. The rest of the study area has moderate mineral resource potential for gold in volcanic- and sediment-hosted deposits. Tuffs associated with the Mahogany Mountain caldera have low potential for zinc resources. These tuffs are exposed locally throughout the study area. North-trending fault zones within and adjacent to the study area have moderate potential for geothermal energy resources. Sedimentary rocks that underlie the northern and western parts of both study areas have moderate mineral resource potential for bentonite and diatomite, low mineral resource potential for fluorite, and low potential for oil and gas energy resources.

Manuscript approved for publication, June 11, 1990

Character and Setting

The Blue Canyon (OR–003–073) and Owyhee Breaks (OR–003–059) Wilderness Study Areas lie along the west margin of the Mahogany Mountain caldera approximately 62 mi west of Boise, Idaho, and 25 mi northwest of Jordan Valley, Oreg. (fig. 1). The study area includes part of the caldera-collapse structure, the west topographic wall of the caldera, and parts of a high plateau southwest of the caldera. The principal drainage in the region is the Owyhee River, a tributary of the Snake River. The river flows from west to east, then north across the study area through a spectacular, deeply eroded canyon. In the western part of the study area, the river has cut through a thick sequence of poorly consolidated volcaniclastic sedimentary rocks that have slumped and eroded to form a broad 5-mi-wide basin known as The Hole in the Ground. In the central part of the study area, the river encounters older, resistant ash-flow tuffs and intrusive rocks that form steep, rugged parts of the canyon known as the Owyhee Breaks. North of the study area, the river empties into the 25-mi-long Lake Owyhee.

The study area is underlain by a thick sequence of middle Miocene rhyolite flows and ash-flow tuffs and middle Miocene to Pliocene sedimentary rocks and basalt flows. Time spanned by the middle Miocene is herein considered to extend from approximately 11.2 to 16.6 million years before present, or Ma (see "Appendixes" for geologic time chart). The oldest rocks, rhyolite flows exposed in the east-

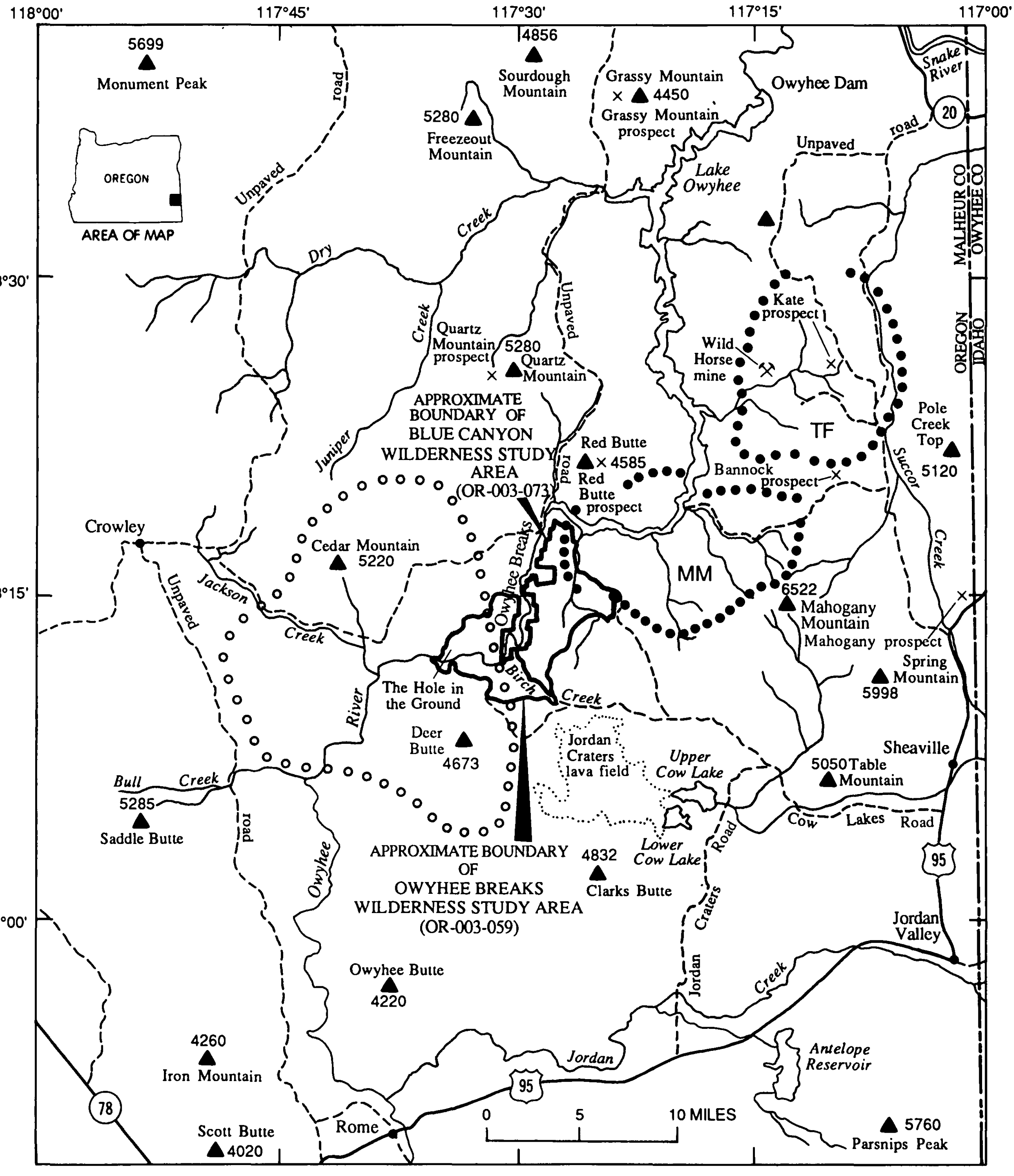

Figure 1. Index map showing location of Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon. Gold prospects shown by X. Heavy dotted lines indicate inferred margins of the Three Fingers (TF) and Mahogany Mountain (MM) calderas. Open-circle dotted line indicates approximate margin of a possible caldera based on geophysical data.

central part of the study area, erupted from a precaldera silicic magma chamber beneath Mahogany Mountain, 7 mi east of the study area. Continued silicic volcanism during the middle Miocene resulted in the eruption of ash-flow and air-fall tuffs and the formation of the Mahogany Mountain and Three Fingers calderas and a possible caldera west of the study area (fig. 1). The rhyolite tuffs probably underlie most the study area at depth.

The area has undergone extensional tectonism, resulting in basin-and-range topography, and occupies a north-plunging lacustrine basin of regional extent that is cut by north- and northwest-trending faults. During the Miocene and Pliocene, lacustrine and fluvial volcaniclastic sedimentation within the basin was accompanied by intermittent episodes of basaltic and andesitic volcanism. Rocks that were deposited during this time are exposed locally throughout the study area. Plateau-forming basalts cap these sedimentary rocks and are the youngest rocks in the study area.

Identified Resources

No energy resources have been identified within or adjacent to the study area. Several prospects, claims, and two mines contain identified resources of jasper. The deposits are commonly restricted to brecciated, silicified, and pyritized welded tuff along fault and fracture zones. The southern part of the Blue Canyon Wilderness Study Area has an estimated 4.8 million short tons (st) of jasper-bearing welded tuff. Less than 0.1 percent of the rock contains usable jasper, and less than 0.001 percent contains high-value jasper.

The southern part of that study area also has an estimated 5.8 million st of identified perlite resources, and the western and northern parts have occurrences of bentonite.

The Owyhee Breaks Wilderness Study Area has occurrences of bentonite, jasper, and zeolite minerals.

An estimated 5 million yd^3 of sand and gravel deposits are exposed in the Owyhee River, on small isolated benches near the river, and in the Blue Canyon and other drainages within both study areas. Because they are remote and inaccessible, none of the river gravels are expected to be quarried.

Welded tuff exposed within the study area is suitable for construction; however, because similar tuff elsewhere is more accessible and closer to existing markets, this tuff does not constitute a resource.

Mineral Resource Potential of the Blue Canyon Wilderness Study Area

Three samples of a silicified lithic-rich tuff collected in the northern part of the Blue Canyon Wilderness Study Area contain anomalous concentrations of gold, silver, mercury, and molybdenum. The silicified tuff caps a sequence of sedimentary rocks and is exposed along a north-trending normal fault. Silicified parts of the tuff have high potential for gold, silver, mercury, and molybdenum resources.

Five samples of silicified and brecciated tuff collected along two north-trending fault zones in the central part of the study area contain anomalous concentrations of gold, mercury, and molybdenum. Silicified and brecciated rocks exposed along these fault zones have high potential for gold, mercury, and molybdenum resources.

Geochemical associations favorable for gold in epithermal hot-spring deposits have been identified in the study area. The volcanic and sedimentary stratigraphy and structure of known gold prospects in the region can be traced into the study area. Therefore the entire study area, except those parts having high resource potential for gold, has moderate potential for gold resources in volcanic- and sediment-hosted deposits.

In the central part of the Mahogany Mountain caldera, 4 mi east of the study area, anomalous concentrations of zinc were detected in 43 samples of caldera-forming rhyolite tuff and in 10 samples of rhyolite vent breccia. Therefore, parts of the study area underlain by this tuff have low resource potential for zinc in volcanogenic disseminated deposits.

Approximately one-third of the stream-sediment and nonmagnetic-panned-concentrate samples collected for this investigation contain anomalous fluorine. The fluorine anomalies are probably associated with either lacustrine sedimentary rocks or epithermal hot-springs mineralization. Sedimentary rocks that underlie the north and central parts of the study area have low potential for fluorite resources.

In the same parts of the study area, beds of bentonite and diatomite are intercalated with the lacustrine sedimentary rocks. The bentonite units typically form low subdued hills and have estimated maximum thicknesses of 50 ft. A sample of bentonitic clay collected in the northern part of the study area contains the swelling clays smectite and illite. Beds of diatomite exposed along the northern tip of the study area have maximum thicknesses of 5 ft, are very clean, and may be of industrial quality. The sedimentary rocks have moderate potential for bentonite and diatomite resources.

Approximately 1.5 mi west of the study area, a thermal spring issues from a north-trending fault zone (fig. 2). Another thermal spring issues from a north-trending fault zone approximately 2.5 mi east of the study area near Lake Owyhee. Although no thermal springs were identified in the study area, geothermal waters may exist at depth along north-trending fault zones. Areas along these fault zones have moderate potential for geothermal energy resources.

A 650-ft-thick sequence of interbedded carbonaceous claystone and siltstone that underlies the northern part of the study area could serve as source rocks for oil and gas resources. North of the study area, similar rocks are folded to form three south-plunging anticlines. Such folded rocks could serve as trap structures for oil and gas reservoirs.

Therefore, sedimentary rocks exposed in the northern part of the study area have low potential for oil and gas energy resources.

Mineral Resource Potential of the Owyhee Breaks Wilderness Study Area

Five samples of silicified tuff, conglomerate, and black chert (siliceous sinter) collected in the central part of the study area contain anomalous concentrations of gold. Sedimentary rocks and tuffs that underlie this area are cut by north- and northwest-trending fault zones. Gold resources have been discovered in similar rocks in a similar geologic setting at the Red Butte gold prospect, 8 mi north-northeast of the study area. Therefore, this area is considered to have high resource potential for gold in volcanic- and sediment-hosted hot-spring deposits.

Geochemical associations favorable for gold in epithermal hot-spring deposits have been identified in the study area. The volcanic and sedimentary stratigraphy and structure of known gold prospects in the region can be traced into the study area. Therefore, the remaining study area has moderate potential for gold resources in volcanic- and sediment-hosted deposits.

In the central part of the Mahogany Mountain caldera, 10 mi east of the study area, anomalous concentrations of zinc were detected in 43 samples of caldera-forming rhyolite tuff and in 10 samples of rhyolite vent breccia. Therefore, parts of the study area underlain by this tuff have low potential for zinc resources in volcanogenic disseminated deposits.

Approximately one-third of the stream-sediment and nonmagnetic-panned-concentrate samples collected for this investigation contain anomalous fluorine. The fluorine anomalies are probably associated with lacustrine sedimentary rocks or epithermal hot-springs mineralization. Sedimentary rocks that underlie the northwestern part of the study area have low potential for fluorite resources.

In the same part of the study area, beds of bentonite and diatomite are intercalated with the lacustrine sedimentary rocks. A sample of bentonitic clay collected near the northwest boundary of the study area is 80 to 95 percent smectite, a clay mineral that has swelling properties. Thin beds of diatomaceous earth are also exposed in the northern and northwestern parts of the study area. The sedimentary rocks have moderate potential for bentonite and diatomite resources.

Near the central part of the study area, a thermal spring (fig. 2) issues from a north-trending fault zone. Another thermal spring issues from a north-trending normal fault approximately 6.5 mi northeast of the study area near Lake Owyhee. Similar fault zones that cut the study area may be associated with geothermal waters at depth. Therefore, north-trending fault zones within and adjacent to the study area have moderate potential for geothermal energy resources.

A 1,000-ft-thick sequence of lacustrine and fluvial sedimentary rocks that underlie the northwestern part of the study area could serve as source rocks for oil and gas resources. These rocks have low potential for oil and gas energy resources.

INTRODUCTION

These mineral surveys were requested by the U.S. Bureau of Land Management and are the result of a cooperative effort by the U.S. Geological Survey and 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). Studies by the U.S. Geological Survey are designed to provide a reasonable 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 definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Area Description

The contiguous Blue Canyon (OR–003–073) and Owyhee Breaks (OR–003–059) Wilderness Study Areas encompass 25,800 acres along the Owyhee River in eastern Oregon. The study area is approximately 24 mi north of Rome, Oreg., and 9 mi west of Mahogany Mountain (fig. 1). The area is accessible from U.S. Highway 95 via the Cow Lakes and Jordan Craters improved gravel roads that approach the study area from the east. Maximum elevation in the study area is approximately 4,750 ft above sea level along the plateau rim east of the Owyhee River; minimum elevation is about 2,680 ft along the river. The area is drained by several small creeks that flow north or south into the Owyhee River. The climate is semiarid, and the average annual precipitation is 10 in. or less. Vegetation is sparse and includes sagebrush and grasses at all elevations.

Juniper, aspen, and cottonwood trees grow along creek bottoms and in protected gulches.

Previous and Present Investigations

Previous geologic investigations that include the study area are a reconnaissance geologic map of the Owyhee region by Kittleman and others (1967) and an aeromagnetic survey by Boler (1979). An airborne radiometric and aeromagnetic survey of the study area was conducted by geoMetrics, Inc. (1979) during the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program. A preliminary evaluation of the mineral resources of the Owyhee Breaks Wilderness Study Area was made by the Oregon Department of Geology and Mineral Industries (DOGAMI) (Gray and others, 1983). Other energy and mineral resource studies that include the study area were conducted by Bukofski and others (1984) and Robinson and others (1985).

During the summers of 1985 and 1988, the U.S. Geological Survey mapped the geology of the study area at a scale of 1:24,000. The Diamond Butte 7.5-minute quadrangle, which includes the Red Butte gold prospect and the northern part of the study area, was mapped by Vercoutere and others (1987). The Jordan Craters North 7.5-minute quadrangle, which includes the southeastern part of the study area, was mapped by V.E. Barlock and Vander Meulen (unpub. data) as part of the present wilderness study. The geology of The Hole in the Ground 7.5-minute quadrangle, which includes the western part of the study area, was mapped by Plumley (1986). A caldera collapse structure, referred to as the Mahogany Mountain caldera, which underlies the eastern part of the study area (fig. 1), was first recognized by Rytuba and others (1985).

The U.S. Bureau of Mines investigation consisted of prefield and field studies (Causey, 1989a, b). During the prefield study, current and past mining-related and claim-location data were examined. These data were gathered from the libraries and records of the U.S. Bureau of Mines and the U.S. Bureau of Land Management, from State, County, and other government agencies, and from the Mineral Industry Location System file. Field studies included a ground reconnaissance to search for evidence of possible mineralized areas and unrecorded mining activity. Additional information is available from the U.S. Bureau of Mines, Western Field Operations Center, E. 360 Third Avenue, Spokane, WA 99202.

The U.S. Geological Survey conducted a combined geologic, geochemical, and geophysical survey of the wilderness study areas during 1988. Field investigations focused on correlating geochemical and geophysical anomalies with rock units and geologic structures. Rock, stream-sediment, and nonmagnetic heavy-mineral-concentrate samples were analyzed for 35 elements by semiquantitative emission spectrography and argon plasma-atomic emission spectrography. Atomic absorption was used to analyze for gold and mercury; an ion-selective electrode method was used to detect fluorine; and the presence of uranium was determined by ultraviolet fluorescence.

APPRAISAL OF IDENTIFIED RESOURCES

By J. Douglas Causey
U.S. Bureau of Mines

History and Production

Most of the precious metal exploration activity in the region is north of the Blue Canyon and Owyhee Breaks Wilderness Study Areas. Some of the recently discovered gold prospects include Red Butte, Quartz Mountain, and Grassy Mountain, 4, 8, and 23 mi north of the study area, respectively (fig. 1; Wheeler, 1988). These discoveries produced a claim-staking rush in 1988–89 that includes most of the study area. Near Rome, Oreg., 25 mi south of the study area (fig. 1), sedimentary rocks known as the "Rome beds" have been extensively explored and evaluated for fluorite and zeolite minerals. These rocks contain as much as 16 percent fluorite and 90 percent zeolite minerals (Sheppard, 1976; Santini and LeBaron, 1982; Mumpton, 1983). Jasper has been mined in and around the Honeycombs Wilderness Study Area (Scott, 1986) 8 mi northeast of the study area and in the southern part of the Blue Canyon Wilderness Study Area.

In 1964, the Big Hole jasper claim was staked by Arnold H. Peterson and Emmett Morris, and the Sheep Head Ridge and associated jasper claims were staked by John Turner and Emmett Morris in the area now covered by the Meadowlark mine (fig. 2). Since the 1970's, several jasper claims have been located in this area known as the Sheep Head mining district. Jasper produced from this area is called Morrison Ranch jasper or Morrisonite. In 1976, three jasper claims (North Birch, Middle Birch, and South Birch) were located by Dale Huell along Birch Creek at the boundary of the Blue Canyon and Owyhee Breaks Wilderness Study Areas (site 7, fig. 2, table 1). Bulldozer cuts are apparent, but no mining occurred at these prospects.

Flower jasper was mined from the Rocky Rim claim (site 4, fig. 2, table 1), which was established in 1986. It operated for a few months before it was closed by the U.S. Bureau of Land Management for not having filed a plan of operation. The mine area, which is less than 2 mi from the Morrison Ranch area, was completely reclaimed and no outcrop of flower jasper is exposed.

Jasper is exposed in numerous small pits throughout the Morrison Ranch area (fig. 2). The total amount of jasper recovered from these pits is unknown. Value of the

Table 1. Mines, prospects, mineralized areas, and occurrence in the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon

["Occurrence" indicates commodity is too low grade, too market dependent, or too small to classify at this time]

Site (fig. 2)	Name	Summary	Workings and production	Resource and sample data
1	Jasper prospect............	Tuffs and tuffaceous sedimentary rocks, fractured and filled with silica. Silica (jasper) is commonly tan with some blue-gray zones. Result is a picture-type jasper as thick as 6 in.	Seven small prospect pits, most of which do not have exposed bedrock. Less than 100 lb of jasper have been removed.	No resources delineated. Two samples analyzed for 18 elements, none contain anoma lous concentrations of metals.
2,3	Morrison Ranch: Meadowlark and Christine Marie mines (jasper, morrisonite).	Jasper occurs as fracture fillings in highly brecciated welded tuff. Jasper crops out in linear pattern indicating a possible correlation with east-trending faults.	Three mine areas and several smaller prospects. Largest mine area had an estimated 25,000 to 30,000 short tons of jasper-bearing rock removed from an open pit. Total jasper production not known.	Mines have a calculated reserve of 4.7 million short tons of jasper-bearing rock. Of 31 samples analyzed for 18 elements, none contain anomalous concentrations of metals.
	Perlite exposures.........	Perlite occurs as irregular-shaped bodies within welded tuff near Meadowlark jasper mine. Perlite bodies are not large enough to be mined individually and possibly are in landslide blocks.	No workings or production........................	An estimated 5.8 million short tons of subeconomic perlite resources. One sample analyzed for 18 elements does not contain anomalous concentrations of metals.
4	Rocky Rim claim (flower jasper).	Host rock is tuff and tuffaceous sedimentary rocks. Jasper is seen only as float; none crops out because workings have been reclaimed.	Three pits, all of which were back-filled with soil. Production estimated to have been less than 3 short tons of jasper.	No jasper resources delineated because mine was reclaimed. Of 5 samples analyzed for 18 elements, 1 contains 27 ppb gold.
5	Jasper prospect............	Brecciated welded tuff of Birch Creek. Breccia fragments are supported in matrix of jasper, clay, and calcite.	Four distinct prospect pits. Some mining probably occurred, but no record of production was found.	Prospect has a calculated reserve of 125,000 short tons of jasper-bearing rock. Of 3 samples of jasper and 1 sample of tuff analyzed for 18 elements, none contain anomalous concentrations of metals.

6	Stewart claims...............	Tuffs and tuffaceous sedimentary rocks contain small amounts of jasper and silicified wood. Wood is locally opalized and highly fractured.	No workings, no known production.............	No resources delineated. Quantity and quality of jasper or silicified wood are not sufficient to be commercially minable.
7	North Birch, Middle Birch, and South Birch claims (jasper and zeolite).	Volcaniclastic sedimentary rocks host greenish-gray to tan jasper. No distinctive or unusual patterns were observed in jasper deposits examined.	Bulldozer scrapings along ridge that parallels Birch Creek. No record of production, but a few tons of jasper may have been removed.	No jasper resources delineated. Deposit classified as zeolite occurrence. Two samples analyzed for 34 elements. Jasper is generally of uniform color without distinctive patterns. This jasper deposit is of interest to lapidary enthusiasts but of minimal commercial value. X-ray analysis of one sample indicates it is about 65 percent quartz, 20 percent sanidine, and 15 percent heulandite (zeolite).
8	Clay occurrence.............	Tuffs altered to gray and greenish-gray clay.	No workings or production........................	Deposit classified as an occurrence that contains less than 40,000 short tons of bentonitic clay. X-ray analysis of one sample indicates it is 85 to 90 percent smectite (bentonitic clay) and 10 to 15 percent quartz.
9	Jasper prospect..............	Fractured, bleached, and red iron-oxide-stained welded tuff with jasper cement. Jasper is multicolored, fractured, and commonly fills fractures less than 1 in. thick.	No workings or production........................	Deposit has no commercial value. Two samples collected; neither contains anomalous concentrations of metals. Jasper is fractured, is in narrow seams, and is not exposed over a large area.

jasper varies; most of the material averages at least $2.50/lb ($5,000/st). Operators of the Meadowlark and Christine Marie mines in the ranch area estimate that more than 3 short tons (st) of jasper were recovered between 1986 and 1988. An estimated 25,000 to 30,000 st of rock have been mined from the main workings on the Meadowlark mine (table 1). The rest of the workings on this and surrounding claims probably had less rock removed. Probably less than 100 st of rock was mined from the largest pit at the Christine Marie mine.

Mines, Prospects, Claims, and Mineralized Areas

Jasper, tuffs, perlite, alluvial deposits, and basalt flows were sampled for this investigation. Two placer samples, one clay sample, and 95 rock samples were collected. Sample descriptions and analytical results are reported in Causey (1989a, b). The Meadowlark, Christine Marie, and associated claims (sites 2, 3, fig. 2, table 1) have an estimated 4.7 million st of rock containing 1 to 5 percent jasper. Of this rock, less than 0.1 percent is estimated to be recoverable for lapidary purposes, and less than 0.001 percent is high-value jasper. An estimated 125,000 st of jasper-bearing rock are calculated for an unnamed prospect (site 5, fig. 2, table 1) west of the Rocky Rim claim; less than 0.1 percent is considered recoverable for lapidary purposes. On the basis of previous mining activity, additional resources of flower jasper are very likely on the Rocky Rim claim (site 4, fig. 2, table 1), even though the area has been reclaimed. Other jasper prospects in the study area may contain additional resources, but defining them without further exploration is not possible.

Perlite resources are exposed near the Meadowlark mine (fig. 2). There are an estimated 5.8 million st of perlite having an expanded density of less than 14 lb/ft^3. These resources are far from existing markets, contain as much as 15 percent red jasper, and would be competing in an industry that is self-supporting at present in the United States.

An estimated 10 million yd^3 of sand and gravel are present in the Blue Canyon drainage, and approximately half of this resource is within the study area. However, adequate and more accessible deposits of sand and gravel outside of the study area are closer to existing markets.

A small amount of gold was found in gravels in the Blue Canyon drainage. No known deposits of placer gold occur in the study area.

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

Zeolite resources have been identified southwest of the study area in the adjoining Lower Owyhee Canyon Wilderness Study Area (Causey, 1989c; Evans and others, 1990). The Blue Canyon Wilderness Study Area has small isolated exposures of tuff and sedimentary rock that contain low-grade zeolite minerals (heulandite and (or) clinoptilolite), but they are not considered to be resources. Rhyolite tuffs that underlie most of the Owyhee Breaks Wilderness Study Area are not highly altered to zeolite minerals. There is no record of zeolite claims in either study area.

In the northern and western parts of the study area, tuffaceous sedimentary rocks include beds that have been altered to bentonitic clays. A sample of bentonite collected in the northern part of the Owyhee Breaks Wilderness Study Area contains 80 to 95 percent smectite, a clay mineral that has swelling properties. However, these beds are far from existing markets, and no prospects or resources for them were identified in the study area.

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The author would like to thank Eugene Mueller and Darrell Jacobitz, claimants, for tours of their claims and samples of jasper.

Identified Resources of the Blue Canyon Wilderness Study Area

The Blue Canyon Wilderness Study Area contains marginally economic inferred resources of jasper, subeconomic inferred resources of perlite, and occurrences of sand and gravel. Detailed information on these resources is found in Causey (1989a). Other mineral commodities found in the study area are not of sufficient grade or volume to be resources, or they are covered by excessive amounts of overburden.

Identified Resources of the Owyhee Breaks Wilderness Study Area

The Owyhee Breaks Wilderness Study Area contains occurrences of bentonite jasper, zeolite minerals, and sand and gravel. Detailed information about these commodities is found in Causey (1989b). The northern part of the study area has an estimated 40,000 st of bentonite clay. Sand and gravel deposits are exposed along the Owyhee River and on small isolated benches near the river. Because these deposits are small and inaccessible, no mining is expected. Sand and gravel deposits exposed along the Owyhee River north of Rome, Oreg. (fig. 1), and in the southern part of the study area along Birch Creek contain trace amounts of gold. No economic placer gold deposits are known in the region. No other energy or mineral resources were identified in the Owyhee Breaks Wilderness Study Area.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

Caldera and Structural Evolution

The Blue Canyon and Owyhee Breaks Wilderness Study Areas lie within the north-central part of the Basin and Range physiographic province, a region characterized by east-west extensional tectonism. The eastern part of the study area includes the west margin of the Mahogany Mountain caldera (fig. 1), a collapse structure that resulted from the eruption of voluminous ash-flow and air-fall tuffs. The caldera, and its associated tuffs, is one of five calderas that make up the Lake Owyhee volcanic field in eastern Oregon (Rytuba and others, 1990a). The volcanic field extends westward from the Idaho border (fig. 1) to about longitude 118°30′ and northward from Jordan Valley, Oreg. (fig. 1), to about latitude 44°15′.

The Mahogany Mountain caldera is expressed topographically as an 8- by 12-mi elliptical depression that has been deeply eroded by the Owyhee River. The caldera margin (fig. 1) parallels the base of the topographic wall that is well exposed along the north escarpment of Mahogany Mountain. The topographic margin of the Mahogany Mountain caldera is controlled in part by north-trending normal faults, which suggests that caldera collapse may have occurred along these preexisting faults. The volcanic and structural evolution of the caldera generally parallels the stages of caldera evolution proposed by Smith and Bailey (1968). Three episodes of silicic volcanism are associated with the formation of this caldera: (1) an extensive precaldera rhyolite dome and flow complex at Mahogany Mountain, (2) rhyolite ash-flow and air-fall tuffs that erupted concurrently with the collapse of the caldera, and (3) postcaldera rhyolite dikes and plugs that intrude caldera-forming tuffs. Although mineralization in the study area is associated with a later post-caldera episode of silicic and intermediate volcanism, it was probably localized along the caldera ring faults.

In the east-central part of the study area, precaldera rhyolite flows form the southwest wall of the caldera and are the oldest rocks exposed in the study area (fig. 2). Rhyolite ash-flow and air-fall tuffs that erupted concurrently with the collapse of the caldera filled the resulting depression with an estimated 2,600 vertical ft of intracaldera tuff (Vander Meulen, 1989). These intracaldera tuffs represent the second stage of silicic volcanism and are part of the Leslie Gulch Ash-Flow Tuff Member of the Sucker Creek Formation of Kittleman and others (1965) (also see Kittleman, 1973). A potassium-argon age obtained from the tuff is 15.5±0.5 Ma (Vander Meulen and others, 1987b). All ages reported in this investigation were obtained from sanidine mineral separates. Major- and trace-element analyses indicate that the tuff is chemically zoned, ranging from high-silica, weakly peralkaline comendite to intermediate-silica comendite trachyte (Vander Meulen, 1989).

Silicic volcanism associated with the Mahogany Mountain caldera concluded with rhyolite intrusions. Rhyolite plugs that intrude the south-central part of the study area may be related to this episode of volcanism. A potassium-argon age obtained from a northwest-striking rhyolite dike, 6 mi east of the study area, is 14.9±0.4 Ma (Vander Meulen and others, 1987b). The rhyolite intrusions are locally brecciated, silicified, and cut by quartz veins.

The west half of the study area lies within a 15- by 30-mi gravity low (fig. 3) that may reflect a concealed caldera filled with low-density tuff and sedimentary rocks. The unit mapped as the tuff of Birch Creek, first described by Plumley (1986), may have erupted from this possible caldera.

North-trending normal faults that cut the map area (fig. 2) define a horst that is flanked by two grabens in the north-central part of the study area. The north-trending fault traces are generally discontinuous and poorly defined, although one fault in the north-central part of the study area can be traced for approximately 5 mi. Faults that divide the horst from the eastern graben are superimposed on, and parallel to, the west margin of the Mahogany Mountain caldera. Within this graben, most of the caldera margin is buried by postcaldera basalt flows, sedimentary rocks, and debris slides; this sequence suggests that subsidence along the graben-forming faults continued after caldera collapse. Subsidence within the western graben displaced a thick sequence of partly consolidated tuffaceous and lacustrine sedimentary rocks and diverted the east-flowing Owyhee River northward along its strike.

A second and younger set of faults, striking N. 35° W. to N. 55° W., offsets the north-trending faults. These younger faults are best exposed in the northern part of the study area. They are discontinuous; segments are a mile or less in length and may have been reactivated several times during the late Miocene to Pliocene. The northwest-trending faults parallel three major shear zones that cut the northern part of the Basin and Range, including the Brothers and Vale fault zones (Lawrence, 1976), and the DeLamar-Duck Valley structural trend (Rytuba, 1989). The Brothers fault zone, located approximately 60 mi southwest of the study area, extends northwest 160 mi across central Oregon from Steens Mountain to the Cascade Range. At the surface, the 15-mi-wide fault zone is delineated by a series of en echelon faults and fractures striking N. 55° W. (Walker 1977; Lawrence, 1976). The Vale fault zone is part of the northern is subparallel to the Brothers fault zone. The surface expression of this major 15-mi-wide fault zone is delineated by a series of northwest-striking faults (Walker, 1977; Ekren and others, 1981; Ferns, 1989a, b, c; Ferns and Ramp, 1989) that extend 120 mi from north-central Nevada into eastern Oregon. The study area is 14 mi southwest of the main fault zone. In this part of the Lake Owyhee volcanic field, most of the known sediment-hosted hot-spring gold deposits are localized where northwest-trending faults intersect older north-trending normal faults and younger north-northeast-trending normal faults.

Volcanic Stratigraphy

The stratigraphically lowest rocks exposed in the study area are the precaldera rhyolite flows of Mahogany Mountain (unit Trf, fig. 2), formerly called the Jump Creek Rhyolite by Kittleman (1973). In the east-central part of the study area, these flows form the southwest topographic wall of the Mahogany Mountain caldera. The northern part of this rhyolite complex subsided with the formation of the caldera and is no longer exposed.

Three mappable ash-flow tuff units are exposed in the study area: units Tlg, Tsc, and Tbc (fig. 2). The tuffs were originally mapped as the Leslie Gulch Ash-Flow Tuff of the Sucker Creek Formation (Kittleman and others, 1965) but are here divided into three separate, informally designated units. From oldest to youngest they are the tuff of Leslie Gulch (Vander Meulen and others, 1987b), the tuff of Spring Creek (Vander Meulen and others, 1987b), and the tuff of Birch Creek (Plumley, 1986).

In the study area, the tuff of Leslie Gulch consists of an interbedded sequence of partly welded to nonwelded rhyolite ash-flow tuff and several smaller air-fall and surge deposits, all of which cooled as single unit. Throughout the study area, this composite tuff sheet dips between 10° and 20° west and has a minimum thickness of 900 ft. The unit is exposed west and south of the caldera margin and is interpreted as an outflow ash-flow tuff that erupted from the caldera. In the north-central part of the study area, near the projected caldera margin, the tuff locally consists of matrix-supported orange-brown angular pumice blocks as large as 10 in. across. This near-vent pumiceous tuff indicates that at least part of the outflow unit was erupted from a caldera ring vent. The unit is generally massive and unsorted, showing only crude layering, although parts of the tuff grade up into well-bedded air-fall tuff. The tuff is typically crystal poor with 1 to 5 percent quartz and sanidine phenocrysts. The unit is exposed locally throughout most of the study area and probably underlies the entire study area at depth. The tuff erodes to irregular spires and steep slopes that are honeycombed with pockets from wind erosion. Internal stratigraphy of the outflow tuff is relatively consistent.

Following the collapse of the Mahogany Mountain caldera, two post-caldera rhyolite ash-flow tuffs unrelated to the Mahogany Mountain caldera erupted from nearby centers and ponded in the caldera moat. The tuff of Spring Creek (unit Tsc, fig. 2) was the first ash-flow tuff to pond in the caldera and unconformably overlies the tuff of Leslie Gulch. It is a composite ash-flow tuff that erupted from the Three Fingers caldera (Vander Meulen and others, 1989) 20 mi northeast of the study area (fig. 1). The tuff consists of multiple ash-flow sheets that cooled as a single unit. In the south-central part of the study area the tuff of Spring Creek has a maximum thickness of 600 ft.

The tuff of Birch Creek (unit Tbc, fig. 2) is the younger of the two postcaldera ash-flow tuffs. Gravity data and stratigraphic relations indicate that the vent for the tuff is within or west of the study area. Chemically, the tuff of Birch Creek is calc-alkaline rhyolite (Plumley, 1986). The tuff ranges from approximately 200 ft thick in the central part of the study area, where it forms an angular unconformably with the underlying tuff of Leslie Gulch, to an estimated 500 ft thick in the southern part of the study area near the Owyhee River. Thicker parts of the tuff are welded to densely welded and contain irregular-shaped pods and stringers of dark-colored vitrophyre. Repetition of vitrophyric zones and welding zonation within the ash-flow sequence indicate that the tuff is composed of two cooling units. Locally, the tuff displays rheomorphic features such as recumbent folds and ramp structures and has well-developed eutaxitic foliation. It contains plagioclase, hornblende, and biotite phenocrysts.

In the central and southern parts of the study area, rhyolite and dacite plugs and dikes (units Trp and Tdi, fig. 2) cut the entire sequence of caldera-forming and postcaldera tuffs. The intrusions crop out as discontinuous irregular bodies, as thick as 60 ft, that typically pinch and swell along strike. They are highly resistant to erosion and form steep spired ridges that typically rise hundreds of feet above the surrounding topography. Most of these intrusions contain phenocrysts of alkali feldspar and plagioclase and are chemically classified as high-potassium dacite (Plumley, 1986). Hydrothermal silicification and calcification is common in the intrusions and adjoining country rock.

In the southern part of the study area along the Owyhee River, two large intermediate-silica plugs (unit Tai, fig. 2) intrude the tuff of Leslie Gulch. Composition ranges from basaltic andesite to high-potassium andesite. The intrusions have a maximum exposed thickness of approximately 700 ft. Chemically and petrographically these rocks are similar to, and probably comagmatic with, porphyritic andesite flows intercalated with the lower part of the sedimentary sequence (discussed below).

In the northern part of the study area, a large 0.5- by 1-mi mafic to intermediate plug (unit Tbi, fig. 2) intrudes a thick sequence of sedimentary rocks. The west margin of this basaltic intrusion is in fault contact with the tuff of Leslie Gulch.

Several vitric and crystal-vitric air-fall tuffs and one lithic-rich ash-flow tuff are intercalated with the sedimentary rocks and are mapped as part of the sedimentary rocks (unit Ts, fig. 2). The lithic-rich tuff crops out across the northern part of the study area, has a maximum thickness of approximately 80 ft, and forms a resistant cap rock near the upper part of the sedimentary sequence. The tuff is commonly silicified and locally contains anomalous concentrations of gold, silver, mercury, and molybdenum.

The youngest volcanic rocks in the study area are plateau-forming olivine tholeiitic-basalt flows (unit Tb, fig. 2) that unconformably overlie the sedimentary rocks and rhyolite flows of Mahogany Mountain. The lava flows cap plateaus, mostly in the southern part of the study area, and yield whole-rock potassium-argon ages ranging from 3.8 to 0.2 Ma (Hart and Mertzman, 1983). Along the plateau rim, the basalt flows are as thick as 100 ft; at two locations in the southern part of the study area, flows cascaded over the rim and ponded in a north-trending paleovalley where they are as thick as 330 ft. Remnants of these ponded basalt flows cap intercanyon buttes and are exposed as discontinuous ledges along the river canyon. One vent area for the basalt flows is a small shield volcano centered at Deer Butte (fig. 1), 2 mi southwest of the study area.

Sedimentary Stratigraphy

Several sediment-hosted hot-spring gold prospects recently have been discovered north and east of the study area; as a result, the sedimentology of the study area has been extensively investigated. In the northern and western parts of the study area, an estimated 1,000-ft-thick sequence of sedimentary rocks (unit Ts, fig. 2) unconformably overlies the caldera-forming and postcaldera tuffs. The general lithology from the base up consists of tuffaceous sandstone, interbedded palagonite tuff and basaltic-andesite flows, evaporite deposits and diatomaceous earth interbedded with thick sequences of claystone and siltstone, and arkosic sandstone and conglomerate units. This general sequence indicates the evolution of a lake from initial basin filling to the point of total inundation, subaerial exposure, followed by subsidence and resumption of deep-water deposition. This sedimentary cycle was not interrupted until basin-and-range tectonism extended the region and voluminous basalt flows covered the sedimentary rocks (fig. 2).

Locally in the northern part of the study area, excellent exposures of tuffaceous sedimentary rocks with large-scale crossbeds form the basal part of the section. The dominant lithology is pebble- and sand-size tuffaceous detritus with minor basaltic and rhyolitic fragments. Detritus is upward fining, well sorted, and moderately rounded. The entire unit has an estimated thickness of 70 ft. Contact between the large composite sets (crossbeds) and the underlying fine-grained sedimentary rocks is sharp. The composite sets contain both stratified and cross-stratified units of similar or gradational lithology. Forsets dip at angles between 11° and 17° to the west and are approximately 120 ft in length. McKee and Weir (1953) have described similar sedimentary structures in lacustrine deltas. These large-scale crossbedded volcaniclastic sandstone horizons most likely formed by the progradation of a steep deltaic lobe adjacent to a topographic high.

At the extreme northeast edge of the study area and near the Owyhee River in the western part of the study area, palagonite tuffs (unit Tpt, fig. 2) stratigraphically overlie the tuffaceous sedimentary rocks. The unit has a total estimated thickness of 120 ft and contains basaltic blocks, lithic and pumice fragments, and ash. Stratified parts of the palagonite tuff contain parallel beds, parallel crossbeds, lithic trains, and inverse grading of tephra. Features exposed near the base include cut-and-fill structures, dunes, explosion breccia, and sag structures. The breccia contains conspicuous biotite- and hornblende-bearing blocks of the welded tuff of Birch Creek. Flow features near the base are those created during the formation of basaltic tuff cones, specifically the stage dominated by base surge (Wohletz and Sheridan, 1983). Similar tuff cone deposits are described by Cummings and Growney (1988) in a detailed study of basaltic hydrovolcanic deposits, 14 mi north of the study area. In the northern and western parts of the study area, the palagonite tuffs are exposed along north-striking fault zones, as are basaltic dikes and plugs that intrude delta deposits. Palagonite tuffs that locally overlie fine-grained claystone and are near a preserved delta suggest that these basaltic eruptions occurred in relatively deep water. The spatial association of palagonite tuffs with north-trending normal faults is also apparent north of the study area, near the Red Butte gold prospect (fig. 2). Several of the known sediment-hosted hot-spring gold prospects in the region, including Red Butte, Quartz Mountain, and Mahogany (fig. 1), are floored by thick sequences of palagonite tuff or basalt flows.

Stratigraphically above the palagonite tuffs is a sequence of claystone and siltstone that typically exceeds 50 ft in thickness and is locally as thick as 650 ft. These rocks contain carbonaceous material, leaf fragments, small twigs, and possibly fish vertebrae. Thick sequences, greater than 50 ft, of finely laminated claystone are intercalated with lenticular horizons of organic-rich detritus. Within these thick carbonaceous sequences, dark basal layers of carbonaceous claystone or siltstone typically grade up into more mottled, bioturbated, lighter colored strata. The top of each gradational layer contains root casts, calcium carbonate nodules, and intermittent undulatory horizons of caliche. In several locations the bedding was destroyed by bioturbation. Dark organic-rich clays that contain scattered silt lenses, evidence of bioturbation, and fluid-escape structures are characteristic of lake-bottom depositional environments associated with delta-fill processes (Coleman, 1976).

Interbedded with the claystone and siltstone are beds of diatomaceous earth and thin evaporite deposits, primarily of gypsum. Large extensive sheets of gypsum were not seen, although exposed strata are planar and as much as 2 in. thick. The diatomaceous earth is exposed in the northern part of the study area. Individual beds of diatomite, which are very clean and possibly of industrial quality, are typically 2 to 4 in. thick and range up to 5 ft thick. Locally, the diatomaceous earth is well bedded to finely laminated, consolidated to punky, and contaminated in part with calcium carbonate and volcanic ash. Thicker beds are massive and very clean; however, the massive beds are poorly exposed and crop out only where slopes are oversteepened. Nonalkaline conditions are necessary for the preservation of diatomite because the solubility of silica increases abruptly at a pH greater than 9 (Krauskopf, 1959). To preserve large amounts of diatomite, immediate coverage is necessary, such as deposition in a stable basin or preservation by a cover of volcanic tuffs and flows.

In the study area, arkosic sandstone and gravel beds range from 10 to 40 ft thick and overlie the fine-grained claystone and siltstone beds. The prefix "arkosic" has been used for sandstone units that contain more than 25 percent feldspar. The remaining detritus in the sandstone is mostly quartz, minor biotite, and fragments of basalt and rhyolite. The arkosic sandstone and gravel beds are locally well indurated and silicified and contain medium-scale planar crossbeds that grade laterally into zones of planar-bedded fine-grained sedimentary rocks. These beds are regionally extensive and syndepositional with hot-spring sinter deposits at the Red Butte and Katie gold prospects. Arkosic sandstone and conglomerate beds within the study area are interpreted as stratigraphically equivalent to the silicified and mineralized sedimentary rocks exposed at the Red Butte gold prospect, 2.5 mi north of the study area.

Landslide deposits (unit Qls, fig. 2) cover approximately 3 mi² in the western part of the study area and approximately 7 mi² northeast of the study area. The deposits consist of rotated blocks and debris slides that have developed in poorly consolidated tuffaceous sedimentary rocks along the plateau rims. Rotated basalt blocks displaced along transverse cracks form broad arcuate headwall scarps along the plateau rims. These slides commonly terminate in canyon bottoms as bulbous toes covered with pressure ridges. From head to toe, some of the slides are 3 mi long. Other surficial deposits consist of talus, colluvium, and alluvium. The thickest alluvial deposits are restricted to the Owyhee River and main stream drainages.

Geochemical Studies

In 1988, the U.S. Geological Survey conducted a reconnaissance geochemical study of the Blue Canyon and Owyhee Breaks Wilderness Study Areas. Stream sediments and heavy-mineral concentrates from stream sediments were selected as the primary sample media on the basis of their ability to reveal elemental anomalies. During this study, 47 stream-sediment samples and 46 nonmagnetic heavy-mineral-concentrate samples were collected in and near the study area and were analyzed. Stream-sediment and concentrate samples were collected from first- and second-order, primarily dry stream beds. In addition, 82 rock samples, predominantly silicified and (or) brecciated volcanic and sedimentary rock from outcrops or stream cobbles, were collected to determine the suite of elements associated with the observed alteration.

Stream-sediment and nonmagnetic heavy-mineral-concentrate samples represent composites of eroded bedrock exposed upstream from sample sites. Stream-sediments reflect bedrock geochemistry useful in identifying basins that contain concentrations of elements possibly related to mineralized rock. Nonmagnetic heavy-mineral-concentrate samples provide information about the chemistry of a limited number of minerals which may be ore forming or ore related. Such selective concentration of minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples.

All samples were analyzed for 35 elements (antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, gallium, germanium, gold, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, niobium, phosphorus, scandium, silver, sodium, strontium, thorium, tin, titanium, tungsten, vanadium, yttrium, zinc, and zirconium) by using a six-step semiquantitative emission-spectrographic method described by Crock and others (1987). In addition, the nonmagnetic concentrates were also analyzed spectrographically for platinum and palladium. Rock and stream-sediment-samples were analyzed for gold, mercury, arsenic, antimony, cadmium, bismuth, and zinc nonspectrographically to provide data on elements not determined spectrographically or to provide data at low levels of detection. The mercury analyses were done by atomic absorption and the arsenic, antimony, cadmium, bismuth, and zinc analyses were done by inductively coupled argon plasma–atomic emission spectrography (Crock and others, 1987). Gold analyses were done by graphite-furnace atomic absorption (Meier, 1980), which has a lower level of detection of 2 parts per billion (ppb). This method does not break down silicate minerals; therefore, detected values represent detrital gold.

All of the stream-sediment samples and 15 of the rock samples were analyzed for uranium by Centanni ultraviolet fluorescence (O'Leary and Viets, 1986). All of the stream-sediment samples, 13 concentrate samples, and 2 rock samples were analyzed for fluorine by an ion-selective electrode method (O'Leary and Viets, 1986). Detailed analytical data on which the following account is based have not been published (M.J. Malcolm and others, unpub. data, 1990). Summaries of the analyses are presented in tables 2–4. One

Table 2. Geochemical summary for 46 U.S. Geological Survey nonmagnetic panned-concentrate samples from the Blue Canyon and Owyhee Breaks Wilderness Study Areas and adjacent areas, Oregon

[All values expressed in parts per million. First-column values are lower levels of determination for emission spectrometry (S) and ion-selective electrode (ISE) analytical methods. L represents detection below the limit of analytical determination, > represents detection above it]

Anomalous elements		Threshold values	Range of anomalous values	No. of anomalous sample sites
Ag	(S 1)	1	1.5–70	3
As	(S 20)	L(20)	30–700	2
Ba	(S 50)	10,000	10,000–>10,000	22
F	(ISE 100)	3,000	3,100–380,000	12
La	(S 50)	500	500–1,000	6
Mo	(S 10)	15	15	1
Nb	(S 50)	150	150–200	6
Pb	(S 20)	150	150–15,000	7
Sb	(S 200)	L(200)	L(200)–500	2
Sn	(S 20)	100	100–2,000	10
Sr	(S 200)	3,000	7,000	1
Y	(S 20)	700	700–1,000	20

Table 3. Geochemical summary for 47 U.S. Geological Survey minus-80-mesh stream-sediment samples from the Blue Canyon and Owyhee Breaks Wilderness Study Areas and adjacent areas, Oregon

[All values are expressed in parts per million. First-column values are lower levels of determination for emission spectrometry (S), atomic absorption (AA), inductively coupled plasma–atomic emission spectroscopy (ICP), ion-selective electrode (ISE), and fluorimetric (F) analytical methods. L represents detection below the limit of analytical determination]

Anomalous elements		Threshold values	Range of anomalous values	No. of anomalous sample sites
As	(ICP 1)	3	3–30	36
Au	(AA 0.002)	0.002[1]	0.002–0.007	3
B	(S 10)	20	20	3
Ba	(S 20)	1,000	1,000–2,000	26
Be	(S 1)	5	5	1
Cd	(ICP 0.05)	0.3	0.3–0.6	6
Co	(S 5)	70	70	1
Cr	(S 10)	300	300	7
F	(ISE 100)	600	620–3,200	15
Ga	(S 5)	50	50	1
Hg	(AA 0.02)	0.10	0.10–0.18	4
La	(S 20)	50	50–70	32
Mo	(S 5)	L(5)	L(5)–7	5
Nb	(S 20)	30	30	1
Pb	(S 10)	30	30	2
Sb	(ICP 1)	1	1–3	3
Sr	(S 100)	1,000	1,000	7
U	(F 0.4)	4	8.7	1
V	(S 10)	500	500–700	4
Y	(S 10)	70	70	1

[1] Analytical method used does not break down the silicate minerals, so detected gold is detrital.

Table 4. Geochemical summary for 82 U.S. Geological Survey rock samples from the Blue Canyon and Owyhee Breaks Wilderness Study Areas and adjacent areas, Oregon

[All values are expressed in parts per million. First-column values are lower levels of determination for emission spectrometry (S), atomic absorption (AA), inductively coupled plasma–atomic emission spectroscopy (ICP), and ion-selective electrode (ISE) analytical methods. L represents detection below the limit of analytical determination]

Anomalous elements		Threshold values	Range of anomalous values	No. of anomalous sample sites
Ag	(S 0.5)	L(0.5)	L(0.5)–3	19
As	(S 200)	L(200)	L(200)	3
As	(ICP 1)	3	3.4–309	51
Au	(AA 0.002)	0.002[1]	0.002–0.04	17
B	(S 10)	20	20–70	7
Ba	(S 20)	1,000	1,000–3,000	20
Be	(S 1)	5	5–7	7
Cd	(ICP 0.05)	0.3	0.4	3
Co	(S 5)	70	70	1
F	(ISE 100)	1,000	90,000	1
Ga	(S 5)	50	50	6
Ge	(S 10)	5	L(10)–100	5
Hg	(AA 0.02)	0.1	0.1–2.2	20
La	(S 20)	50	50–150	14
Mn	(S 10)	3,000	3,000	1
Mo	(S 5)	L(5)	L(5)–150	37
Nb	(S 20)	30	30	7
Pb	(S 10)	30	50–70	2
Sb	(S 100)	L(100)	L(100)	1
Sb	(ICP 1)	1	1–14	33
Sn	(S 10)	5	20	1
Sr	(S 100)	1,000	1,000–1,500	3
V	(S 10)	500	500	1
Y	(S 10)	70	70–150	19
Zn	(S 200)	L(200)	L(200)–200	7
Zn	(ICP 0.05)	150	150	1

[1] Analytical method used does not break down the silicate minerals, so detected gold is detrital.

water sample from a thermal spring north of the Owyhee River, in the western part of the study area (fig. 2), contains no gold or uranium at a detection limit of 0.1 ppb.

Most of the rock units exposed in the study area are silicic pyroclastic deposits or basalt flows. Too few unmineralized rocks were collected to provide a sufficient data base for a statistical approach to calculating geochemical threshold values. Therefore, the threshold values (lowest anomalous values) chosen for rock and stream-sediment samples were calculated at two to three times the concentrations for bulk continental crust (see Taylor and McLennan, 1985, p. 62, 67). Whenever threshold values for elements were below their lower levels of detection, the quantitative values were considered anomalous. Threshold values for the nonmagnetic concentrate samples were based on the experience with other geochemical surveys in the region. Data presented in tables 2–4 indicate the calculated threshold values, the range of anomalous values, and the

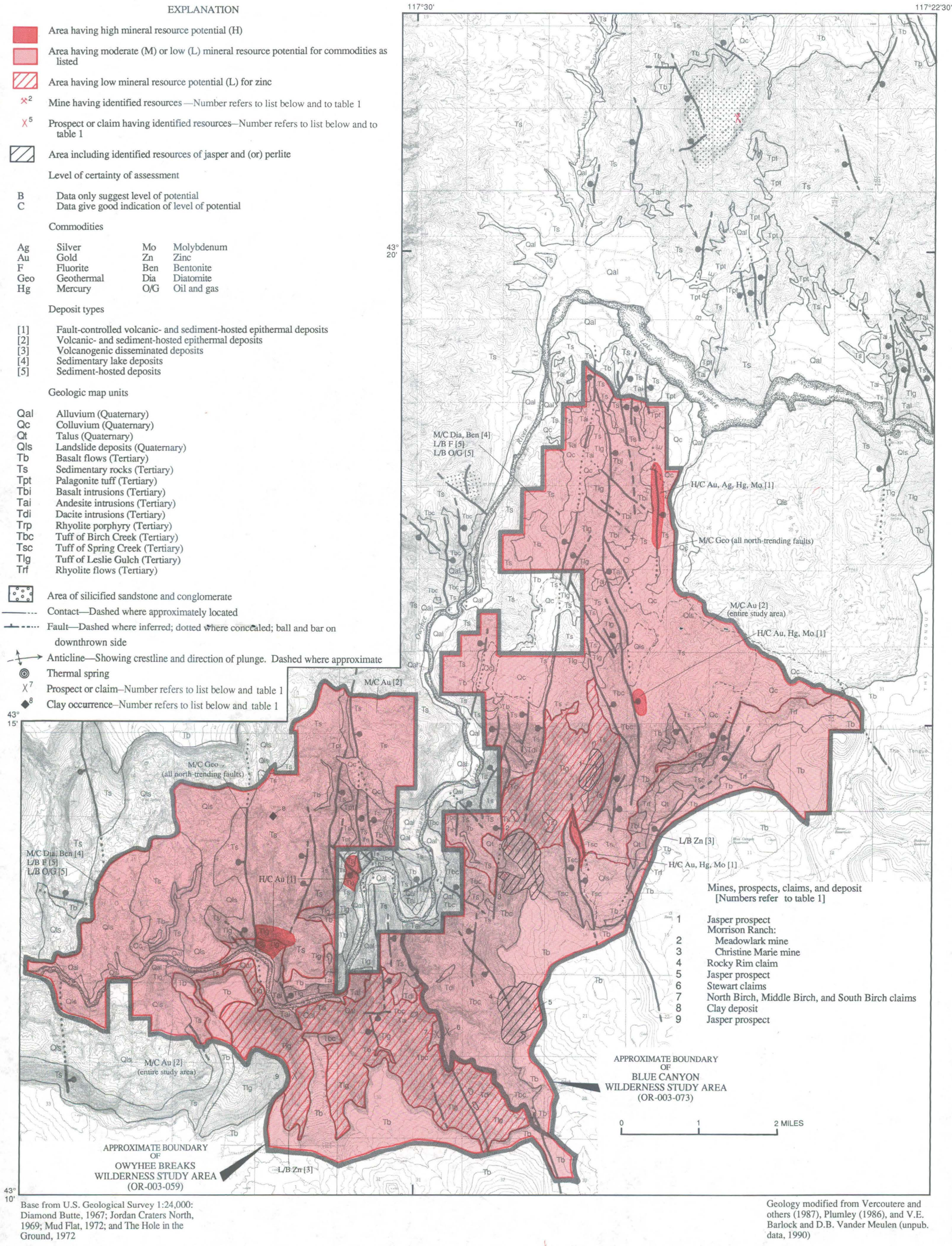

Figure 2. Mineral resource potential and generalized geology of Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon.

number of sample sites containing anomalous concentrations of metals (elements) in the map area, for each sample medium.

Regional Gold Mines and Prospects

Ferns and Huber (1984) reported several epithermal gold deposits in southeastern Oregon which they described as fossil geothermal systems that formed near the surface in hot-spring systems. The systems are commonly associated with Tertiary fault zones, rhyolitic volcanic centers, and tuffaceous sedimentary rocks. Systems favorable for gold generally cover several square miles, contain anomalous concentrations of mercury and antimony, and have extensive caps of siliceous sinter (opalite) and large zones of clay alteration.

Several deposits of this type are near the study area (Wheeler, 1988). They are pervasively silicified and brecciated and are hosted by fluvial and lacustrine sandstone and conglomerate that have been faulted. The highest gold concentrations are usually in sandstone adjacent to conglomerate beds or brecciated rocks. Most of the deposits have associated clay alteration, silicification, and disseminated pyrite. The geochemistry of these deposits is characterized by anomalous concentrations of mercury and arsenic. Gold is, for the most part, micron size.

Quartz veins, clay alteration, hydrofractured rock, and pervasive silicification of host rocks was present at all the disseminated gold prospects examined. In addition, northwest-trending structures intersect north-trending basin-and-range faults at these prospects. Siliceous sinter is exposed at the Grassy Mountain, Red Butte, Quartz Mountain, Katie, and Mahogany prospects (fig. 1). Of rock samples collected from the Quartz Mountain prospect, 10 have anomalous values that range from 10 to 850 ppb gold, 0.2 to 5.5 parts per million (ppm) silver, 7 to 90 ppm arsenic, 6 to 77 ppm antimony, 120 to more than 5,000 ppb mercury, and 30 to 700 ppm fluorine. At the Red Butte prospect, 18 rock samples have values that range from 5 to 1,120 ppb gold, 11 to 1,000 ppm arsenic, and 25 to 700 ppb mercury.

In 1988, more than 40 companies were exploring for gold in the northern Basin and Range province of southeast Oregon, where approximately 5,000 new claims were filed. The main area of interest is an epithermal-gold province in the northeastern part of Malheur County, Oreg. (Ferns, 1989d), which includes the study area, and adjacent Owyhee County, Idaho, where a total of at least 28 prospects are being evaluated. The Grassy Mountain prospect (fig. 1), has reserves of more than 1 million ounces at a grade of 0.065 oz/short ton gold (Ferns and Ramp, 1989). The deposit is a hot-spring-type epithermal system hosted by arkosic sandstones. The age of mineralization for the Red Butte, Quartz Mountain, and Katie prospects (fig. 1) is probably middle Miocene. At the Mahogany gold prospect, veins of quartz and adularia cut the host rocks; a K-Ar age on adularia from one of these veins dates the mineralization at 12.6 Ma (Rytuba and others, 1990b). Gold mineralization at prospects north of this area, such as Grassy Mountain, is associated with younger intermediate and silicic intrusions (Cummings, 1989; Ferns and Ramp, 1989).

The DeLamar silver mine, 35 mi east-southeast of the study area in Owyhee County, Idaho, and several nearby prospects are similar Miocene hot-spring-type epithermal deposits. The DeLamar mine produced more than 17 million oz of silver and 230 oz of gold by bulk mining methods between 1977 and late 1987 and an estimated 42 million ounces of silver and 600,000 oz of gold by underground lode-vein mining between 1863 and 1914. Production is predominantly from silver selenide minerals and native gold in quartz veins hosted by a rhyolite ring-dome complex (Halsor and others, 1984, 1988; Barrett, 1985; Ekren, 1985). Mineralization is controlled by north-trending faults that intersect younger northwest-trending faults. Principal gangue minerals in the veins are quartz and adularia, with lesser amounts of calcite, barite, pyrite, fluorite, and siderite. Alteration zones are dominated by clays associated with pyrite and quartz.

The Red Butte prospect is an epithermal hot-spring-type gold deposit characterized by silicified lacustrine and fluvial volcaniclastic sedimentary rocks, quartz veins, and hydrothermal explosion breccia (Evans and Cummings, 1986). They report that anomalous concentrations of gold, mercury, arsenic, and antimony are present in banded quartz, quartz-adularia veins, silicified sandstone, and rarely in calcite-quartz veins in basalt. Silicification is both structurally and stratigraphically controlled; silicified mudstones are generally barren. Part of a hydrothermal explosion crater and vent exposed on the southeast side of Red Butte lies at the intersection of north and northwest-trending faults. The Red Butte mineralizing system developed as silica-saturated hot-spring fluids issued into cooler lake waters. Silica flocculation near the vent formed massive beds of siliceous sinter. Gold and pyrite were also deposited at the vent. During this study, samples collected from the siliceous sinter, silicified mudstones and sandstones, and the veins and breccia yielded anomalous values as high as 0.040 ppm gold, 220 ppm arsenic, 51 ppm antimony, and 1.03 ppm mercury. Correlation coefficients comparing gold to arsenic, antimony, and mercury show no linear correlations, but samples high in gold are usually enriched in arsenic and antimony. A sample of silicified breccia collected by the U.S. Geological Survey from the hydrothermal explosion crater along the southeast side of Red Butte contains 0.04 ppm gold, 2.2 ppm mercury, 310 ppm arsenic, 17 ppm antimony, 3 ppm silver, 20 ppm molybdenum, and more than 10,000 ppm barium. A nonmagnetic concentrate sample collected at the site contains 80 percent fluorite and some pyrite.

The Mahogany prospect (fig. 1) is hosted by tuffs, tuffaceous sedimentary rocks, and volcaniclastic sandstones (Gilbert, 1988). The prospect lies along a north-trending fault zone that localized hydrothermal solutions of a hot-spring system. The dominant alteration is described as silicification and argillation with abundant quartz, calcite, and quartz-adularia veins. Chalcedony is the predominant type of silica. Arsenic, antimony, mercury, and silver anomalies accompany the gold mineralization. Anomalous concentrations of gold, as much as 7.4 ppm, are typically confined to quartz-calcite stockwork zones, banded quartz-calcite veins, and breccia dikes within a lithic tuff. Gold mineralization is spatially associated with silicified hydrothermal explosion breccia and fossilized siliceous hot-spring sinter deposits.

Results and Interpretation

The volcanic and sedimentary stratigraphy and the structure of the study area are similar to those features in nearby areas that have been prospected for epithermal gold deposits. In the southern and western parts of the study area, Plumley (1986) indicated that hydrothermally altered and silicified rocks typical of hot-spring systems are restricted to volcaniclastic sedimentary rocks of the Sucker Creek Formation (Kittleman and others, 1965), tuff of Birch Creek, and tuff of Leslie Gulch. In the north-central part of the study area, altered and mineralized rocks are locally associated with northwest-trending faults and the west margin of the Mahogany Mountain caldera (Vander Meulen, 1989).

Rocks at most sample sites show evidence of silicification and (or) brecciation. Quartz, opal, chalcedony, or silicified sedimentary rocks are present in outcrop or as cobbles in streams at 25 of 45 sites. In the Owyhee Breaks Wilderness Study Area, a horizontal layer of green silicified tuff 6 to 8 ft thick crops out approximately 3.2 mi downstream from the thermal spring (fig. 2). Brecciated limonitic rocks are common. Pyrite is present in 14 nonmagnetic concentrate samples.

Barite and fluorite are also commonly found in the concentrate samples and may be associated with epithermal mineralization; barium and fluorine are anomalous in all samples of all media (tables 2–4). The fluorite and barite may have been deposited by chemical precipitation along with lake sediments distal to hot-spring vent areas. Fluorite constitutes as much as 16 percent of some lacustrine beds near Rome, Oreg. (fig. 1; Brobst and Pratt, 1973, p. 223). The fluorite-rich beds at Rome lack associated epithermal gold mineralization, but similar occurrences, if more concentrated in fluorite, could constitute a fluorite resource. In the study area, individual beds of sedimentary rock would have to be sampled to locate potential deposits. The highest concentrations of fluorine in stream-sediment and concentrate samples are from a site at Red Butte. Plumley (1986) reported that barium values average 1,200 ppm for the tuff of Birch Creek; 1,100 ppm for andesite intrusions; and 800 ppm for the tuff of Leslie Gulch. These values are above normal for silicic tuffs and intermediate intrusions and may have contributed to the barium anomalies in the stream-sediment and concentrate samples from the study area.

Reconnaissance geochemical studies and initial mineral resource appraisals for the study area were conducted the Oregon Department of Geology and Mineral Industries (Gray and others, 1983), Barringer Resources, Inc. (Bukofski and others, 1984), and Robinson and others (1985). Although their samples were analyzed for fewer elements, and threshold values varied, anomalies similar to those in the present study were detected in their stream-sediment samples.

During the present study, anomalous gold was detected in two stream-sediment samples (0.002 and 0.004 ppm) and in two nonmagnetic concentrate samples (30 and 700 ppm). One of the nonmagnetic concentrate samples was collected near river level at the base of a waterfall in the south-central part of the study area, and the other came from the northwestern part of the study area below perched alluvial gravels presumably deposited by the Owyhee River. Gold and silver anomalies in the concentrate samples may be due to placer gold flakes derived from Owyhee River sediments. Ten rock samples collected in the study area have gold values ranging from 0.002 to 0.024 ppm. They were collected from silicified tuffs and sedimentary rocks in the western part of the study area west of the Owyhee River and in the north-central part of the study area west of Blue Canyon.

Three concentrate samples from the western part of the study area contain 1.5 to 70 ppm silver. In two of these samples, the silver is associated with the 30- to 700-ppm gold values discussed above. Silver is anomalous in 12 rock samples (0.5–3 ppm), but none was detected in the stream-sediment samples.

Two stream-sediment samples and 15 rock samples collected in the central part of the study area have anomalous mercury (0.10–0.16 ppm and 0.10–0.72 ppm, respectively). Thirty-four stream-sediment samples contain 3 to 27 ppm arsenic, and 32 rock samples contain 3 to 250 ppm arsenic. Anomalous antimony was detected in two stream-sediment samples (1 and 2 ppm), and two concentrate samples contain 500 ppm antimony; 23 rock samples contain 1 to 7 ppm antimony. Anomalous concentrations of antimony and lead detected in the stream-sediment and concentrate samples may represent contamination from lead shot.

All samples collected for this investigation are anomalous in at least one element; 26 samples are anomalous in the combination of gold, silver, arsenic, mercury, antimony, and molybdenum. These elements probably best characterize and delineate areas for epithermal hot-spring gold deposits. Other low-level anomalies that may also be associated with epithermal hot-spring mineralization in the study area include barium, beryllium, boron, cadmium, fluorine, lead, strontium, and uranium.

Berger and Eimon (1983) indicated that the nature and economics of epithermal precious-metal deposits are determined by the geometry of the fracture system, permeability and composition of the host rocks, and hydrodynamics of the fluid system. In their model, barren quartz veins carrying anomalous concentrations of arsenic, antimony, and mercury can extend hundreds of feet above an ore zone. Anomalies found during this study may be of this type, although the presence of the epithermal pathfinder suite of elements does not necessarily indicate the presence of an ore body (Nelson, 1988).

Other low-level anomalies are probably due to lithologic controls. Anomalous concentrations of cobalt, chromium, and vanadium are probably derived from mafic flows and intrusions and reflect normal abundances of these elements in these rock types. Ore-grade cobalt, chromium, and vanadium deposits are not likely in the geological environment of the study area. Anomalous concentrations of lanthanum, niobium, and yttrium are probably derived from the chemically zoned tuff of Leslie Gulch (Vander Meulen, 1989).

One stream-sediment sample collected from a small tributary drainage in the southern part of the study area contains 8.7 ppm uranium. The tributary drains landslide deposits in sedimentary rock. Petrified wood is abundant at the site but was not analyzed for uranium; however, no scintillometer deflection occurred over samples of petrified wood. A high germanium value (100 ppm) was obtained from a green sandstone cobble collected at the same site. This and other scattered anomalous germanium and gallium values probably do not indicate a resource. High anomalous zinc values, with which economic quantities of these metals are generally associated (Weeks, 1973), were not detected in the study area.

Geophysical Studies

Aeromagnetic Survey

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 2-mi intervals 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 are available at a scale of 1:500,000 for the Boise 1° by 2° quadrangle (geoMetrics, Inc., 1979) as part of a program for the U.S. Department of Energy. These data consist of east-west profiles spaced at 3-mi intervals and flown 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 may be a guide to mineralization. Boundaries between magnetic and relatively less magnetic rock units are located approximately at the steepest gradient on the flanks of magnetic anomalies. Most anomalies in the study area are probably caused by the preponderance of basalt flows and other volcanic rocks. The flight altitude was sufficient to suppress most of the short-wavelength anomalies generated by small rock units at or near the surface. These short-wavelength anomalies can be seen on the low-level profiles across the study area (geoMetrics, Inc., 1979). The aeromagnetic map (U.S. Geological Survey, 1972) shows that the study area has relatively small magnetic highs and lows that are probably caused by volcanic rocks concealed below the surficial sediments and young lava flows rather than by the presence of any mineral resources.

Gravity and Gamma Ray Surveys

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. Stations were about 3 to 5 mi apart, and about 16 stations were used for this study. West of approximately 117°30′ W. longitude, the study area lies within the eastern part of a 14-mi-wide subcircular gravity low having a maximum amplitude of 15 to 17 milligals (fig. 3). The east edge of this low is marked by a steep gravity gradient that slopes down to the west and is probably caused by a concealed fault striking north at about 117°30′ W. longitude. The fault appears to be the southernmost end of a major fault zone extending at least 70 mi north of the study area (Lillie, 1977). The accompanying subcircular gravity low west of this fault, and lying outside the study area, does not have an easily identified source. The low extends 15 mi west and northwest of the study area, across the Owyhee River canyon. Its lowest point is near the canyon bottom where the thickest section of silicic welded tuff is exposed (Evans and others, 1990). Explanations for the gravity low include a small concealed granitic batholith, a concealed basin filled with low-density sedimentary rocks, or a concealed caldera that contains low-density sedimentary and volcanic rocks. The third explanation is the most likely because it offers a possible source for the tuff of Birch Creek and for thick sequences of rhyolite and welded tuff exposed 8 mi southeast of the study area. Such a caldera might have associated mineralization. Another smaller gravity low approximately 6 mi in diameter lies within and east of the study area (fig. 3). This low is probably caused by a thick sequence of tuffs and sedimentary rocks that fill the western part of the Mahogany Mountain caldera.

Aerial gamma-ray spectrometer measurements are available along the 3-mi-spaced east-west profiles illustrated by geoMetrics, Inc. (1979). Statistically significant anomalies for uranium were not found within the borders of the study area.

Mineral and Energy Resource Potential of the Blue Canyon Wilderness Study Area

Gold prospects have been located by several exploration companies that are prospecting north and east of the Blue Canyon Wilderness Study Area (fig. 1) where hot-spring gold mineralization is commonly associated with intersecting north-, northwest-, and northeast-trending fault zones, localized silicic volcanism, hydrothermal explosion breccia, caps of siliceous sinter, and syndepositional arkosic sandstone and conglomerate beds. These criteria were used to rate the resource potential for gold in the study area.

A lithic-rich rhyolite ash-flow tuff exposed in the northern part of the study area is locally altered and silicified. The tuff ranges from 5 to 80 ft thick and typically caps the sedimentary sequence. Samples of the silicified tuff collected along a north-trending fault contain anomalous concentrations of gold, silver, mercury, and molybdenum. Silicified parts of the tuff, therefore, have high mineral resource potential for gold, silver, mercury, and molybdenum, certainty level C (fig. 2).

In the central part of the study area, samples of silicified and brecciated tuff collected along two north-trending fault zones contain anomalous concentrations of gold, mercury, molybdenum, and barium. At the Red Butte gold prospect to the north, a similar sample of brecciated rock collected along a north-trending fault zone

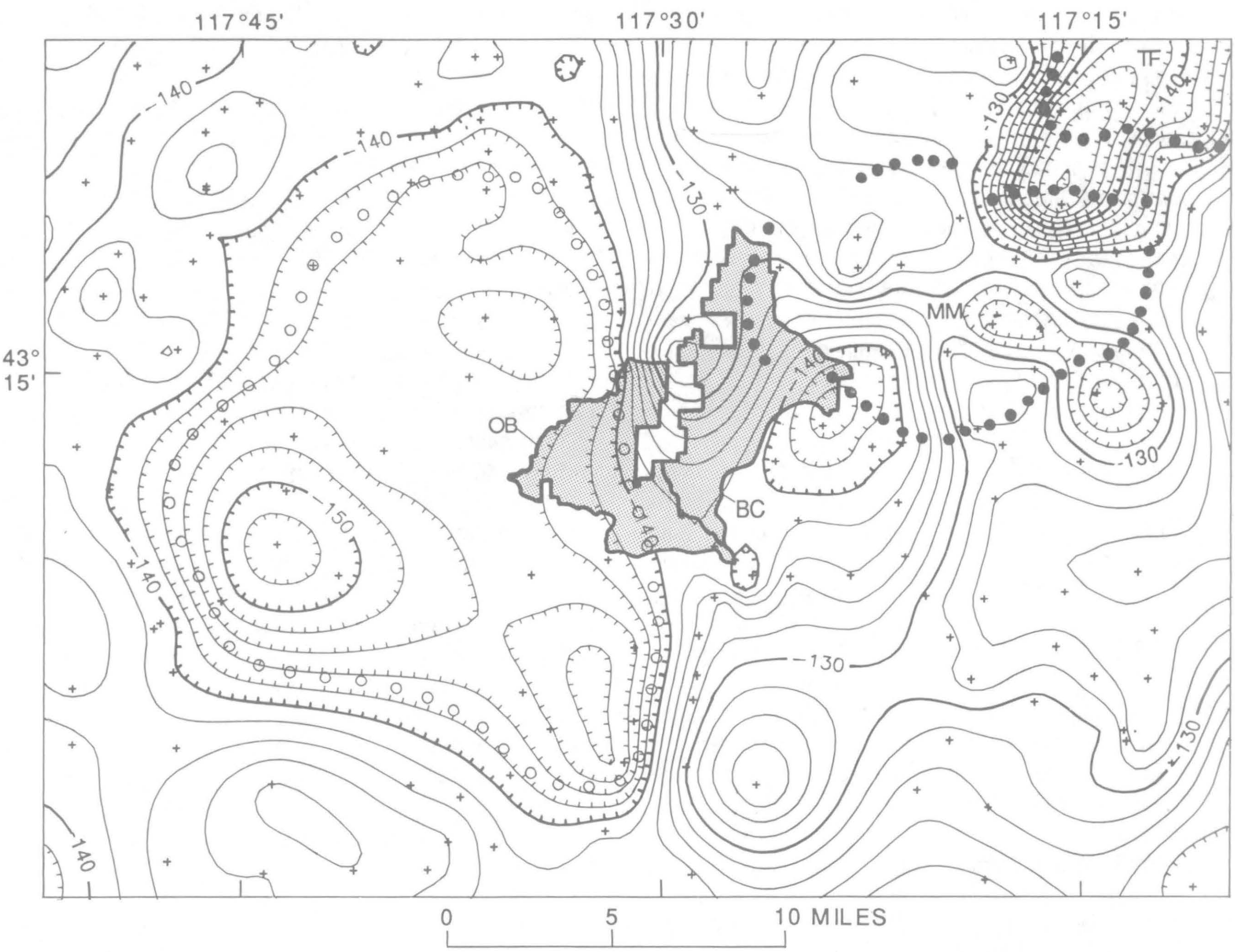

Figure 3. Bouguer gravity anomaly map of part of the Lake Owyhee volcanic field, eastern Oregon. Contour interval, 2 milligals; hachured in direction of gravity low. Cross (+) indicates gravity station. Heavy lines indicate approximate boundaries of Blue Canyon (BC) and Owyhee Breaks (OB) Wilderness Study Areas (shaded area). Heavy dotted lines indicate inferred margins of the Three Fingers (TF) and Mahogany Mountain (MM) calderas. Open-circle dotted line indicates approximate margin of a possible caldera based on geophysical data.

contains anomalous concentrations of gold, silver, mercury, arsenic, antimony, molybdenum, and barium. Therefore, silicified and brecciated rocks along these fault zones have high potential for gold, mercury, and molybdenum resources, certainty level C.

Because mineral associations for epithermal hot-spring gold deposits have been identified in the study area, and because the general volcanic and sedimentary stratigraphy and structure can be traced into the study area from known gold prospects in the region, the the rest of study area has moderate potential for volcanic- and sediment-hosted gold resources, certainty level C.

Samples of the tuff of Leslie Gulch have extraordinarily high zinc concentrations (Vander Meulen and others, 1987a), which are associated with pumice fragments in the tuff. Volcanogenic disseminated zinc deposits of this type were previously unrecognized in the world. Areas underlain by this tuff unit have low potential for zinc resources, certainty level B.

Stream-sediment and nonmagnetic panned concentrate samples from areas underlain by sedimentary rocks contain anomalous fluorine. Authigenic fluorite in lacustrine and tuffaceous sedimentary rocks is reported by Sheppard and Gude (1969) 25 mi south of the study area near Rome, Oreg. Similar deposits of diagenetic fluorite may occur in the study area; therefore, sedimentary rocks within the study area have low potential for fluorite resources, certainty level B.

In the northern part of the study area, beds of bentonite and diatomite are intercalated with a thick sequence of lacustrine sedimentary rocks. The bentonite units typically form low subdued hills and have estimated maximum thicknesses of 50 ft. Two swelling clay minerals, smectite and illite, were identified. Diatomite beds are exposed primarily in the northern and northwestern parts of the study area. The beds are typically 2 to 4 in. thick but are locally as thick as 5 ft. The thicker beds are very clean and possibly of industrial quality. Northern and western parts of the study area underlain by the sedimentary rocks have moderate potential for bentonite and diatomite resources, certainty level C.

In the adjoining Owyhee Breaks Wilderness Study Area, a thermal spring issues from a north-trending fault zone (fig. 2). Another thermal spring issues from a north-trending, high-angle normal fault about 2.5 mi east of the Blue Canyon Wilderness Study Area on the south edge of Lake Owyhee. Recorded temperature of this spring water is 50 °C (Bliss, 1983). Several thermal springs and wells are about 27 mi northeast of the study area (Oregon Department of Geology and Mineral Industries, 1982). An area less than 20 mi northeast of the study area may be underlain at shallow depth (less than 3,280 ft) by thermal water of sufficient temperature for direct-heat applications (Oregon Department of Geology and Mineral Industries, 1982). Although no thermal springs were identified in the study area, geothermal waters may exist at depth along north-trending fault zones. Areas adjacent to these fault zones have moderate potential for geothermal energy resources, certainty level C.

Sedimentary rocks in the northern part of the study area could serve as source rocks for oil and gas resources. An estimated 650-ft-thick sequence of finely laminated carbonaceous claystone and siltstone contains intercalated lenticular horizons of carbonaceous material and organic-rich detritus. The sedimentary rocks directly north of the study area are folded to form several anticlines (fig. 2). These north- to northeast-trending, south-plunging anticlines could be excellent traps for oil and gas reservoirs. No geologic evidence suggests that these sedimentary rocks and trap structures are of greater extent at depth. A drilling program in conjunction with seismic studies is needed to test the rocks for their oil and gas potential. Sedimentary rocks in the northwestern part of the study area have low potential for oil and gas energy resources, certainty level B.

Mineral and Energy Resource Potential of the Owyhee Breaks Wilderness Study Area

Gold prospects have been located by several exploration companies that are prospecting north and east of the Owyhee Breaks Wilderness Study Area (fig. 1) where hot-spring gold mineralization is commonly associated with intersecting north-, northwest-, and northeast-trending fault zones, localized silicic volcanism, hydrothermal explosion breccia, caps of siliceous sinter, and syndepositional arkosic sandstone and conglomerate beds. These criteria were used to rate the resource potential for gold in the study area.

In the central part of the study area, samples of silicified tuff, conglomerate, and black chert (siliceous sinter) contain anomalous concentrations of gold. These altered and mineralized rocks are exposed along north- and northwest-trending fault zones. The altered rocks and faults are similar to those exposed at the Red Butte gold prospect to the north; therefore, this area and a similar one just outside the east border have high mineral resource potential for gold in fault-controlled volcanic- and sediment-hosted hot-spring gold deposits, certainty level C.

Because mineral associations for epithermal hot-spring gold deposits have been identified in the study area, and because the general volcanic and sedimentary stratigraphy and structure can be traced into the study area from known gold prospects in the region, the entire study has moderate potential for volcanic- and sediment-hosted gold resources, certainty level C.

Samples of the tuff of Leslie Gulch have extraordinarily high zinc concentrations (Vander Meulen and others, 1987a), which are associated with pumice fragments in the tuff. Volcanogenic disseminated zinc deposits of this type were previously unrecognized in the world. Areas underlain by this tuff unit have low potential for zinc resources, certainty level B.

Stream-sediment and nonmagnetic panned-concentrate samples from areas underlain by sedimentary rocks contain anomalous fluorine. Authigenic fluorite in lacustrine and tuffaceous sedimentary rocks is reported by Sheppard and Gude (1969) 25 mi south of the study area near Rome, Oreg. Similar deposits of diagenetic fluorite may occur in the study area; therefore, sedimentary rocks within the study area have low potential for fluorite resources, certainty level B.

In the northern part of the study area, beds of bentonite and diatomite are intercalated with a thick sequence of lacustrine sedimentary rocks. Locally, bentonitic clay beds form low subdued hills and the underlying slip surfaces for large landslide deposits. A sample of bentonitic clay collected near the north boundary of the study area contains 80 to 95 percent smectite, a clay mineral that has swelling properties. Thin beds of diatomaceous earth are also exposed in the northern and northwestern parts of the study area. Therefore, parts of the study area underlain by the sedimentary rocks have moderate potential for bentonite and diatomite resources, certainty level C.

In the central part of the study area along the Owyhee River, a thermal spring issues from a north-trending fault zone (fig. 2). Another thermal spring issues from a north-trending, high-angle normal fault approximately 6.5 mi northeast of the study area on the south side of Lake Owyhee. Recorded temperature of this spring water is 50 °C (Bliss, 1983). Several thermal springs and wells are about 30 mi northeast of the study area (Oregon Department of Geology and Mineral Industries, 1982). An area less than 24 mi northeast of the study area may be underlain at shallow depth (less than 3,280 ft) by thermal water of sufficient temperature for direct-heat applications (Oregon Department of Geology and Mineral Industries, 1982). In the study area, geothermal waters issue from one north-trending fault zone and may exist at depth along similar fault zones. Areas adjacent to these fault zones have moderate potential for geothermal resources, certainty level C.

In the northern part of the study area, a 1,000-ft-thick sequence of lacustrine and fluvial sedimentary rocks overlies two ash-flow tuff units. These middle to upper Miocene sedimentary rocks could serve as source rocks for oil and gas resources. However, no current geologic evidence suggests that these rocks are of greater extent at depth or that they have trapped any oil and gas. A drilling program in conjunction with seismic studies is needed to test the sedimentary rocks for their oil and gas potential. Sedimentary rocks in the northern part of the study area have low potential for oil and gas resources, certainty level B.

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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.

LEVEL OF RESOURCE POTENTIAL →

A	B	C	D
U/A	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
UNKNOWN POTENTIAL	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL

LEVEL OF CERTAINTY →

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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 Early	96 138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	[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.

Mineral Resources of Wilderness Study Areas: East–Central Oregon

This volume was published as separate chapters A–G

U.S. GEOLOGICAL SURVEY BULLETIN 1741

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

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(B) Mineral Resources of the Sheep Mountain Wilderness Study Area, Baker County, Oregon, by Roger P. Ashley, Robert C. Roback, Robert L. Turner, Robert C. Jachens, Terry J. Close, and Richard L. Rains.

(C) Mineral Resources of the Camp Creek and Cottonwood Creek Wilderness Study Areas, Malheur County, Oregon, by William J. Keith, Robert L. Turner, Andrew Griscom, John R. Benham, and Michael S. Miller.

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(E) Mineral Resources of the Gold Creek and Sperry Creek Wilderness Study Areas, Malheur County, Oregon, by James G. Evans, James G. Frisken, Andrew Griscom, Don L. Sawatzky, and Michael S. Miller.

(F) Mineral Resources of the Lower Owyhee Canyon Wilderness Study Area, Malheur County, Oregon, by James G. Evans, Robert L. Turner, Andrew Griscom, Don L. Sawatzky, and J. Douglas Causey.

(G) Mineral Resources of the Blue Canyon and Owyhee Breaks Wilderness Study Areas, Malheur County, Oregon, by Dean B. Vander Meulen, Vincent E. Barlock, Patrick S. Plumley, James G. Frisken, Andrew Griscom, and J. Douglas Causey.

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