MINERAL RESOURCES OF THE BADLANDS WILDERNESS STUDY AREA AND THE BADLANDS WILDERNESS STUDY AREA ADDITIONS, CROOK AND DESCHUTES COUNTIES, OREGON

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and 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 submitted to the President and the Congress. This report presents the results of a mineral survey of the Badlands Wilderness Study Area (OR-005-021) and the Badlands Wilderness Study Area Additions (also OR-005-021), Crook and Deschutes Counties, Oregon.

CONTENTS

FIGURES

SUMMARY

Abstract

At the request of the Bureau of Land Management, 20,727 acres of the Badlands Wilderness Study Area and 11,303 acres of the Badlands Wilderness Study Area additions (OR-005-021) in Crook and Deschutes Counties, central Oregon, were evaluated for identified mineral resources (known) and mineral resource potential (undiscovered). The original study area and the subsequent additions are considered together in this report. Throughout this report, "study area" refers to the entire 32,030 acres for which a mineral survey was requested. Fieldwork for this report was carried out in 1986-88. There are no identified resources in the study area, and no areas of mineralized or altered rock were found. Sand and gravel occur in the study area, but other sources are closer to existing markets. Basalt is abundant in the study area and has a number of uses. However, basalt is widespread in the region and the basalt found in the study area has no characteristics that make it more useful than basalt found elsewhere. There is a low potential for geothermal resources and for oil and gas in the study area.

Character and Setting

The Badlands Wilderness Study Area is about 8 mi southeast of Bend (fig. 1), and lies close to the geographic center of Oregon. The study area is located in the northern part of the High Lava Plains physiographic province, in an area of basaltic lava flows that cover the nose of the Blue Mountains anticlinorium, which extends northeast. The High Lava Plains province extends generally west, south, and southeast of the study area and consists of relatively undeformed lava flows, playas, lava buttes, and scattered cinder cones. Topographic relief in the province is generally moderate. Most of the tributary streams are seasonal and most of the drainages are interior. Most of the region consists of lava-capped rolling hills with abundant blocky or platy outcrops of basalt flows. A number of the interior basins contain ephemeral lakes-Malheur and Harney Lakes are good examples. Two notable volcanic features in the region are the scenic Newberry Crater caldera 20 mi southwest of the study area, and the large number of lava tubes-many of which are found in the northern part of the study area in an area known as the Badlands.

Climate in this high desert area is arid to semiarid. Vegetation consists mostly of juniper trees, sagebrush, bitterbrush, rabbit brush, and bunchgrass.

Identified Resources

There are no identified resources in the Badlands Wilderness Study Area or Badlands Additions.

Mineral Resource Potential

Geological, geochemical, and geophysical studies revealed no evidence of altered or mineralized rock or anomalies that would indicate the presence of undiscovered mineral deposits. The study area has low potential for geothermal resources and for oil and gas.

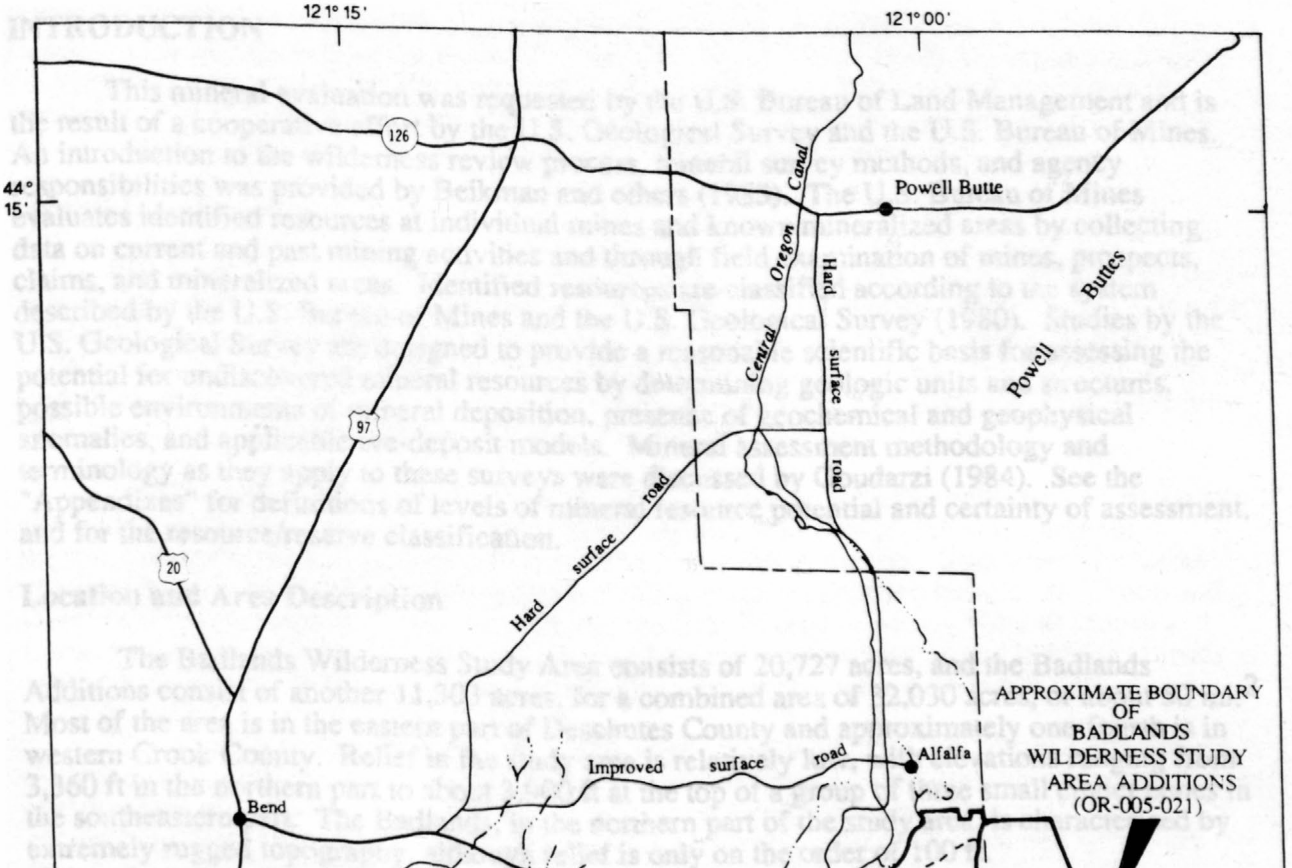

Figure 1. Index map showing location of the Badlands and Badlands Additions Wilderness Study Areas, Crook and Deschutes Counties, Oregon. Dashed lines denote jeep trails.

INTRODUCTION

This mineral evaluation was requested by the U.S. Bureau of Land Management and is the result of a cooperative effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to the system described by the U.S. Bureau of Mines and the 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. Mineral assessment methodology and terminology as they apply to these surveys were discussed by Goudarzi (1984). See the "Appendixes" for definitions of levels of mineral resource potential and certainty of assessment, and for the resource/reserve classification.

Location and Area Description

The Badlands Wilderness Study Area consists of 20,727 acres, and the Badlands Additions consist of another 11,303 acres, for a combined area of 32,030 acres, or about 50 $mi.^2$ Most of the area is in the eastern part of Deschutes County and approximately one-fourth is in western Crook County. Relief in the study area is relatively low, with elevations ranging from 3,360 ft in the northern part to about 3,900 ft at the top of a group of three small cinder cones in the southeastern part. The Badlands, in the northern part of the study area, is characterized by extremely rugged topography, although relief is only on the order of 100 ft.

The study area is underlain mostly by Miocene (see "Appendixes" for geologic time chart) and younger basalt flows that are largely overlain by a discontinuous, thin veneer of sand and silt. Lava flow features such as pressure ridges, pressure domes (tumuli), lava tubes, and collapse features are common in the study area. Northwest-trending small-displacement normal faults cut the older basalt flows in the eastern part of the study area but do not extend into the younger basalt flows that cover the western two-thirds of the study area. There are no mines or prospects in the study area, and no areas of altered or mineralized rock were identified.

Stream drainages are poorly developed in the study area, though a few seasonal streams drain the southern part . The Central Oregon Canal (fig. 1) runs along part of the northwest boundary of the study area and supplies water to irrigate nearby farms.

Access to the study area is provided by a network of unpaved roads that lead from Oregon Highway 20, which extends southeast from Bend (fig. 1). Graded roads around the perimeter of the study area are well maintained and can be used by 2-wheel-drive vehicles. The interior jeep roads are not as good, and 4-wheel-drive vehicles are required on many of them. The roads in and around the study area are generally open year-round.

Previous Investigations

Most geologic investigations of the study area have been conducted as part of regional reconnaissance mapping (Williams, 1957; Walker and others, 1967, Swanson, 1969; Peterson and others, 1976; MacLeod and Sherrod, in press). More detailed studies mention the volcanic features, geothermal resources, and tectonics (Lowry, 1940; Greeley, 1971; Brown and others, 1980; Hawkins and others, 1989). MacLeod and others (1982) mapped the southwestern part of the study area at a scale of 1:62,500 for their study of Newberry volcano. Peterson and others

(1976) discussed the identified resources and resource potential of slab lava throughout Deschutes County (including the Badlands area), and Olson (1987, 1989) discussed more fully the identified resources of the Badlands and Badlands Additions Wilderness Study areas in particular. The U.S. Bureau of Land Management (1983, 1985) published reports that contain information on their mineral-resource investigations of the study area.

Present Investigations

Fieldwork by the U.S. Geological Survey during the 1986, 1988, and 1989 field seasons included geochemical sampling and checking of existing geologic maps. Geophysical data were obtained from several sources and interpreted to help evaluate mineral resource potential of the study area. Geochemical samples of rocks, stream sediments, and plants were obtained from the study area and analyzed in U.S. Geological Survey laboratories. The analytical results are from H.D. King, U.S. Geological Survey, Denver, CO (written commun., 1990).

The mineral investigation by the U.S. Bureau of Mines included collection of information related to current and past mining activity in the region. A library search was made for information on mines and prospects located in and near the study area. This search included checking U.S. Bureau of Land Management mining claim recordation indices, the Crook and Deschutes Counties mining claim records, and the U.S. Bureau of Mines Mineral Industry Location System (MILS). U.S. Bureau of Land Management land status and land use records as well as U.S. Bureau of Mines files and production records also were examined.

Because no mines, prospects, or claims were identified by the U.S. Bureau of Mines in the pre-field studies, fieldwork in the spring of 1986 consisted of a general reconnaissance of the area for sites possibly overlooked in the mining records and literature. Sand and gravel occurrences were identified in the study area, though no resources or mineralized sites were found, and few samples were collected.

APPRAISAL OF IDENTIFIED RESOURCES

by Jerry E. Olson

U.S. Bureau of Mines

No mineral resources were identified within or adjacent to the study area. Sand and gravel in the western and eastern parts of the study area may be suitable for local road aggregate or other purposes, but other sources have sufficient quantities for projected needs (U.S. Highway Department, written commun., 1986). An unknown quantity of slab lava, commonly found in young lava flows in the region, has been removed intermittently on a noncommercial basis from the study area (U.S. Bureau of Land Management, written commun., 1986) The quality and quantity of stone observed in the study area is generally less than that required to be of commercial value.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

The oldest rocks in the study area are Miocene and Pliocene basalt flows that fringe the southeast and east margins. Horse Ridge, a shield volcano just south of the study area (MacLeod and Sherrod, in press), yielded a potassium-argon (K-Ar) age of 7.61 0.08 Ma (million years before present) (Fiebelkorn and others, 1983). Basalt lava north of the study area yielded K-Ar ages of 8.83 1.36 and 5.96 2.08 Ma (Evans and Brown, 1981).

Most of the area, however, is covered by Pleistocene basalt and basaltic andesite that was erupted from the north flank of Newberry Volcano. All the lava flows in the Badlands were probably tube fed from vents higher up on Newberry Volcano, and the broad mound about 1 mi in diameter that forms the southwestern part of the Badlands Wilderness Study Area is probably a rootless vent, the debouching point for lava that built up a small lava fan there (N.S. MacLeod and D. R. Sherrod, U.S. Geological Survey, written commun., 1990). Evidence for this origin of the mound is that the Skeleton Cave and Arnold Ice Cave lava tube systems lead away from Newberry Volcano in the direction of the mound. The lava that forms the mound is degassed, which also supports the interpretation that it was tube fed and was not erupted from a proximal vent. Greeley's (1971, plate 3) map, however, suggests a vent at the mound, as does the map by Peterson and others (1976). If the mound were in fact a small shield volcano, there should be a magnetic anomaly centered over it. But in fact the broad magnetic anomaly shown in figure 3 is centered about 2.5 mi southeast of the mound, and the magnetic contours strike across the mound with no deflection. This evidence supports the idea of the mound as a rootless vent rather than a shield volcano (D.R. Sherrod, written commun., 1990).

The Pleistocene lava flows of the study area commonly have youthful flow features such as tumuli, pressure ridges, ropy surface texture, lava tubes, and collapse features. The flows are locally blanketed by the Mazama ash bed and older windblown sand and silt. The Mazama ash was erupted about 7,500 years ago (Bacon, 1983) from Mt. Mazama, a large volcano, about 85 mi southwest of the study area in Crater Lake National Park.

Unconsolidated Pleistocene and Holocene deposits of sand and lesser amounts of silt and gravel mantle large parts of the study area. At higher elevations, eolian sands predominate, but in the lower elevations, sheetwash and fluvial deposits are more prevalent.

In the southeastern part of the study area, three relatively small basaltic cinder cones, as high as 150 ft, are aligned in a northwest direction (fig. 2). The cones consist of scoriaceous basaltic cinders, are rounded from erosion, and are mantled with reddish, cindery soil.

The study area is broken by a series of subparallel, northwest-trending normal faults of the Brothers fault zone (Lawrence, 1976). In the southern and eastern parts of Oregon, hot-spring gold mineralization is associated with similar northwest-trending fault zones (Rytuba, 1989). The faults are well developed in the eastern part of the study area (the Badlands Additions) but are not evident in the Badlands proper, which includes most of the study area west of 121° longitude. This distribution indicates that the faulting largely predates the youngest flows that formed the Badlands area. Within the study area, vertical offsets along the faults are generally measured in tens of feet or less in the Pleistocene lava flows, whereas on Horse Ridge, less than 2 mi south of the study area, vertical offsets are as much as 200 ft on faults in Miocene and Pliocene flows.

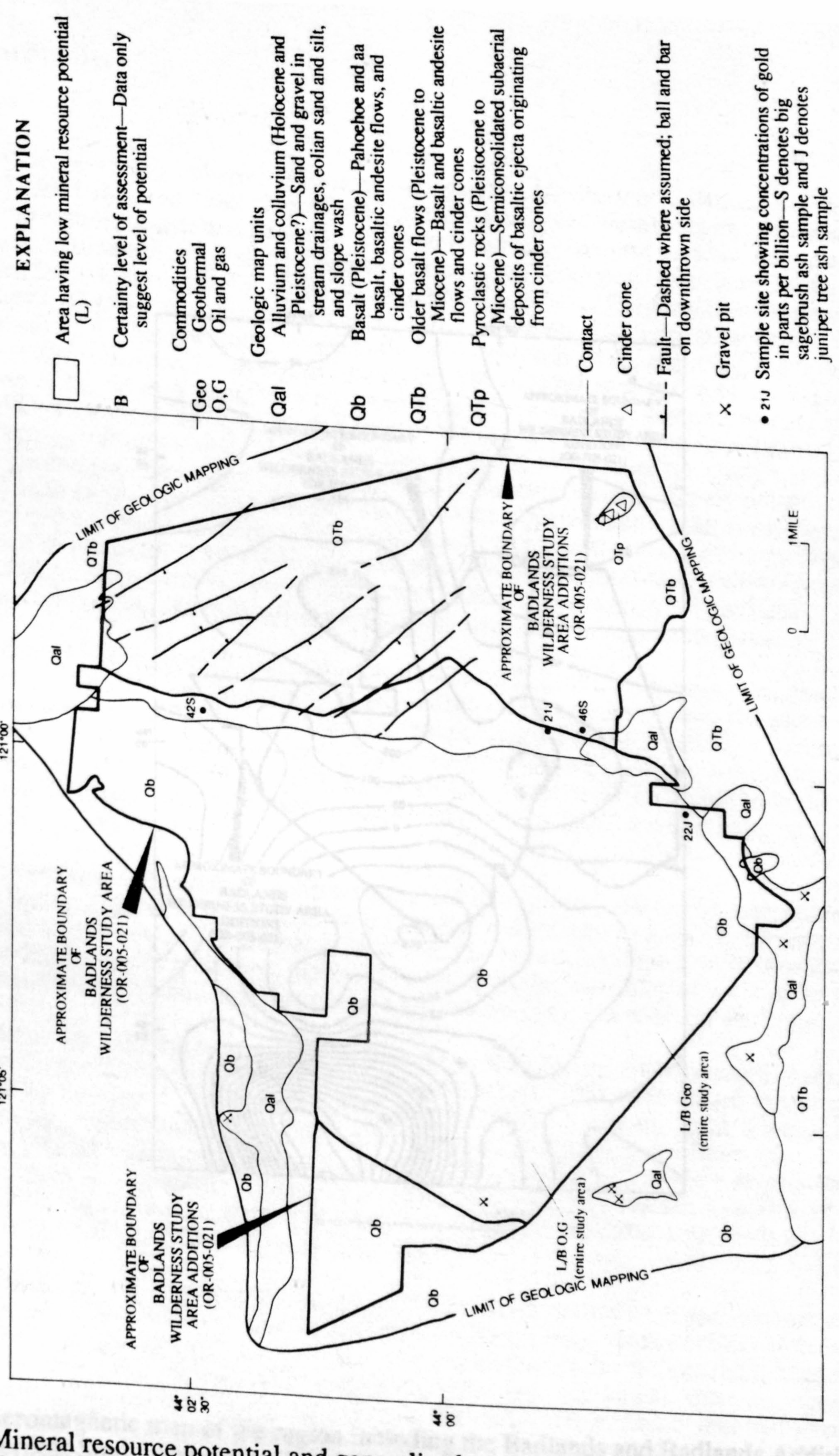

Figure 2. Mineral resource potential and generalized geology of the Badlands and Badlands Additions Wilderness Study Areas, Crook and Deschutes Counties, Oregon. Geology adapted from Peterson and Groh (1974), Walker (1977), and MacLeod and Sherrod [in press].

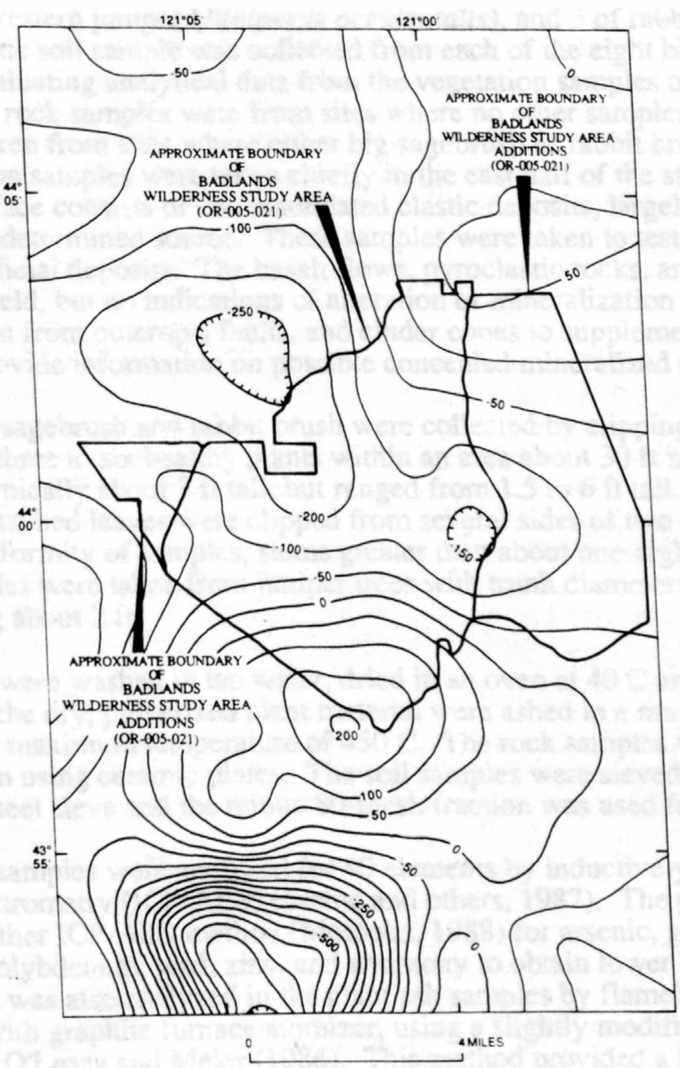

Figure 3. Aeromagnetic map of the region including the Badlands and Badlands Additions Wilderness Study Areas, Crook and Deschutes Counties, Oregon (adapted from Couch and others, 1978). Residual magnetic contour interval 50 nannoteslas (nT); flight elevation 9,000 ft.

Geochemical Studies

Methods

A reconnaissance geochemical survey was conducted in the study area during the summers of 1986, 1988, and 1989. Rock and vegetation samples were used as sample media in this survey. Stream-sediment and heavy-mineral concentrate sampling was not done because very few stream drainages in the study area contain suitable sediment. Geochemical samples were collected from 126 sites and include 60 samples of rock, 64 of big sagebrush (*Artemesia tridentata* Nutt.), 45 of western juniper (*Juniperus occidentalis*), and 3 of rabbit brush (*Chrysothamnus* sp.). One soil sample was collected from each of the eight big sagebrush sample sites to aid in evaluating analytical data from the vegetation samples of big sagebrush. All except one of the 60 rock samples were from sites where no other samples were taken. The juniper samples were taken from sites where either big sagebrush or rabbit brush samples were collected. The vegetation samples were taken chiefly in the east half of the study area where much of the ground surface consists of unconsolidated clastic deposits, largely eolian (windblown) sand of undetermined source. These samples were taken to test for mineralized rock underlying the surficial deposits. The basalt flows, pyroclastic rocks, and cinder cones were examined in the field, but no indications of alteration or mineralization were found. The 60 rock samples were taken from outcrops, faults, and cinder cones to supplement field examinations and to provide information on possible concealed mineralized rock.

Samples of big sagebrush and rabbit brush were collected by clipping new growth, including stems, from three to six healthy plants within an area about 30 ft in diameter. The sampled plants were typically about 3 ft tall, but ranged from 1.5 to 6 ft tall. For juniper samples, stems with attached leaves were clipped from several sides of two adjacent juniper trees. To maintain uniformity of samples, stems greater than about one-eighth inch diameter were excluded. Samples were taken from juniper trees with trunk diameters ranging from about 1 to 4 ft and averaging about 2 ft.

Plant samples were washed in tap water, dried in an oven at 40 C and then pulverized in a Wiley mill. Splits of the dry, pulverized plant material were ashed in a muffle furnace during a 24-hour period with a maximum temperature of 450 C. The rock samples were crushed and pulverized to 0.15 mm using ceramic plates. The soil samples were sieved with an 80-mesh (0.18 mm) stainless steel sieve and the minus-80-mesh fraction was used for analysis.

All plant ash samples were analyzed for 40 elements by inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Lichte and others, 1987). The plant ash samples were also analyzed by another ICP-AES method (Motooka, 1988) for arsenic, gold, silver, bismuth, cadmium, copper, molybdenum, lead, zinc, and antimony to obtain lower limits of determination. Gold was also analyzed in the plant ash samples by flameless atomic absorption spectrophotometry with graphite furnace atomizer, using a slightly modified version of the method described in O'Leary and Meier (1986). This method provided a lower limit of determination of 0.001 ppm (parts per million) gold.

The rock and soil samples were analyzed by a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). Rocks collected during the early part of the study were analyzed for 31 elements; rocks and the soils collected later were analyzed for those and an additional four elements. The rock and soil samples also were analyzed by ICP-AES for antimony, arsenic, bismuth, cadmium, and zinc; and by atomic absorption for gold and mercury using methods described by Crock and others (1987).

Results

Anomalous concentrations of elements were determined by visual inspection of the raw data. Histograms and map plots of gold in vegetation samples also were examined. In evaluating data for big sagebrush, the baseline concentrations--the expected or central 95 percent range of the concentration data--given by Gough and Erdman (1983) for big sagebrush from the western United States were consulted. A study using big sagebrush in the Gold Run mining district, near Winnemucca, Nevada (Erdman and others, 1988) was consulted in evaluating the data from plant samples from the study area. The data for this study were compared with those from a study of seasonal variation of element contents of vegetation ash from ponderosa pine and white fir taken from the Quartz Mountain, Oregon, hot-spring type disseminated gold deposit (Ashton and Riese, 1989).

Four samples of plant ash contain anomalous concentrations of gold. Two big sagebrush ash samples taken from adjacent sites in a wide area of unconsolidated valley fill in the south-central part of the study area (fig. 2) contain gold concentrations of 46 and 42 ppb (parts per billion). Examination of histograms of geochemical data from the study area suggests that these values are anomalous. The highest anomalous concentrations of gold were found in western juniper ash samples taken 0.5 mi north of a big sagebrush sample site that contains 31 ppb gold (21 ppb in juniper), and about 1 mi southwest of a big sagebrush sample site that contains 31 ppb gold (22 ppb in juniper). Another anomalous gold concentration of 26 ppb was detected in a big sagebrush sample collected near Dry River in the north-central part of the study area (fig. 2).

No other elements, including those typically found in association with gold such as arsenic and antimony, were found in anomalous concentrations in any plant sample. The anomalous gold values in plant samples from the study area are considered weak and do not necessarily indicate gold mineralization at or near the surface. The gold values may be the result of leakage upward along fractures or faults and may be derived from mineralized rock at some unknown depth. Alternatively, the anomalous values may come from fine-grained placer gold washed down Dry River during Pleistocene glacial periods from an undetermined upstream location, possibly from the silicic domes in the John Day Formation to the northeast. The absence in vegetation samples of anomalous concentrations of elements commonly associated with gold mineralization decreases the likelihood of gold mineralization in the study area. Further, no anomalous concentrations of gold or associated elements were found in any of the rock or soil samples from the study area. There is not enough evidence of gold mineralization to indicate even low potential.

Geophysical Studies

Aerial gamma-ray spectroscopy

Analysis of aerial gamma-ray spectroscopy by J.S. Duval (U.S. Geological Survey, written commun., 1985) shows that the Badlands Wilderness Study Area has overall moderate radioactivity with values of 2-3 percent potassium (K), 2.5 to 4 ppm equivalent uranium (eU), and 12 to 16 ppm equivalent thorium (eTh). The data were collected as part of the National Uranium Resource Evaluation (NURE) program, and the quadrangles covering the area that includes the study area are referenced in Bendix Field Engineering Corp. (1983). No potassium or uranium anomalies have been found in the study area or immediate vicinity. A weak thorium anomaly is present in the northern part of the study area. Although uranium occurrences have been found in the region (Ferns and Huber, 1984), the radioactivity data for the study area are typical of the region, may be related to underlying rocks of the John Day Formation, and probably do not indicate any undiscovered mineral resources.

Analysis of linear features shown on Landsat satellite imagery

Linear features shown in Landsat multispectral scanner (MSS) images (scale, 1:800,000) were mapped by photogeologic interpretation for part of central Oregon that includes the study area to elucidate features bearing on mineral resource potential that could not be discerned on conventional aerial photographs or by geologic field methods. The satellite imagery revealed that linear features are poorly expressed over the western part of the study area. A weak concentration of northeast-trending linear features lies southeast of the study area, and a local concentration of northwest-trending linear features is contiguous to the southeastern part of the study area. The northwest-trending linear features correspond to faults in the Brothers fault zone, which extends southeast from the study area. The analysis of linear features provides little new information with which to assess mineral resource potential.

Gravity and magnetics

Regional aeromagnetic maps that include the study area (Couch and others, 1978; Connard and others, 1983) show magnetic signatures typical of young basaltic terrane. The only magnetic anomaly of note is south of the study area over Horse Ridge at about 43°53' N. latitude, 121°05' W. longitude (fig. 3). The anomaly is negative and, because of the widespread distribution of basaltic lava flows in the region, suggests that Horse Ridge has a strong reversed magnetization and therefore that the lavas in this locality were erupted during a time of reversed magnetic polarity. Because this anomaly is due to reversed magnetic polarity and not to mineralization, it provides no indication of mineral resource potential.

There is a broader positive anomaly north of Horse Ridge, centered at about 43°57'30"N. latitude and 121°2'30"W. longitude (fig. 3). The broad gradients associated with this anomaly indicate that its source may be below the surface. On regional aeromagnetic compilations, however, this anomaly appears fairly typical for central Oregon.

The study area is located along a very long, linear northeast-trending gravity anomaly that extends from the northeast corner of Oregon to central Oregon, and may continue to the Klamath Mountains. The anomaly is probably related to pre-Cenozoic rocks of the Blue Mountains and Klamath Mountains, and was recently interpreted by Riddihough and others (1986) to reflect a pre-Tertiary continental margin. Although of interest from a tectonic point of view, this gravity anomaly does not indicate any particular favorability for mineral resources.

Mineral And Energy Resource Potential

Potential for oil and gas in the wilderness study area was determined to be low by Fouch (1983) on the basis of the exploration and production history of the region, the lack of data on thermal maturation levels, and the results of drilling in Neogene strata in the region. The volcanic and volcaniclastic sedimentary rocks exposed at the surface to the northeast may project under the Pleistocene volcanic units of the study area. These sedimentary units are permissible for small deposits of hydrocarbon resources. A number of local basins elsewhere in eastern Oregon contain coaly beds or lignite (Fouch, 1983), and a number of oil shows have been found in eastern Oregon (Deacon and Benson, 1971). However, there is no geologic evidence of a sedimentary basin underlying the study area. As of 1984, there were three oil and gas leases encompassing 8,500 acres in the eastern part of the study area (U.S. Bureau of Land Management, 1985). Though there are no indications of oil or gas in or near the study area, and there is no evidence that the rocks in the subsurface are particularly favorable for oil and gas, local occurrences of oil and gas are present elsewhere in the region and the terrane underlying the study area may be permissible for small deposits of oil or gas. Without additional data, the potential for oil and gas in the study area can be rated only as low, certainty level B.

The geothermal potential of the western United States is discussed on a regional basis in Muffler (1979), which indicates no particular favorability for geothermal resources in the study area or immediate vicinity. No thermal springs or thermal wells are reported in or near the study area by Riccio (1978) or Muffler (1979). The nearest area having demonstrated geothermal resource potential is around Powell Buttes, about 7 mi north of the study area. At Powell Buttes, there is potential for 100° Centigrade (212° Farenheit) temperatures at depths of approximately 3,300 feet (Brown and others, 1980). The location of geologically recent (late Tertiary to Quaternary) volcanic centers and cones in the region together with the geothermal resource potential at Powell Buttes indicate a regional permissibility for geothermal resources. However, the lack of evidence for geothermal resources in the study area and surrounding proximal areas indicates only low potential for geothermal resources, certainty level B.

Evidence of alteration or mineralization that might indicate potential for metallic resources was not found in the study area. Analysis of plant samples revealed a few localities with weakly anomalous gold concentrations of as much as 46 parts per billion (ppb). Because the gold anomalies are weak relative to background levels, they probably do not indicate gold mineralization at or near the surface. These anomalous gold concentrations may result from migration of gold upward from more mineralized rock along faults from unknown depths, or from fine-grained placer gold transported from outside the study area. Areas of gold mineralization typically have anomalous concentrations of other associated elements. No such anomalous concentrations of pathfinder or associated elements were found in any samples from the study area, and this greatly decreases the likelihood of gold mineralization. Field examinations, sample analyses, and evaluation of geophysical data revealed no indications of any alteration or mineralization, and there are no data that would indicate potential for gold or other metallic mineral resources in or near the study area.

Slab lava is found in the study area and can be used for facing or building stone. An unknown quantity of this material has been removed at random from the Badlands Additions, but most of the basalt in the study area is not of commercial grade (Olson, 1989). Peterson and others (1976) report that only the top few feet of the Badlands lavas are jointed in such a way that they break into useable slab stone, and that these lavas are of marginal quality for crushed stone because of vesicularity, the lack of closely spaced jointing, and limited local supply. Furthermore, basalt is exceedingly abundant and accessible in the region. Basalt has a number of commercial uses other than as building stone; it also can be used as a source of mineral fiber. Though the basalt in the study area has an oxide content that makes it suitable for the manufacture of mineral fiber (Olson, 1989), similar basalt is widespread in the region; and there are no characteristics that differentiate the basalt found in the study area to make it more desirable than other basalt in the region.

Sand and gravel are abundant in the study area, but other sources are closer to existing markets. The sand and gravel in the study area have no characteristics that would make them preferable to that from other known sources in the region.

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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 UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH 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 →

Abstracted with minor modifications from:

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RESOURCE/RESERVE CLASSIFICATION

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

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

GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late 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.