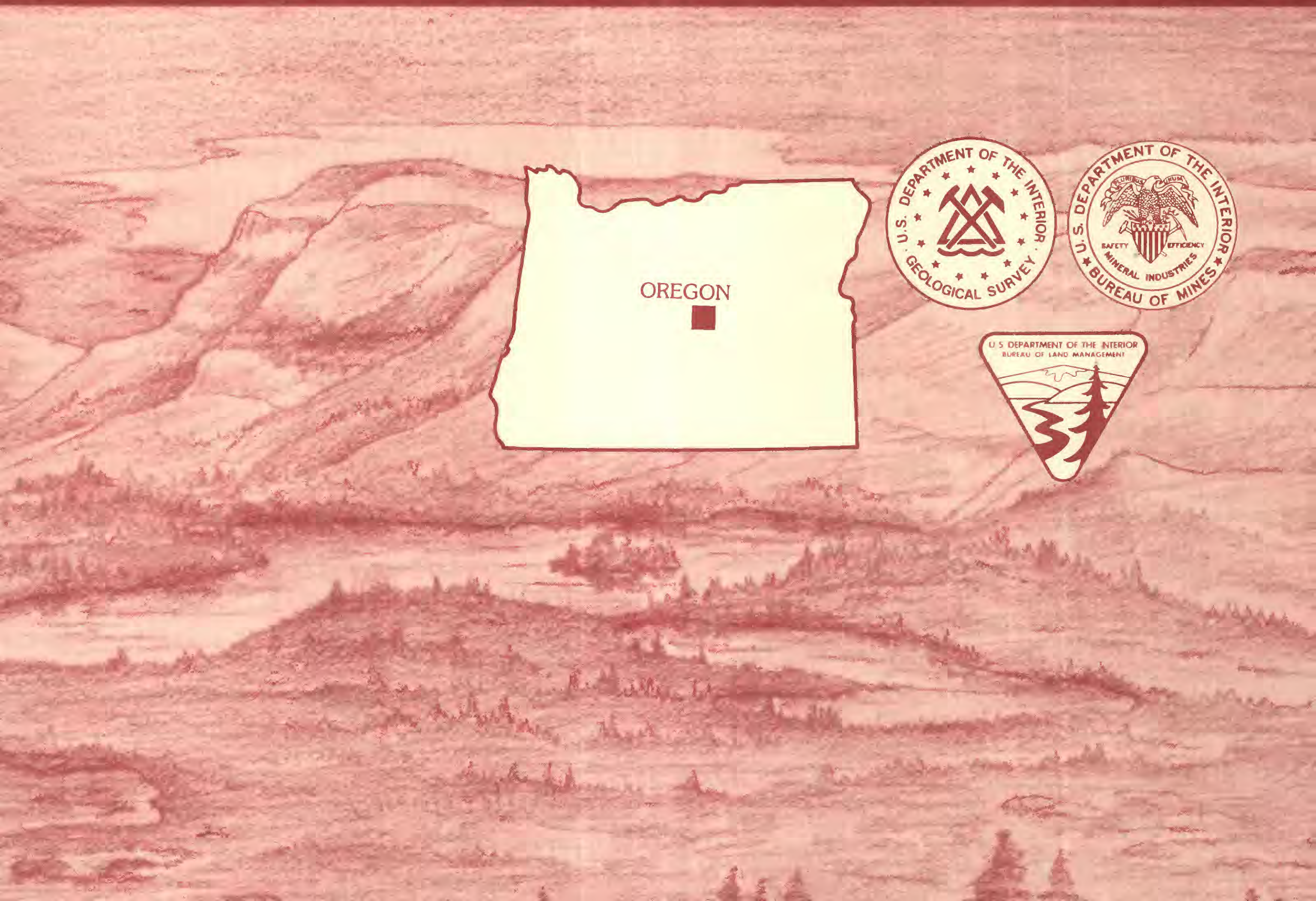
Mineral Resources of the South Fork and Sand Hollow Wilderness Study Areas, Crook County, Oregon

U.S. GEOLOGICAL SURVEY BULLETIN 1744-A



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Chapter A

Mineral Resources of the South Fork and Sand Hollow Wilderness Study Areas, Crook County, Oregon

By JAY A. ACH, JAMES T. BATESON, RICHARD J. BLAKELY, and HARLEY D. KING
U.S. Geological Survey

JERRY E. OLSON
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1744

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
CENTRAL AND FAR WESTERN OREGON

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys of 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 parts of the South Fork (OR-005-033) and Sand Hollow (OR-005-034) Wilderness Study Areas, Crook County, Oregon.

CONTENTS

FIGURES

Mineral Resources of the South Fork and Sand Hollow Wilderness Study Areas, Crook County, Oregon

By Jay A. Ach, James T. Bateson, Richard J. Blakely, *and* Harley D. King
U.S. Geological Survey

Jerry E. Olson
U.S. Bureau of Mines

SUMMARY

Abstract

At the request of the U.S. Bureau of Land Management, approximately 25,392 acres (17,001 and 8,391 acres, respectively) of the South Fork and Sand Hollow Wilderness Study Areas (OR-005-033 and OR-005-034) in central Oregon were evaluated for mineral resources (known) and mineral resource potential (undiscovered). Throughout this report, "wilderness study areas" and "study areas" refer to the 25,392 acres for which mineral surveys were requested. Fieldwork for this report was carried out in 1985 and 1986. No mines, significant prospects, or mining claims are located inside the study areas, and no identified resources were found; however, both areas are under lease for oil and gas. The west-central part of the South Fork Wilderness Study Area has a low mineral resource potential for mercury. The northwestern and southwestern parts of the Sand Hollow Wilderness Study Area also have a low mineral resource potential for mercury. Both study areas have a low potential for oil and gas resources and for geothermal energy resources.

Character and Setting

The South Fork and Sand Hollow Wildernesss Study Areas are located approximately 60 mi east of Bend and about 10 mi south of Paulina, in central Oregon (fig. 1). Rolling hills and gentle slopes are typical of most of the study areas. The South Fork of the Crooked River cuts a deep canyon through the South Fork study area.

Volcanic rocks of the Clarno Formation are the oldest rocks exposed in the study areas. The Clarno Formation is overlain by the John Day Formation, and the Picture Gorge Basalt, part of the Columbia River Basalt Group, overlies the John Day Formation. The uneven, faulted surface of the Picture Gorge Basalt is unconformably overlain by tuffaceous sedimentary rocks that are in turn overlain by two thin ash-flow tuff units, the Devine Canyon Ash-flow Tuff and the Rattlesnake Ash-flow Tuff. On Twelvemile Table (fig. 1), thin flows of the basalt of Twelvemile Table overlie the Rattlesnake Ash-flow Tuff.

Identified Resources

No identified mineral resources exist within or adjacent to the wilderness study areas. Agate and common opal occur in areas along the north boundary of the South Fork study area. No other mineralized zones occur within the areas studied, and no mines or prospects are present. Bentonite is periodically mined from sedimentary rocks of the John Day Formation within 2 mi of the southwest boundary of the Sand Hollow study area. Similar sedimentary rocks are not exposed within the study areas.

Mineral Resource Potential of the South Fork Wilderness Study Area

The South Fork Wilderness Study Area has low mineral resource potential for mercury in the west-central part

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of the area. This potential is indicated by anomalously high mercury concentrations in stream-sediment samples.

The South Fork study area also has low potential for petroleum and natural gas. A dry hole is located about 2 mi north of this study area. A log of the hole indicates that potential source rocks are thin or absent and potential reservoir rocks, although probably present, may be of poor quality. Additionally, no favorable reservoir structures are known in the study area.

A low potential also exists for geothermal energy in the study area. This potential, which is unlikely to be explored or exploited, is indicated by two springs near the study area that have slightly elevated temperatures.

Mineral Resource Potential of the Sand Hollow Wilderness Study Area

A low mineral resource potential for mercury exists in the northwestern and southwestern parts of the Sand Hollow Wilderness Study Area. This potential is indicated by anomalously high mercury concentrations in stream-sediment samples.

The Sand Hollow study area has low potential for petroleum and natural gas. The dry hole mentioned above is located about 5 mi northeast of this study area. Potential source rocks are thin or absent and potential reservoir rocks are likely to be of poor quality. No favorable reservoir structures are known in the study area.

A low potential also exists for geothermal energy in the study area. This potential, which is unlikely to be explored or exploited, is indicated by the two springs mentioned above that have slightly elevated temperatures.

INTRODUCTION

This mineral resource study is a joint effort by the U.S. Geological Survey and the U.S. Bureau of Mines. Mineral assessment methods and terminology are discussed in Goudarzi (1984). Identified resources are classified according to a system that is a modification of that described

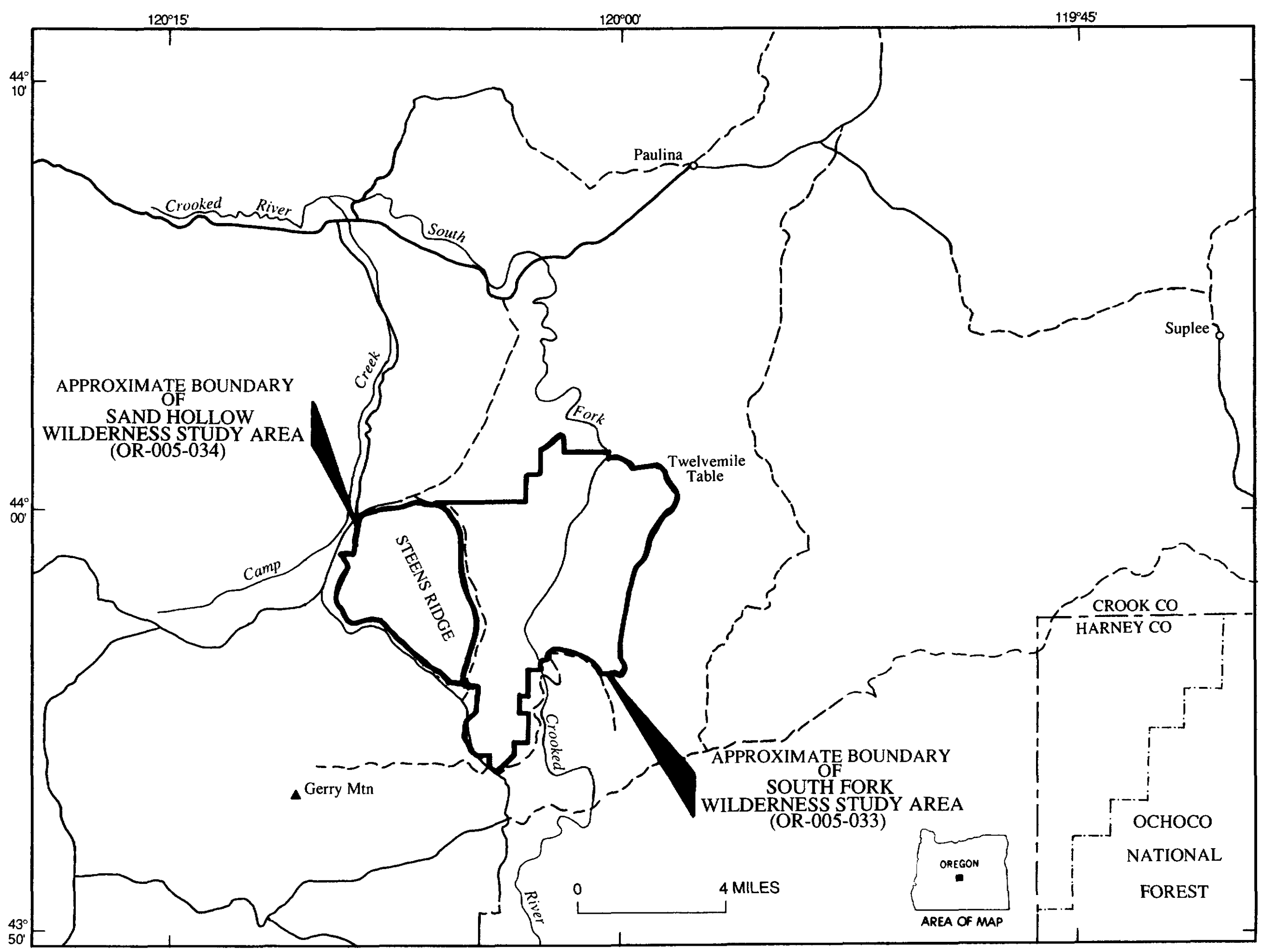


Figure 1. Index map showing location of the South Fork and Sand Hollow Wilderness Study Areas, Crook County, Oregon.

by McKelvey (1972) and described by the U.S. Bureau of Mines and the U.S. Geological Survey (1980). See the appendixes for the definition of levels of mineral resource potential, certainty of assessment, and classification of identified resources. 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 geological units and structures, possible environments of mineral deposition, presence of geophysical and geochemical anomalies, and applicable ore-deposit models. 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.

Area Description

The U.S. Bureau of Land Management requested that a total of 25,392 acres of the South Fork and Sand Hollow Wilderness Study Areas (OR-005-033 and OR-005-034), 17,001 and 8,391 acres, respectively, be evaluated for their mineral resource potential. The study areas are about 60 mi east of Bend and about 10 mi southwest of Paulina, in central Oregon (fig. 1). The topography of the areas is dominated by rolling hills that extend to the flat tablelands of Twelvemile Table to the east. The South Fork of the Crooked River has cut a steep, 600- to 700- ft-deep canyon through the South Fork study area. Elevations range from approximately 3,860 ft at the canyon bottom to 4,986 ft at the top of Steen's Ridge. The region has a semiarid climate (Strahler, 1969), and an average of about 15 in. of precipitation a year (Meteorology Committee, Pacific Northwest River Basins Commission, 1969). The vegetation consists mainly of range grasses, sagebrush, and juniper trees. Deer and coyotes are the larger mammalian residents of the study areas.

Access to the study areas from county roads to the west is provided by graded dirt and gravel roads and jeep trails. The two study areas are separated by a graded dirt road.

Previous and Present Investigations

Parts of the study areas are included in geologic maps by Walker and Repenning (1966), Walker and others, (1967), Brown and Thayer (1966), Swanson (1969), and Greene and others (1972). Davenport (1971) investigated the Rattlesnake Ash-flow Tuff and other tuffs in the vicinity. Dickinson and Vigrass (1965) studied the pre-Tertiary rocks in the area around Suplee, approximately 15 mi east of the study areas.

Previous reconnaissance studies of the geology and mineral resources of wilderness study areas in the region were carried out by Terradata (1983) and Barringer Resources, Inc. (1984). The uranium resource potential for the region was evaluated as part of the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program (High Life Helicopters, Inc./ QEB, Inc., 1981a, b, c, d).

The U.S. Geological Survey carried out field investigations in the study areas during the summers of 1985 and 1986. This work included geologic mapping and geochemical sampling. An analysis was made of available geophysical data.

The U.S. Bureau of Mines conducted a library search for information on mines and prospects within and near the study areas. Additional data were obtained from records of Crook County, the U.S. Bureau of Land Management, and the U.S. Bureau of Mines. Field studies by U.S. Bureau of Mines personnel were carried out in 1986 (Olson, 1987). Fieldwork consisted of a general reconnaissance of the areas for mining-related activity that may not have been recorded. Additionally, bentonite deposits within 2 mi of the southwest boundary of Sand Hollow study area, agate and common opal occurrences near the north boundary of the South Fork study area, and occurrences of possible zeolites were investigated. From these areas, four samples were analyzed for bentonite, and seven samples were analyzed for zeolites. Complete analytical data are on file at the U.S. Bureau of Mines, Western Field Operations Center, E. 360 Third Ave., Spokane, Wash. 99202.

Acknowledgments

The U.S. Geological Survey wishes to thank the staff of the Prineville, Oregon, District Office of the U.S. Bureau of Land Management for providing logistical support, background information, and the use of the Bureau's facilities at the Paulina Guard Station. Calvin Westmoreland and family graciously provided access to their ranch as well as good conversation and a fine cup of coffee.

The U.S. Bureau of Mines thanks Dennis Davis, U.S. Bureau of Land Management, for providing information pertaining to the geology and general mineral character of the areas studied. U.S. Bureau of Mines geologist Fredrick Johnson ably assisted the U.S. Bureau of Mines author in prefield and field work.

APPRAISAL OF IDENTIFIED RESOURCES

By Jerry E. Olson
U.S. Bureau of Mines

No identified mineral resources exist in the South Fork and Sand Hollow Wilderness Study Areas. The study areas do not lie in an established mining district and no records of historic or active claims exist.

No mineralized zones were found within the study areas. Low-grade bentonite deposits are periodically mined in Camp Creek Valley within 2 mi of the southwest boundary of the Sand Hollow study area but are confined to probable lacustrine rocks of the John Day Formation that do not extend into the areas studied. Common opal and agate occur in several locations along the north boundary of the South Fork study area and may be of recreational interest. Several sites were sampled to determine whether zeolite minerals are present, but analytical results were negative.

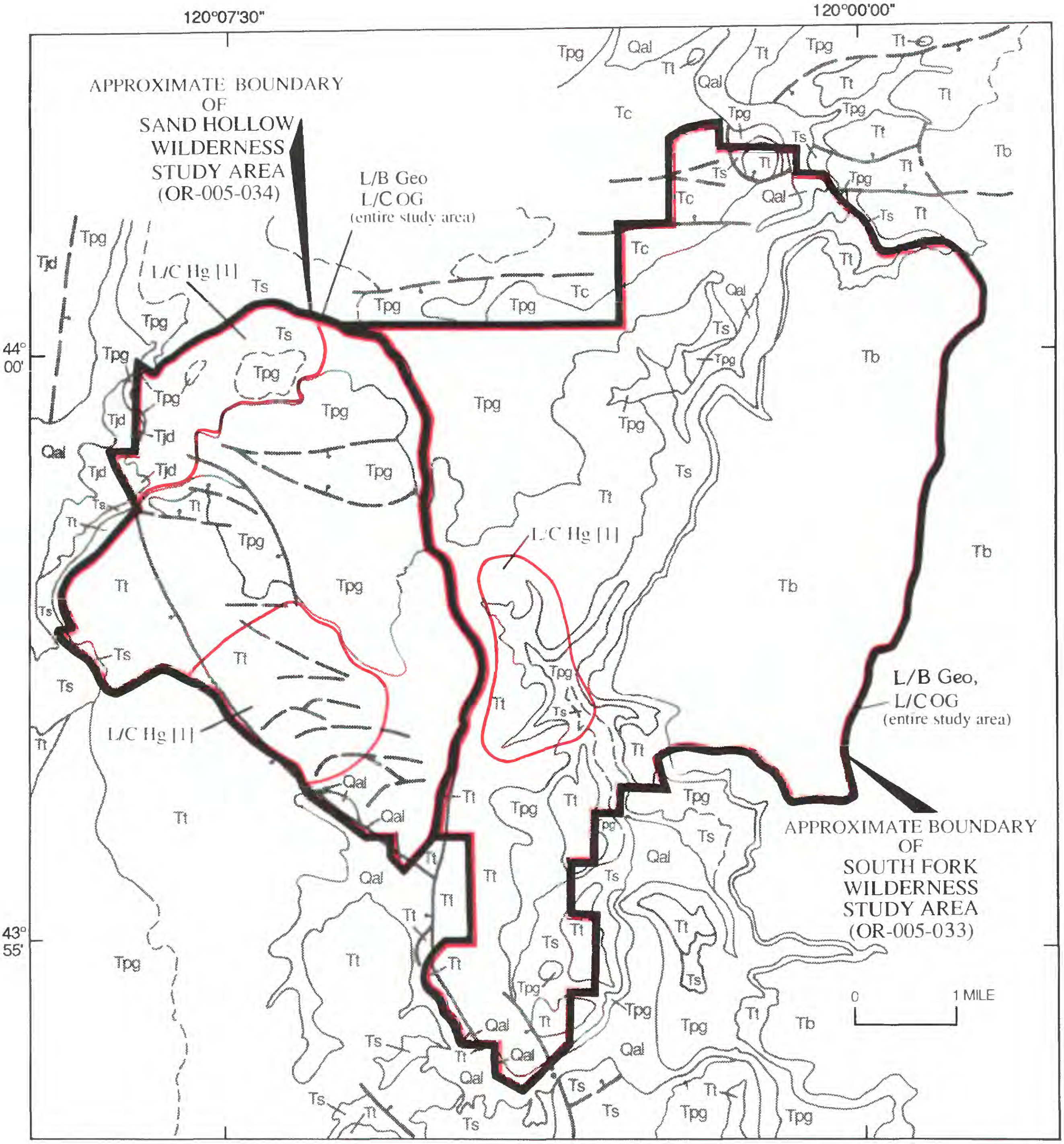


Figure 2. Map showing mineral resource potential and geology of the South Fork and Sand Hollow Wilderness Study Areas, Crook County, Oregon.

EXPLANATION

Area having low mineral resource potential (L)

Levels of certainty of assessment

B Data suggest level of potential

C Data give good indication of level of potential

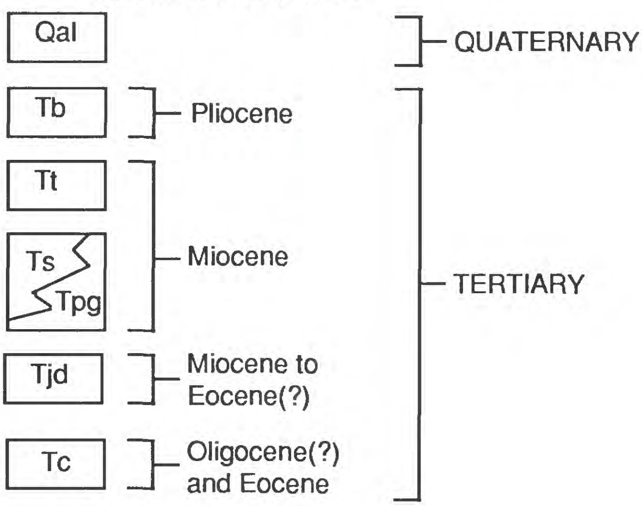
Commodities

Hg Mercury
OG Oil and natural gas
Geo Geothermal

[ ] Deposit type

1 Epithermal mercury deposits in volcanic and volcanoclastic rocks

Correlation of map units



Geologic map units

Qal Alluvium (Quaternary)
Tb Basalt of Twelvemile Table (Tertiary)
Tt Ash-flow tuffs (Tertiary)
Ts Tuffaceous sedimentary rocks (Tertiary)
Tpg Picture Gorge Basalt (Tertiary)
Tjd John Day Formation (Tertiary)
Tc Clarno Formation (Tertiary)

Contact—Dashed where approximate
Fault—Dashed where approximate; bar and ball on downthrown side

Figure 2. Continued.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Jay A. Ach, James T. Bateson, Richard J. Blakely, *and* Harley D. King,
U.S. Geological Survey

Geology

Pre-Tertiary basement rocks are not exposed within or near the South Fork and Sand Hollow Wilderness Study Areas (see appendixes for geologic time chart). However, older rocks are exposed in the area around Suplee, approximately 15 mi east of the study areas. There, two small outcrops of highly folded, fossiliferous limestone constitute the only known exposures of Devonian rocks in Oregon (Kleweno and Jeffords, 1962; Buddenhagen, 1967). South of Suplee, highly folded and faulted Mississippian, Pennsylvanian, and Permian marine and non-marine clastic rocks, chert, and limestone are exposed (Merriam and Berthiaume, 1943; Mamay and Read, 1956; Buddenhagen, 1967). East of Suplee, Dickinson and Vigrass (1965) mapped and described a thick section of Permian through Cretaceous rocks. The Permian rocks east of Suplee consist primarily of an undetermined thickness of felsites (light-colored, fine-grained igneous rocks) that contain minor interbeds of limestone, chert, and volcaniclastic sedimentary rocks. Some Permian metamorphosed mafic rocks (greenstones) that include possible pillow basalts are also exposed there; such rocks could represent the upper part of an ophiolite sequence. The Mesozoic section east of Suplee consists of 33,000 to 34,000 ft of marine sedimentary rocks, including mudstone, siltstone, sandstone, and less abundant limestone and conglomerate. These rocks are at least partially volcaniclastic in origin.

Well logs from the Texaco Federal No. 1 drillhole, located about 2 mi north of the South Fork study area, indicate that the Mesozoic sedimentary sequence beneath the study areas is not as thick as it is in the area around Suplee. This hole was drilled to a total depth of 7,998 ft in 1971 near the crest of a Cenozoic anticline. From the surface, the hole first penetrated 1,500 to 1,560 ft of the lower Tertiary Clarno Formation. The well log describes the interval from 1,560 to 1,890 ft as Cretaceous siltstone and sandstone and the interval from 1,890 to 3,500 ft as Jurassic sandstone, claystone, and bentonite. Thompson and others (1984) studied microfossils from this hole and revised the well stratigraphy. They found that the rocks in the interval from 1,500 to 2,040 ft are nonmarine and uppermost Cretaceous and Paleocene, from 2,040 to 2,220 ft the rocks are marine and mid-Cretaceous, and from 2,220 to 3,500 ft the rocks are nonmarine and mid-Cretaceous. Both studies indicate that the interval from 3,500 ft to the bottom of the hole consists of pre-Cretaceous, predominantly volcanic rocks. Newton (1974) notes that some traces of gas were detected in the Cretaceous interval in this hole. The log for this hole indicates that these gas traces were barely above backround levels. Such minor traces of gas are common in dry holes and have little significance (Dan E. Wermiel, oral commun., 1987).

The oldest unit exposed in the study areas belongs to the Eocene and lowermost Oligocene (?) Clarno Formation (George W. Walker, oral commun., 1987). In the areas studied, the Clarno Formation consists predominantly of rusty brown andesite lava flows and breccia and interbedded tuffaceous sedimentary rocks.

The John Day Formation overlies the Clarno Formation. Fine-grained sandstone, siltstone, and claystone form the bulk of the John Day Formation. These rocks occur in light pastel shades of green, gray, tan, and white, and are commonly bentonitic. Locally, thin flows of dark gray to black, aphanitic to microcrystalline, flow-foliated basalt or andesite are present. The age of the John Day Formation ranges from about 37 to about 19 m.y. (million years), latest Eocene to early Miocene (George W. Walker, oral commun., 1987).

In most of the area studied, the lower Miocene Picture Gorge Basalt of the Columbia River Basalt Group is the oldest unit exposed at the surface. This unit is approximately 15 to 16 m.y. in age (Watkins and Baksi, 1974; Fiebelkorn and others, 1982) and overlies the John Day Formation. The Picture Gorge Basalt is composed of thick, highly fractured flows of aphanitic to finely crystalline olivine basalt. Columnar joints are commonly well developed in individual outcrops. Within the study areas, rocks mapped as the Picture Gorge Basalt may include some basalt of the John Day Formation.

Tan to light-gray to white, tuffaceous, fine-grained sandstone and siltstone are interbedded with and overlie the Picture Gorge Basalt. Locally these sedimentary rocks contain minor amounts of small, rounded, white pumice fragments and may include some air-fall tuff. Greene and others (1972) consider this unit to be correlative, in part, with the middle to upper Miocene Mascall Formation of Merriam (1901).

Two thin ash-flow tuff units overlie the tuffaceous sedimentary rocks. Because they are too thin to be shown individually, these two tuffs are grouped together in one unit (Tt) on the map (fig. 2); however, they are easily distinguished in the field. The lowermost tuff unit is the Devine Canyon Ash-flow Tuff. This rhyolite welded tuff is light- to medium-gray to greenish gray and contains 2 to 17 percent phenocrysts of sanidine and quartz (Davenport, 1971). The distinguishing feature of this unit is 1 to 5 percent light yellow-brown to orange-brown accretionary lapilli that are approximately 0.1 to 0.3 in. in diameter. This tuff has a late Miocene potassium-argon age of 9.2 to 9.3 m.y. (Walker, 1979).

The upper tuff unit is the Rattlesnake Ash-flow Tuff, a medium gray peraluminous rhyolite welded tuff. The well developed eutaxitic texture, produced by dark gray, off-white, and medium brown fiamme (flattened, stretched pumice fragments), is distinctive. The unit is phenocryst poor and has one percent or less sanidine and sparsely scattered quartz and clinopyroxene grains. Potassium-argon ages for the unit average 6.4 m.y. (Walker, 1979), late Miocene. The Rattlesnake Ash-flow Tuff is separated from the Devine Canyon Ash-flow Tuff by 0 to 25 ft of tuffaceous sedimentary rocks and nonwelded ash.

In the eastern part of the Sand Hollow study area, the Rattlesnake Ash-flow Tuff is overlain by several thin flows of basalt, the basalt of Twelvemile Table. This basalt is composed of small olivine phenocrysts in a microcrystalline matrix of augite and calcic plagioclase and minor magnetite.

Quaternary deposits consist of alluvium in the canyon bottoms, talus on canyon slopes, and local landslide deposits along the canyon walls.

Normal faults having offsets of tens to hundreds of feet developed in the areas in the middle to late Miocene, after the eruption of the Picture Gorge Basalt and before deposition of the younger units. The Picture Gorge Basalt and older units also are folded in a northeast-trending anticline located immediately north of the study areas. This faulting and folding resulted in a paleotopography of high hills composed of the Picture Gorge Basalt surrounded by younger basins. The tuffaceous sedimentary rocks fill paleobasins developed in the Picture Gorge Basalt, and the ash-flow tuffs overlie the sedimentary rocks but also lap onto or directly overlie the basalt.

In the western part of the Sand Hollow study area, a second episode of faulting produced numerous small offsets in the the upper Miocene ash-flow tuff unit.

Geophysical Studies

Magnetic, gravity, and radiometric data from central Oregon were compiled and examined in order to aid assessment of the mineral resource potential of the Sand Hollow and South Fork Wilderness Study Areas. The sparsely distributed data in all three data sets are adequate for addressing the regional structural and tectonic setting of the study areas but do not permit assessment of mineral resource potential at deposit scales except in limited areas directly beneath detailed profiles.

Magnetic Data

The Sand Hollow and South Fork Wilderness Study Areas lie within a terrane of young, unmetamorphosed volcanic rocks that commonly have large magnetic susceptibilities and large remanent magnetizations. In low-level aeromagnetic profiles, these rocks typically produce high-amplitude, short-wavelength magnetic anomalies that tend to obscure anomalies caused by deeper magnetic sources.

Magnetic data in the vicinity of the study areas are from two sources. An aeromagnetic survey was flown in 1983 at an altitude of 7,500 ft above sea level along east-west flightlines spaced 3 mi apart (U. S. Geological Survey, 1984). These profiles are too high in altitude and too widely spaced to provide detailed information about mineral resource potential, but contour maps of these data show various magnetic anomalies of regional interest. The westernmost part of the study areas is located on or near the east edge of a large magnetic high. The shape and amplitude of the anomaly indicate that its source lies at shallow depth (less than 1 mi) beneath the topographic surface and has horizontal dimensions on the order of 10 mi. This anomaly is located at the west tip of a conspicuous arcuate-shaped belt of anomalies that extends over 100 mi to the east (Committee for the Magnetic Anomaly Map of North America, 1987). In some locations, anomalies of this belt correspond with outcrops of Triassic mafic and ultramafic rocks (Walker, 1977). In this belt, near Suplee, Permian greenstones containing possible pillow basalts are exposed (Dickinson and Vigrass, 1965), and approximately 25 mi to the west of the study areas, possible serpentinite was reported between depths of 4,000 ft and 4,200 ft in the Sunray-Midcontinent Bear Creek No. 1 well. Together, this information suggests that the belt of magnetic anomalies is related to a belt of mafic to ultramafic rocks of Permian and (or) Triassic age; such a belt may represent a Permian and (or) Triassic suture zone. Although similar rocks do not crop out in or near the Sand Hollow and South Fork Wilderness Study Areas, the magnetic data suggest that the westernmost part of the study areas may be underlain at shallow depth by similar mafic or ultramafic rocks.

The second source of magnetic data was compiled under contract to the U.S. Department of Energy as part of the National Uranium Resource Evaluation (NURE) program (High Life Helicopters/QEB, 1981a, 1981b, 1981c, 1981d). These data were measured 400 ft above average terrain along east-west profiles spaced 6 mi apart and north-south profiles spaced 24 mi apart. (North of lat 44° N. and west of long 120° W., east-west profiles are spaced 3 mi apart.) Only two NURE profiles actually cross the study areas and are too widely spaced to describe the spatial distribution of magnetic anomalies between them. Because of the low altitude of the aircraft, these profiles are greatly influenced by highly magnetic volcanic rocks at the surface and near-surface. Some of the individual highs and lows along the magnetic profile may indicate mineralized areas, but are more likely the result of lateral variations in magnetite content in shallow basaltic rocks.

The NURE magnetic profiles show clear evidence of the large, shallowly buried source that was interpreted earlier from high-level magnetic data and presumed to be the west end of a belt of mafic and ultramafic rocks of Permian and (or) Triassic age extending approximately 100 mi to the east. The NURE data indicate that the east edge of the buried source is located very near the west boundary of the study areas and at a depth of less than 1 mi below the topographic surface.

Gravity Studies

Gravity data from the vicinity of the study areas were obtained from the National Geophysical Data Center, National Oceanic and Atmospheric Administration, Boulder, Colorado. Measurements are scattered at 3-to 5-mi spacing in this region, and only two measurements are actually within the study areas. The observed gravity data, based on the International Gravity Standardization Net datum (Morelli, 1974), were reduced to free-air gravity anomalies by using standard formulas (Telford and others, 1976). Bouguer, curvature, and terrain corrections (out to a distance of 103.6 mi from each station) at a standard reduction density of 2.67 g/cm^3 were added to the free-air anomaly at each station to determine complete Bouguer gravity anomalies.

Bouguer anomalies typically reflect shallow density contrasts of interest to resource appraisals, but also include contributions from deep-crustal masses that correlate with topography in a manner consistent with the concept of isostasy. To reduce the effect of deep sources related to isostasy, an isostatic residual-gravity map was constructed from the Bouguer gravity data by removing a regional gravity field computed from a model of the crust-mantle interface, assuming Airy-type isostatic compensation (Jachens and Griscom, 1985). A regional gravity perspective of the setting of the study areas can be seen on Jachens and others (1985).

The Sand Hollow and South Fork Wilderness Study Areas lie in a north-trending trough-shaped gravity low approximately 10 mi wide and 50 mi long. The linear nature of the trough suggests that it may be related to faulting of the pre-Tertiary basement rocks that lie beneath the volcanic cover. The trough is located between two positive anomalies of regional scale. These anomalies appear spatially related to the arcuate-shaped belt of magnetic anomalies discussed earlier and support the interpretation that mafic and ultramafic rocks may exist at shallow depth within or near the study areas.

Radiometric Data

Radiometric data were collected as part of the NURE survey (High Life Helicopters, Inc./QEB, Inc., 1981a, 1981b, 1981c, 1981d). Recordings were made of gamma-ray flux from radioactive isotopes of potassium, thorium, and uranium along east-west flightlines spaced approximately 6 mi apart and at an altitude of 400 ft above average terrain. Only two profiles actually cross the study areas, at lat 43° 58.7' N. and at lat 44° 01.5' N. Count rates were low along these lines except in two locations approximately at lat 43° 58.67' N., long 120° 02.21' W. and at lat 43° 58.59' N., long 120° 08.09' W. Slight anomalies of both equivalent thorium and equivalent uranium occur in these two locales, but they were not considered significant by the NURE study. Both anomalies occur near outcrops of fluvial and lacustrine sediments of Tertiary age. Because only two flightlines cross the study areas and because gamma rays are strongly attenuated by passage through earth materials, these data do not preclude the presence of anomalous amounts of radioactive elements away from the flightlines or buried a few feet or more beneath the ground surface.

Conclusions

Regional magnetic and gravity data suggest that the westernmost part of the Sand Hollow and South Fork Wilderness Study Areas may be underlain at depth by mafic and ultramafic rocks of Permian and (or) Triassic age related to an arcuate belt of similar rocks extending 100 mi to the east. Chromite deposits of economic importance are known to exist in the eastern part of this belt of anomalies. The Canyon Mountain (ultramafic) Complex in Grant County, for example, is one of the largest producers of chromite ore in the state of Oregon (Ferns and Huber, 1984). Although these chromite deposits are located over 30 mi from the study areas, the magnetic and gravity data suggest that similar host rocks may exist at depths of 3000 feet or more within or near the westernmost part of the study areas. The 8,000-ft-deep Texaco Federal No. 1 hole, located 2 mi north (and 8 mi east of the west boundary) of the study areas, did not intersect ultramafic rocks, although given the sketchy nature of drill logs, the existence of such rocks here cannot be ruled out absolutely. This hole is located east of the east edge of the magnetic and gravity anomalies, however, and mafic and ultramafic rocks are not predicted in this area by geophysical models.

Geochemical Studies

A reconnaissance geochemical investigation of the study areas was made using samples of stream sediment, the nonmagnetic fraction of heavy-mineral concentrates from stream sediments, and rock. The stream-sediment and concentrate samples contain material derived from rock units of the drainage basins within the study areas. Sampled drainage basins range in area from less than one to several square miles.

From the two study areas, a total of 49 stream-sediment samples, 39 heavy-mineral-concentrate samples, and 32 rock samples were analyzed for 31 elements by six-step semiquantitative emission-spectrographic methods (Myers and others, 1961; Grimes and Marranzino, 1968), and additional analyses were made using atomic-absorption spectroscopy and inductively coupled argon plasma-atomic emission spectroscopy (Crock and others, 1987). The analyses of stream-sediment and heavy-mineral-concentrate samples identify drainages that have anomalously high concentrations of metallic and metal-related elements. Rock samples were collected from areas of altered bedrock and from each lithologic unit in order to obtain information on trace-element signatures associated with potentially mineralized areas and to provide data on background trace-element concentrations. For this study, anomalous geochemical values were determined by inspection of histograms of the data from both the study areas and the surrounding region and by comparing the data to average crustal abundances in silicic and mafic volcanic rocks. For most elements, a value was considered anomalous if it exceeded the mean value for the element by two standard deviations.

Anomalous concentrations of mercury (greater than 0.18 ppm (parts per million)) were found in seven stream-sediment samples from northwestern and southwestern parts of the Sand Hollow study area. These samples have mercury concentrations of 0.27 to 4.6 ppm. Two stream-sediment samples from the west-central part of the South Fork study area also contain anomalous mercury concentrations (0.23 and 0.55 ppm). One stream-sediment sample from a site approximately 1/2 mi north of the South Fork study area contains 0.28 ppm mercury; the drainage basin from which this sample was collected does not extend into the study area. Cinnabar, the primary ore mineral of mercury deposits, was not observed during microscopic examination of the heavy-mineral concentrates from the sites.

Data from Barringer Resources, Inc. (1984) indicates that the magnetic fraction of a heavy-mineral concentrate of one stream-sediment sample contains 0.03 ppm silver. This sample was collected just over a mile southwest of the Sand Hollow study area. Igneous rocks commonly contain 0.04 to 0.1 ppm silver (Rose and others, 1979); the 0.03 ppm silver present in this sample is not considered anomalous.

Previous regional uranium surveys, mentioned earlier, which included aerial gamma-ray emission studies (High Life Helicopters, Inc./ QEB, Inc., 1981a, b, c, d), found two small areas with equivalent thorium and equivalent uranium anomalies in the study areas. No anomalous concentrations of thorium were found in stream-sediment or rock samples. No stream-sediment geochemical data is available to confirm or deny the existence of the uranium anomalies. No other geological evidence exists that would indicate uranium resources in these anomalous areas.

Mineral and Energy Resource.Potential of the South Fork Wilderness Study Area

Mineral Resource Potential

Investigations by the U.S. Geological Survey indicate that an area in the west central part of the South Fork Wilderness Study Area has low mineral resource potential for mercury in epithermal deposits, certainty level C. (See appendixes for definitions of levels of mineral resource potential and certainty of assessment.)

A low potential for mercury is based solely upon the two mercury anomalies in the stream sediment data from the study area. Permeability of the rocks is an important prerequisite for the emplacement of mercury deposits (Brooks, 1963, p. 21). The Picture Gorge Basalt and the densely welded tuffs lack permeability, and therefore are unlikely host rocks for mercury deposits. With respect to mercury, Brooks (1963) states that the Columbia River Basalt Group is "remarkably unmineralized." Additionally, the rocks in the anomalous areas have not been greatly affected by local faulting or fracturing that would increase permeability and provide pathways for mineralizing fluids or vapors. The tuffaceous sedimentary rocks lying between the Picture Gorge Basalt and welded tuff may have higher permeability and may be more likely host rocks. However, no visible alteration was observed in the tuffaceous sedimentary rocks. Since nearly all mercury deposits worldwide are epithermal deposits (Brooks, 1963), it can be safely assumed that any mercury deposit, if present in the study area, would likely be epithermal.

Small sand and gravel deposits suitable for construction use are present in the study area but are too small to constitute a resource. No undiscovered sand and gravel resources are expected beyond known deposits.

Energy Resource Potential

Investigations by the U.S. Geological Survey indicate that the South Fork Wilderness Study Area has low resource potential for petroleum and natural gas, certainty level C. The geothermal resource potential is low, certainty level B; however, this level of potential may be too high.

The South Fork Wilderness Study Area is considered to have a low potential, certainty level C, for oil and gas. This is consistent with Fouch (1983) who also rated the area as having low potential for oil and gas. Besides being near a dry hole, the area is considered to have low potential because it lies outside of, or on the fringe of, known Cretaceous basins, because few likely source rocks are present, and because potential reservoir rocks probably have low porosity and permeability.

Central Oregon has been explored for oil since the 1930's, but no discoveries of oil or gas have been made (Thompson and others, 1984). Exploration efforts and petroleum resource appraisals are hampered by the meager data available on subsurface geology in central Oregon (Thompson and others, 1984; Fritts and Fisk, 1985a, b). Few deep wells have been drilled, outcrops of pre-Cenozoic rocks are rare, and the thick Cenozoic volcanic cover causes difficulty in the interpretation of geophysical data (Newton, 1974). Additionally, the region is structurally complex and has Cenozoic structures that differ from underlying Mesozoic structures. Little is known about pre-Mesozoic structures (George W. Walker, oral commun., 1987).

The primary exploration targets in central Oregon have been within Cretaceous basins (Newton, 1968; Fritts and Fisk, 1985a, b). Two such basins exist. The larger and older of the basins is the Columbia River Basin of mid- to Late Cretaceous age (Newton, 1966, 1977; Fritts and Fisk, 1985a, b). Most of this basin lies to the north of the study area. Only the south margin passes through the vicinity of the study area (Fritts and Fisk, 1985a, b). The smaller and slightly younger (latest Cretaceous) Ochoco Basin lies to the west and probably never extended as far east as the study area (Thompson and others, 1984).

Oil and gas leases cover the study area. In 1971, Texaco drilled the Federal No. 1 test hole approximately 2 mi north of the South Fork study area. Newton (1974) reported slight gas shows between 1,700 and 3,600 ft in this hole, but the well log indicates only a negligible increase over background gas values in this section of the hole. From approximately 11 to 25 mi to the southwest and west of the study areas, five other holes have been drilled by various companies. No oil or gas shows were reported from four of these holes. The Sunray-Midcontinent Bear Creek No. 1, drilled in 1958, showed slight gas shows at 7,919 ft (Newton, 1969). Well logs for all holes are on file at the Oregon Department of Geology and Mineral Industries, Portland, Oregon.

For purposes of an oil and gas resource potential assessment, it is assumed that the subsurface stratigraphy of the wilderness study area is similar to that in the Texaco Federal No. 1 hole, previously described. The relatively thin, 180-ft-thick sequence of mid-Cretaceous marine sedimentary rocks indicates that the study area lies outside the Ochoco Basin and on the very margin of the Columbia River Basin. Further, the relative paucity of Cretaceous and pre-Cretaceous marine sedimentary rocks indicates that few potential source rocks exist in the area, since pre-Cretaceous rocks are primarily volcanic in origin (Thompson and others, 1984). The 2,000-ft-thick Cretaceous sedimentary section could include potential reservoir rocks, but since the rocks in this section are of mostly non-marine character and may be poorly sorted (George W. Walker, oral commun., 1987), their porosity and permeability may be low, thus reducing their reservoir rock potential. Because it lies outside of or on the fringe of known Cretaceous basins, because few likely source rocks are present, and because potential reservoir rocks may have low porosity and permeability, the area is considered to have low resource potential for oil and gas.

The resource potential for geothermal energy in the study area is low, certainty level B. A certainty level of B is assigned because the existence of a resource is unlikely and the assessment of potential may be too high. Two warm springs, having water temperatures of 73° and 88° F, occur on or within 1/2 mile of the north border of the study area (Bliss, 1983). Mariner and others (1983) classify these springs as representing an isolated system that has a reservoir area of less than 1 sq km. These springs are probably the result of deep circulation along normal faults in an area of normal heat flow (Mariner and others, 1983), indicating low reservoir temperatures. Therefore a geothermal resource, if present, would be a low-temperature resource. The study area does not lie in a region of high heat flow (Riccio, 1978). Previous state and regional geothermal surveys have not indicated any geothermal potential for the study area (Bowen and others, 1978; Riccio, 1978; Muffler, 1979; National Geophysical Data Center, 1982; Reed, 1983; Bliss, 1983). Under the definitions used in this study (see appendixes), the geothermal resource potential is considered low.

Mineral and Energy Resource Potential of the Sand Hollow Wilderness Study Area

Mineral Resource Potential

The investigations by the U.S. Geological Survey indicate that areas in the northwest and southwest parts of the Sand Hollow Wilderness Study Area have low mineral resource potential for mercury in epithermal deposits, certainty level C. (See appendixes for definitions of levels of mineral resource potential and certainty of assessment.)

Mercury anomalies in the stream sediment data indicate a low potential for mercury in two areas (fig. 2). Some of the highest mercury concentrations occur in samples from sites along faults or from sites in drainage basins that have faults upstream. This indicates that faults may have played an important role in acting as conduits for mercury vapors or mercury-bearing solutions and for localizing mercury. Other samples from sites along faults do not have anomalous mercury concentrations, suggesting leakage of fluids or vapors may have only occurred along certain faults or certain portions of faults.

As discussed previously, permeability of the rocks is an important prerequisite for the emplacement of mercury deposits (Brooks, 1963). The Picture Gorge Basalt and the densely welded tuffs lack permeability and therefore are unlikely host rocks for mercury deposits. The tuffaceous sedimentary rocks lying between these other two units may have higher permeability and be more likely host rocks. However, no visible alteration was observed in these sedimentary rocks.

Low-grade bentonite deposits have been mined periodically within 2 mi of the southwest boundary of the Sand Hollow study area, but are confined to probable lacustrine rocks of the John Day Formation. Such rocks do not extend into the Sand Hollow study area, and the area has no mineral resource potential for bentonite.

Small sand and gravel deposits suitable for construction use are present in the study area but are too small to constitute a resource. No undiscovered sand and gravel resources are expected beyond known deposits.

Energy Resource Potential

The investigations by the U.S. Geological Survey indicate that the Sand Hollow Wilderness Study Area has low resource potential for petroleum and natural gas, certainty level C. The geothermal resource potential is low, certainty level B; however, this level of potential may be too high.

The low potential for oil and gas in the Sand Hollow Wilderness Study Area is consistent with the conclusion of Fouch (1983) who also rated the area as having low potential for these commodities. Besides being near a dry hole, the area is considered to have low potential because it lies outside of or on the fringe of known Cretaceous basins, because few likely source rocks are present, and because potential reservoir rocks probably have low porosity and permeability. Oil and gas leases cover the study area. See South Fork "Energy Resource Potential" section above for further discussion.

The resource potential for geothermal energy in the study area is low, certainty level B. A certainty level of B is assigned because the existence of a resource is unlikely and the assessment of potential may be too high. As discussed for the South Fork study area, a warm spring occurs within 1/2 mile of the northeast corner of the Sand Hollow Wilderness Study Area, and another occurs about 4 mi to the northeast (Bliss, 1983). Riccio (1978) and National Geophysical Data Center (1982) indicate that a warm water well and (or) spring occur along Camp Creek, 1 to 4 mi west of the study area. The conclusions reached earlier regarding the potential reservoir system for the South Fork study area apply as well to the Sand Hollow study area. Any geothermal system in the area is likely to be small and of low temperature. Previous state and regional geothermal surveys have not indicated any geothermal potential for the study area (Bowen and others, 1978; Riccio, 1978; Muffler, 1979; National Geophysical Data Center, 1982; Reed, 1983; Bliss, 1983).

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

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

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

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

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

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

LEVELS OF CERTAINTY

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

A	B	C	D
U/A	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 RESOURCE POTENTIAL →

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.
Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40-42.
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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 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.

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SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

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