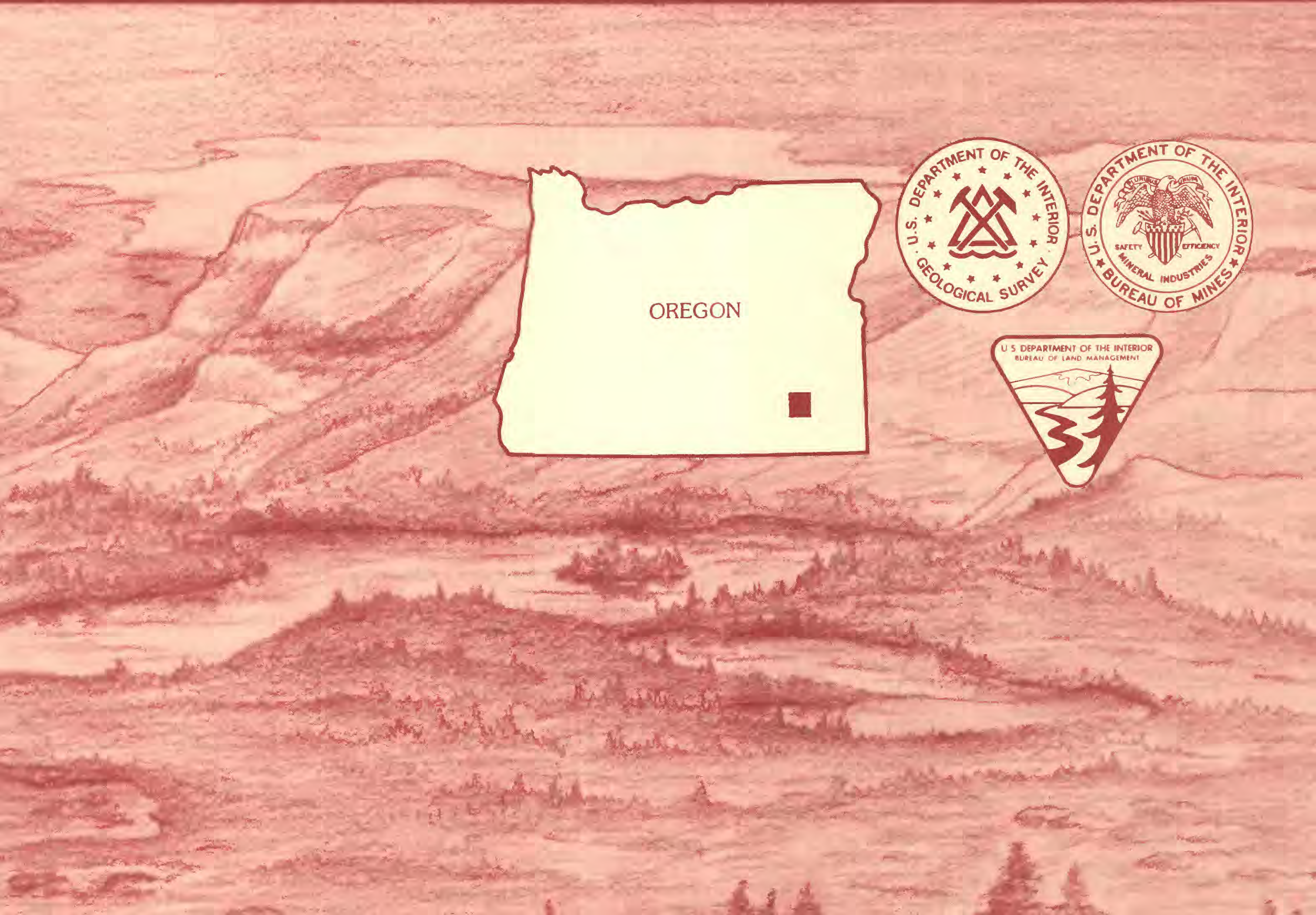
Mineral Resources of the Blitzen River Wilderness Study Area, Harney County, Oregon

U.S. GEOLOGICAL SURVEY BULLETIN 1740–D



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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 22,650 acres of the Blitzen River Wilderness Study Area.

Chapter D

Mineral Resources of the Blitzen River Wilderness Study Area, Harney County, Oregon

By DEAN B. VANDER MEULEN, ANDREW GRISCOM, and HARLEY D. KING
U.S. Geological Survey

PHILLIP R. MOYLE
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1740

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
STEENS MOUNTAIN-RINCON REGION, 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 Study Area

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 part of the Blitzen River Wilderness Study Area (OR–002–086E), Harney County, Oregon.

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FIGURES

Mineral Resources of the Blitzen River Wilderness Study Area, Harney County, Oregon

By Dean B. Vander Meulen, Andrew Griscom, *and* Harley D. King
U.S. Geological Survey

Phillip R. Moyle
U.S. Bureau of Mines

SUMMARY

Abstract

The Blitzen River Wilderness Study Area (OR–002–086E) is located along the western slope of Steens Mountain in southeastern Oregon. At the request of the U.S. Bureau of Land Management, the U.S. Geological Survey and U.S. Bureau of Mines conducted field studies of 21,658 acres of the Blitzen River Wilderness Study Area. In this report, the area studied is referred to as the "wilderness study area," or simply the "study area." Fieldwork was conducted by the U.S. Geological Survey during 1986 and 1987 and by the U.S. Bureau of Mines during 1986 to evaluate the identified mineral resources (known) and the mineral resource potential (undiscovered) of the study area.

No mineral resources were identified in the study area. However, the study indicates moderate potential for geothermal energy resources along northwest-trending fault zones in the western part of the study area. The study area has no potential for oil and gas resources.

Character and Setting

The Blitzen River Wilderness Study Area is located along the west slope of Steens Mountain (fig. 1), 55 mi south of Burns, Oreg., and 35 mi northwest of Fields, Oreg. The study area ranges in elevation from 4,200 ft where the Donner und Blitzen River enters Blitzen Valley to 6,500 ft above sea level along the easternmost boundary. West of the study area, the lower slope of Steens Mountain forms a gentle west-tilted plateau that ends abruptly at Catlow Rim along the east edge of Catlow Valley. Ten miles east of the study area the upper slope rises more than 3,100 ft to the crest of Steens Mountain, 9,670 ft above sea level. Several northwest-flowing rivers and creeks have cut deep gorges into the plateau (fig.1). The Donner und Blitzen River is the largest river in the region and collects most of the tributary drainage on the west side of Steens Mountain. The river flows north through the western part of the study area into the Blitzen Valley (fig. 1).

The oldest rocks exposed in the study area are basalt flows of middle Miocene age (11.2 to 16.6 million years before present, Ma; see appendixes for geologic time chart). The basalt flows that underlie the entire study area are overlain in the northern part by late Miocene rhyolite ash-flow tuff and basalt flows.

Identified Resources

No mines, claims, prospects, or mineralized zones were found, and no mineral or energy resources or occurrences were identified within or adjacent to the study area.

Mineral Resource Potential

Hot springs issue from a northwest-trending fault zone 2 to 5 mi north of the study area. This same fault zone extends southeast through the western part of the study area. Areas along the fault zone and parallel fault zones have moderate potential for geothermal energy resources. The study area has no potential for oil and gas resources.

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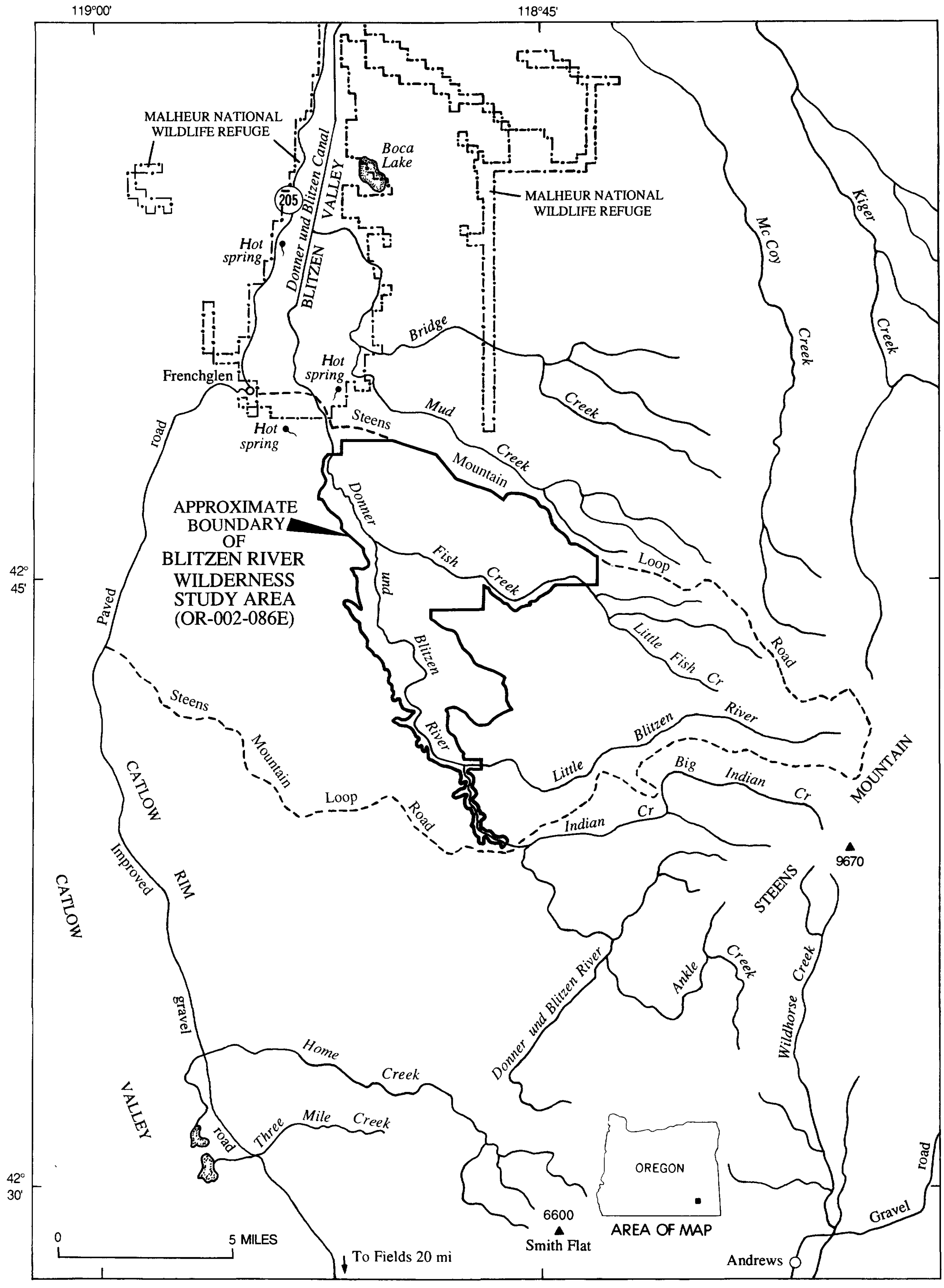

Figure 1. Index map showing location of the Blitzen River Wilderness Study Area, Harney County, Oregon.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is a joint 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 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. Mineral assessment methodology and terminology as they apply to these surveys were discussed by Goudarzi (1984). See appendixes for definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Area Description

The Blitzen River Wilderness Study Area encompasses 22,650 acres in the northern Basin and Range physiographic province of southeastern Oregon. The study area is located along the west slope of Steens Mountain, 3 mi southeast of Frenchglen, Oreg. (fig. 1). The Malheur National Wildlife Refuge borders the northwest corner of the study area. The study area is accessible from Frenchglen by the Steens Mountain Loop Road, an improved gravel road that forms the north boundary of the study area. Several unimproved dirt roads and jeep trails approach the study area from the west and south. Maximum elevation in the study area is approximately 6,500 ft above sea level along the east boundary; minimum elevation is about 4,200 ft above sea level where the Donner und Blitzen River enters Blitzen Valley. The climate is semiarid; juniper groves are common along west-facing ridges and in protected canyons, and sage brush and grasses are profuse across most of the study area. Parts of the study area are currently used for cattle grazing.

Previous and Present Investigations

The geology and groundwater resources of the northern part of the study area were investigated by Piper and others (1939). Other geologic investigations that include the study area are a reconnaissance geologic map of the Adel 1° by 2° quadrangle by Walker and Repenning (1965), an aerial radiometric and magnetic survey by the U.S. Department of Energy (Geodata International, Inc., 1980), and an aeromagnetic survey by the U.S. Geological Survey (1972). From 1981 to 1983 the State of Oregon Department of Geology and Mineral Industries (DOGAMI), conducted reconnaissance geochemical studies of 18 BLM wilderness study areas in southeast Oregon (Gray and others, 1983) that included the Blitzen River Wilderness Study Area. Geochemical and mineralogical studies of heavy-mineral concentrates collected by DOGAMI were conducted by Barringer Resources, Inc. (Bukofski and others, 1984). The U.S. Geological Survey conducted a combined geologic, geochemical, and geophysical survey of the wilderness study area during 1986 and 1987. Investigations focused on correlating geochemical and geophysical anomalies with rock units and geologic structures.

The U.S. Bureau Mines investigated the wilderness study area during 1986. Investigations entailed prefield, field, and report-preparation phases during 1986 and 1987. Prefield studies included library research and perusal of Harney County and U.S. Bureau of Land Management mining and mineral lease records. Field studies involved searches for mineralized areas within the study area. Both ground and aerial reconnaissance studies were conducted in an attempt to identify significant geologic structures and areas of alteration where mining activity might have taken place. Additional information is available from the U.S. Bureau of Mines, Western Field Operations Center, E. 360 Third Avenue, Spokane, WA 99202.

APPRAISAL OF IDENTIFIED RESOURCES

By Phillip R. Moyle
U.S. Bureau of Mines

History and Production

The Blitzen River Wilderness Study Area is about 10 mi west of the north end of the Steens-Pueblo mining district, which is located along the east escarpment of the Steens Mountain-Pueblo Mountains fault block (Bradley, 1982). Small quantities of mercury were produced from the district (Ross, 1942; Williams and Compton, 1953). Minor and others (1987a) identified a small marginal perlite reserve and noted occurrences of mercury, uranium, gold, molybdenum, and zeolite minerals in or near the High Steens Wilderness Study Area, about 5 to 10 mi east of the Blitzen River Wilderness Study Area. Within the past 5 yr, a company exploring for epithermal gold deposits conducted reconnaissance sampling on the western flank of Steens Mountain, including parts of the study area (George Brown, written commun., 1986). However, no claims have

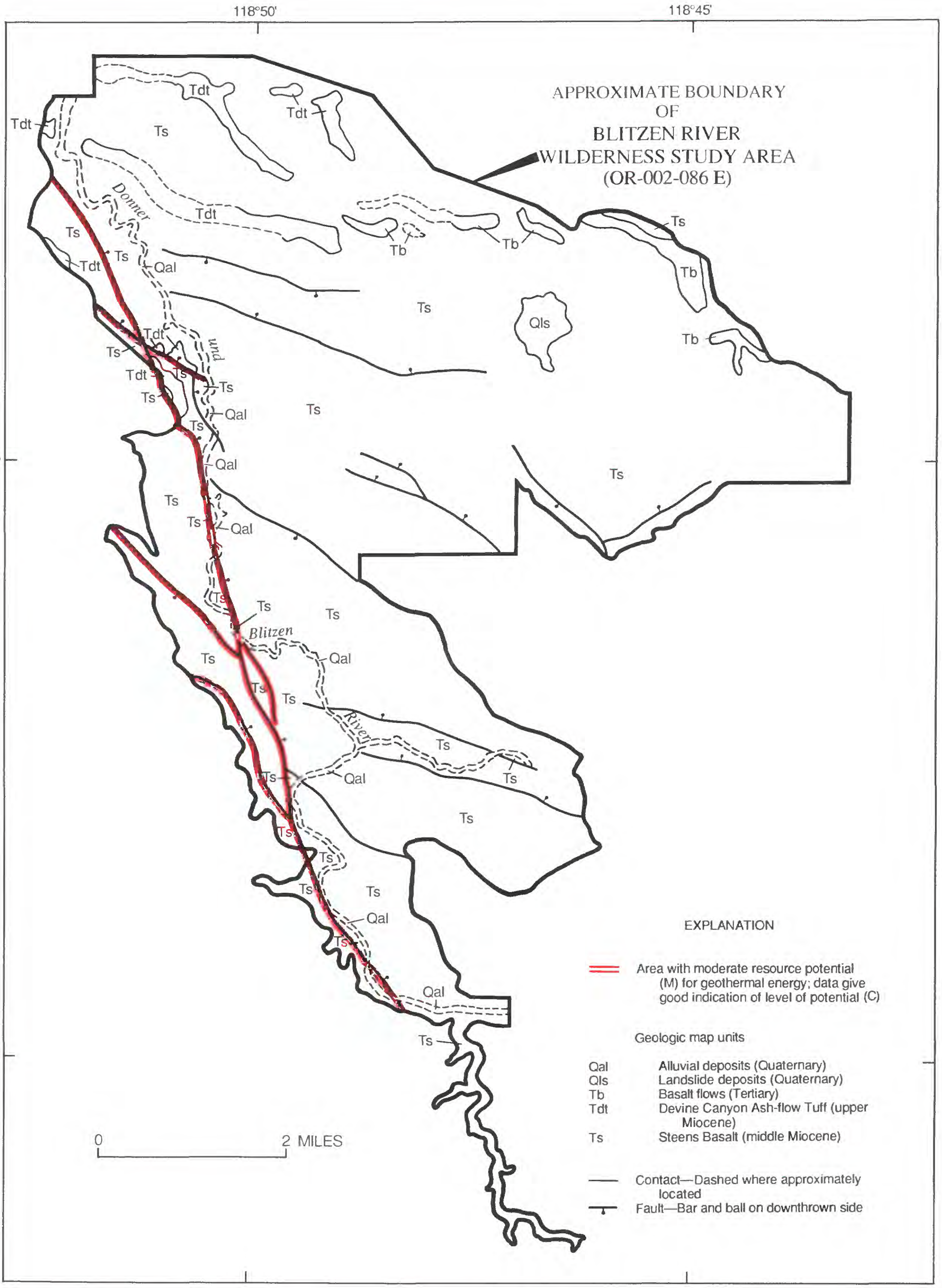

Figure 2. Generalized geologic map and mineral resource potential of the Blitzen River Wilderness Study Area, Oregon.

been located, no mineral production has been recorded, and no workings are present in or adjacent to the study area.

Mines, Prospects, Claims, and Mineralized Areas

The U.S. Bureau of Mines collected 2 rock samples and 14 reconnaissance placer (stream sediment) samples from the study area. The rock samples were analyzed for gold by fire-assay/atomic absorption, for an 11-element geochemical suite by inductively coupled argon-plasma spectrophotometry organic extraction, and for zeolite and clay minerals by X-ray diffraction. Reconnaissance placer samples, partially concentrated in the field, were further concentrated on a laboratory-sized Wilfley table to separate heavy minerals, such as gold, from a lower density gangue. The concentrates were scanned with a binocular microscope to determine heavy-mineral content. Concentrates were also checked for radioactivity and fluorescence.

No mines, prospects, or claims were identified in the Blitzen River Wilderness Study Area. No gold was detected in 14 reconnaissance placer samples collected from drainages within and adjacent to the study area. Two samples of altered tuffaceous sedimentary rock collected in the northwest corner of the study area did not contain metallic values above normal crustal abundance, although heulandite (a zeolite) and smectite (a clay) were detected in one sample. The amount and quality of zeolite and clay were not sufficient to warrant further evaluation as a resource. No metallic and no significant industrial mineral occurrences were found by the U.S. Bureau of Mines in or near the study area (Moyle, 1987).

Erikson and Curry (1977) examined uranium prospects in the nearby Steens-Pueblo mining district and observed that concentrations of oxidized uranium occur in narrow zones in and adjacent to rhyolite breccias and rhyolite dikes in the Pike Creek Formation (Walker and Repenning, 1965). They suggested that these occurrences may be associated with high-angle fracture zones. Although Erikson and Curry (1977) noted that uranium surface shows are "* * *weak, small, and sporadic," they also concluded that significant uranium mobilization had taken place. Uranium-bearing formations are not known to crop out, and no anomalous radioactive emissions were detected in the vicinity of high-angle faults in or near the Blitzen River Wilderness Study Area.

Three low-temperature geothermal springs flow from the flanks of the Blitzen Valley (fig. 1), about 2 to 5 mi northwest of the study area. They range in temperature from 78 to 89 °F and produce from 100 to 1,800 gallons of water per minute that is used for livestock and irrigation (Waring, 1965, p. 40). The Oregon Department of Geology and Mineral Industries (1982) classified the area around the springs as "* * * known or inferred to be underlain at shallow depth (less than 350 ft) by thermal water of sufficient temperature for direct heat applications."

Oil and gas leases issued in 1982–83 for several parcels of land southwest of the study area were terminated in 1984–85. Fouch (1983) assessed lands in wilderness study areas in the Steens Mountain region as having low potential for petroleum resources. However, no geologic structures favorable for oil and gas are known to underlie this study area.

Appraisal of Mineral Resources

There are no identified mineral or energy resources or occurrences in the Blitzen River Wilderness Study Area, and the host formations and depositional environment of the mineral occurrences of the High Steens Wilderness Study Area are not known to be present within or adjacent to this study area. Further studies are needed to confirm the presence and determine the extent of an inferred shallow geothermal resource at the northwest boundary of the study area.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

By Dean B. Vander Meulen, Andrew Griscom, *and* Harley D. King
U.S. Geological Survey

Geology

The Blitzen River Wilderness Study Area is located on the northwest side of the 30- by 90-mi north-trending Steens Mountain-Pueblo Mountains fault block. Strata within this fault block consistently dip 4° to 16° to the west. Most of the region, including the study area, is underlain by middle Miocene Steens Basalt (Piper and others, 1939) (fig. 2). In the study area, the Steens Basalt comprises a thick, chemically homogeneous sequence of basalt flows that are typically 20 to 30 ft thick. The base of the Steens Basalt is not exposed in the study area, although the unit has a maximum thickess of 4,200 ft along the Steens Mountain escarpment (Minor and others, 1987b) 9 mi east of the study area.

In the northern part of the study area, the Steens Basalt is unconformably overlain by a rhyolite ash-flow tuff and younger basalt flows (fig. 2). Whole-rock major-element and trace-element geochemical data (Hildreth, 1981) indicate that the tuff is probably correlative with part of the Devine Canyon Ash-flow Tuff (Walker, 1979), age dated at 9.2 Ma. Maximum thicknesses of the rhyolite tuff and younger basalt flows are each about 60 ft. The rhyolite tuff typically forms a pattern of low flat-topped ridges that probably reflect an inversion of paleotopography; that is, the welded tuff filled paleostream channels or depressions and was later exposed by preferential erosion of the surrounding rock. In the study area, the rhyolite tuff represents distal facies of a caldera-forming ash-flow tuff eruption. Walker (1970) and Greene (1973) indicate that the Devine Canyon Ash-flow Tuff may have erupted from a caldera located in the Harney Basin, 40 mi north of the study area.

Alluvial deposits in the north part of the Donner und Blitzen River (fig. 2) probably form the thickest accumulations of Quaternary sediment in the study area. Colluvium forms thin, extensive veneer deposits on low-angle slopes and terraces throughout the study area. Landslide deposits are present along steeper slopes in the eastern part of the study area.

Steens Mountain rises 9,670 ft above sea level and is the highest point in southeastern Oregon. Because of this unique topography, the west slope of Steens Mountain gathers much more precipitation than surrounding ranges. Piper and others (1939) suggest that scoriaceous and fragmental zones within the Steens Basalt on the west dip slope may serve as good aquifers. Surface runoff is captured by a network of west-flowing creeks and rivers that are tributaries of the Donner und Blitzen River. Annually, the Donner und Blitzen River discharges an average 100,000 acre-feet of water through the western part of the study area (Piper and others, 1939). Water discharge through this drainage far exceeds that of other rivers in the region.

Two different sets of normal faults are recognized in the Blitzen River Wilderness Study Area. The most conspicuous is a set of high-angle normal faults that trend N. 30° W. along the western part of the study area. Most of the Donner und Blitzen River follows this trend (fig. 2). The second set of normal faults trends N. 60°–70° W. (fig. 2) and forms conspicuous escarpments across the central part of the study area. In the southern part of the study area the second fault set changes strike from N. 70° W. to N. 40° W. The more westerly trending sections of these faults parallel the northwest extension of a large fault-disrupted monocline that forms the western escarpment of the High Steens fault block, 0.5 mi east of the study area. The monocline and associated normal faults are considered to be part of the southern section of the Brothers fault zone, a deep-seated regional shear zone (Walker, 1969; Minor and others, 1987a).

Geochemical Studies

Results of earlier reconnaissance geochemical studies in the region of the Blitzen River Wilderness Study Area are reported by Gray and others (1983) and Bukofski and others (1984). In 1986 and 1987, the U.S. Geological Survey conducted a reconnaissance geochemical study of the Blitzen River Wilderness Study Area; this study included the collection and analysis of 28 stream-sediment samples and 30 nonmagnetic heavy-mineral-concentrate samples. The samples were taken from active alluvium in stream channels.

Stream sediments represent a composite of rock and soil eroded upstream from the sample sites. Nonmagnetic heavy-mineral concentrate samples provide information about the chemistry of rock material eroded from the drainage basin upstream from the sample sites. The nonmagnetic fraction of heavy-mineral concentrates may contain ore-forming or ore-related minerals. The selective concentration of minerals permits determination of some elements that are not easily detected in bulk stream-sediment samples.

All of the stream-sediment and heavy-mineral-concentrate samples were analyzed semiquantitatively for 31 elements by using a direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). Stream-sediment samples were also analyzed by inductively coupled argon plasma atomic-emission spectroscopy (ICAP–AES) for antimony, arsenic, bismuth, cadmium, and zinc and by atomic absorption for gold and mercury (Crock and others, 1987). The method used for the gold analysis is described in Thompson and others (1968). Analytical data are by M.S. Erickson (written commun., 1987).

One stream-sediment sample collected from the east-central part of the study area by Gray and others (1983) contains an anomalous concentration of gold (0.155 parts per million, or ppm). The sample was collected from Fish Creek, which drains an area of more than 10 mi^2 before entering the study area 2 mi upstream from the sample-collection site. On the basis of the low concentration of gold in the sediment sample and a lack of gold in the concentrate samples, we believe a gold placer deposit is not likely to be present in the study area. The source of the gold is believed to be outside and east of the study area. No other gold anomalies were detected in the study area.

An anomalous value of lead (200 ppm) was detected in a nonmagnetic heavy-mineral-concentrate sample collected at the north end of the study area near the Steens Mountain Loop Road (fig.1). The anomalous value is believed to be due to a lead artifact, such as a bullet fragment, that contaminated the sample.

A stream-sediment sample collected in a tributary west of the Donner und Blitzen River, in the northern part of the study area, contains 50 ppm tin. A few grains of wood tin, a botryoidal cryptocrystalline form of cassiterite, were identified microscopically. The wood tin probably eroded from fractures in the Devine Canyon Ash-flow Tuff that underlies part of the drainage area upstream from the sample-collection site. The small amount of wood tin observed in the sample and the absence of other tin anomalies in the area suggest that there are no tin resources in the northern part of the study area.

No other elements were detected in anomalous concentrations in these or other concentrate samples. No notably anomalous concentrations of ore-related elements were detected in stream-sediment samples collected in the Blitzen River Wilderness Study Area.

Geophysical Studies

Geophysical evaluation of the mineral resources of the Blitzen River Wilderness Study Area was based on interpretations of aeromagnetic, gravity, and aerial gamma-ray spectrometer surveys.

Aeromagnetic data gathered during two previous surveys were considered for this study. The first was a regional aeromagnetic survey conducted over the study area by the 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 second set of aeromagnetic data was collected over the Adel 1° by 2° quadrangle for the Department of Energy (Geodata International, Inc., 1980). 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. Five of these profiles cross the wilderness study area.

Magnetic minerals, where locally concentrated or depleted, may cause a high or low magnetic anomaly that can be a guide to mineral occurrences or deposits. Boundaries between magnetic and relatively less magnetic rock units are located approximately at the steepest gradient on the flanks of the magnetic anomaly. The majority of the anomalies in the study area are probably caused by the preponderance of lava flows and other volcanic rocks that characteristically have high magnetic susceptibility. Survey aircraft maintained an altitude of 2,000 to 4,000 ft, a distance sufficiently large to suppress most of the short-wavelength anomalies generated by less extensive rock units at the surface.

Two broad magnetic lows, 3 to 5 mi wide and 7 to 10 mi long, extend generally northeast across the study area. The lows are probably caused by parts of the Steens Basalt that are reversely magnetized (Mankinen and others, 1985) or are possibly related to northeast-trending faults that cut the basalt flows adjacent to the study area.

A gravity survey of this general area was conducted by the U.S. Geological Survey in 1986 to supplement available data from the National Geophysical Data Center, Boulder, CO 80303. Station spacing ranges from about 1 to 7 mi, and about 25 stations are situated in the study area. The most conspicuous gravity feature is a large (20-milligal) circular gravity low about 15 mi in diameter centered over the extreme east tip of the study area. The western boundary of the low extends approximately north-south through the study area at long. 118°50' W. (fig. 2). The low has a relatively flat bottom and steep marginal gradients. The source of the low is a mass of low-density rock presumably older than and covered by the exposed volcanic rocks of Steens Mountain. The gravity low seems to be located in a magnetically low area that has large regional magnetic highs on the north, west, and southwest sides of the gravity low. The large low-density mass causing a gravity low may be a sedimentary basin, a granitic pluton, or a caldera depression filled with low-density pyroclastic and sedimentary rocks. The circular form of the gravity low suggests that it may represent a buried caldera. This proposed caldera could be a source for some of the rhyolite and dacite air-fall and ash-flow tuffs mapped below the Steens Basalt and older volcanics (Minor and others, 1987b) on the east flank of Steens Mountain. A buried caldera structure could also explain the alteration and mineralization observed in the underlying tuffs (Minor and others, 1987a). The inferred caldera is covered by a substantial thickness (2,000 to 4,000 ft) of volcanic flows that include the Steens Basalt.

Radiometric data were compiled by Geodata International, Inc. (1980) for the National Uranium Resource Evaluation (NURE) program of the Department of Energy. Aerial gamma-ray spectrometer measurements were taken along east-west flightlines spaced at 3-mi intervals. Recordings were made of gamma-ray flux from radioactive isotopes of uranium, thorium, and potassium or their decay products. Results indicate that statistically significant anomalies for uranium, potassium, and thorium are not present in the study area.

Mineral Resource Assessment

Several thermal springs north of the study area are aligned along known or inferred northwest-trending faults or issue from valley-fill sediments along projected traces of these faults. Relations between thermal waters and fault patterns were first described by Piper and others (1939). Geothermal springs were not identified in the study area, although geothermal springs located 2 to 5 mi northwest of the study area have potential for direct-heat application. These hot springs issue from a northwest-trending fault zone that extends into the western part of the study area. Areas along the fault zone and parallel fault zones have moderate potential for geothermal energy, level C certainty.

Parts of the Steens Basalt on the west dip slope of Steens Mountain may serve as good aquifers (Piper and others, 1939). The Donner und Blitzen River discharges much more water than other rivers in the region.

The Blitzen River Wilderness Study Area is underlain by an estimated 5,000 ft of mafic and intermediate volcanic rocks. These Tertiary volcanic rocks are not sources of hydrocarbons. Geologic structures favorable for the production of oil and gas are not known to underlie the study area. Pre-Tertiary basement rocks exposed about 38 mi south of the study area are metamorphic and intrusive rocks of Mesozoic age (Walker and Repenning, 1965; Roback and others, 1987) and are unlikely sources for hydrocarbons. The absence of rocks capable of producing hydrocarbons and the minimal probability that such rocks exist at depth suggest that the study area has no potential for oil and gas, certainty level D.

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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 →

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
</table>

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

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

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

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

GEOLOGIC TIME CHART

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

EON	ERA	PERIOD	EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary	Holocene	0.010
			Pleistocene	1.7
		Tertiary — Neogene Subperiod	Pliocene	5
			Miocene	24
		Tertiary — 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
		Carboniferous Periods — 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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