UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mineral resource potential of the Bull of the Woods Wilderness Clackamas and Marion Counties, Oregon

By

George W. Walker[1], Norman S. MacLeod[2],
and
Richard J. Blakely[1]

U.S. Geological Survey
Open-File Report 85-247
1985

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1]Menlo Park, California [2]Vancouver, Washington

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STUDIES RELATED TO WILDERNESS

Under provisions of the Wilderness Act (Public Law 88-577 September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have conducted mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey by the U.S. Geological Survey of the Bull of the Woods Wilderness, Mt. Hood and Willamette National Forests, Clackamas and Marion Counties, Oregon. The area was incorporated into the Wilderness Preservation System by passage of the Oregon Wilderness Bill (May 1984).

MINERAL RESOURCE POTENTIAL OF THE BULL OF THE WOODS WILDERNESS CLACKAMAS AND MARION COUNTIES, OREGON

By George W. Walker, Norman S. MacLeod, and Richard J. Blakely

SUMMARY

The Bull of the Woods Wilderness, Clackamas and Marion Counties, Oreg., contains several small prospects originally located for both base and precious metals. Adjacent to the wilderness on the west and southwest is the North Santiam mining district which has yielded small quantities of gold, silver, lead, zinc, and copper ores, principally in the period 1896 to 1947. Renewed interest in the district in the past decade has led to several exploration programs, including geochemical sampling and extensive drilling. These have resulted in the discovery of a large, mineralized breccia pipe a little more than a mile southwest of the wilderness boundary. Analyses of selected samples from within the wilderness indicate the presence of anomalous amounts of copper, silver, zinc, and several other metals. Favorable geologic conditions, as well as anomalous metal values, indicate that the area has a moderate potential for small deposits and possibly for large, low-grade deposits of base and precious metals.

There is no evidence that mineral fuels are present in the area. Nearby hot springs and higher than normal heat flow indicate a potential for geothermal energy, although lack of both thermal springs and large volumes of young volcanic rocks within the wilderness suggest that the potential is probably small.

INTRODUCTION

The Bull of the Woods Wilderness lies a few miles west of the crest of the Cascade Range in Marion and Clackamas Counties of north-central Oregon. It includes approximately 60 mi^2 in the Mt. Hood and Willamette National Forests. The wilderness, as approximately outlined on figure 1, includes a core area originally recommended for wilderness status and several contiguous areas originally designated as nonwilderness during the Roadless and Undeveloped Area Evaluation II (RARE II, January 1979). The wilderness is named for Bull of the Woods, a prominent point (elev. 5,523 ft) in the central part of the area that in years past was the site of a U.S. Forest Service fire lookout.

During this evaluation a reconnaissance geologic map was made of the area and stream-sediment and bedrock samples were collected for both detailed mineralogic and X-ray diffraction studies and for chemical analyses. Some additional geologic mapping and sampling were done in areas immediately contiguous to the wilderness to better understand the distribution of rock units and their lithologic variations in order to make more meaningful inferences regarding the mineral resource potential. Preexisting geophysical surveys were reviewed as a part of the mineral resource evaluation.

Prior to the present study, the geology of a small part of the wilderness was mapped in broad reconnaissance by Thayer (1939) during a regional study of the geology and petrology of a large segment of the north-central Cascade

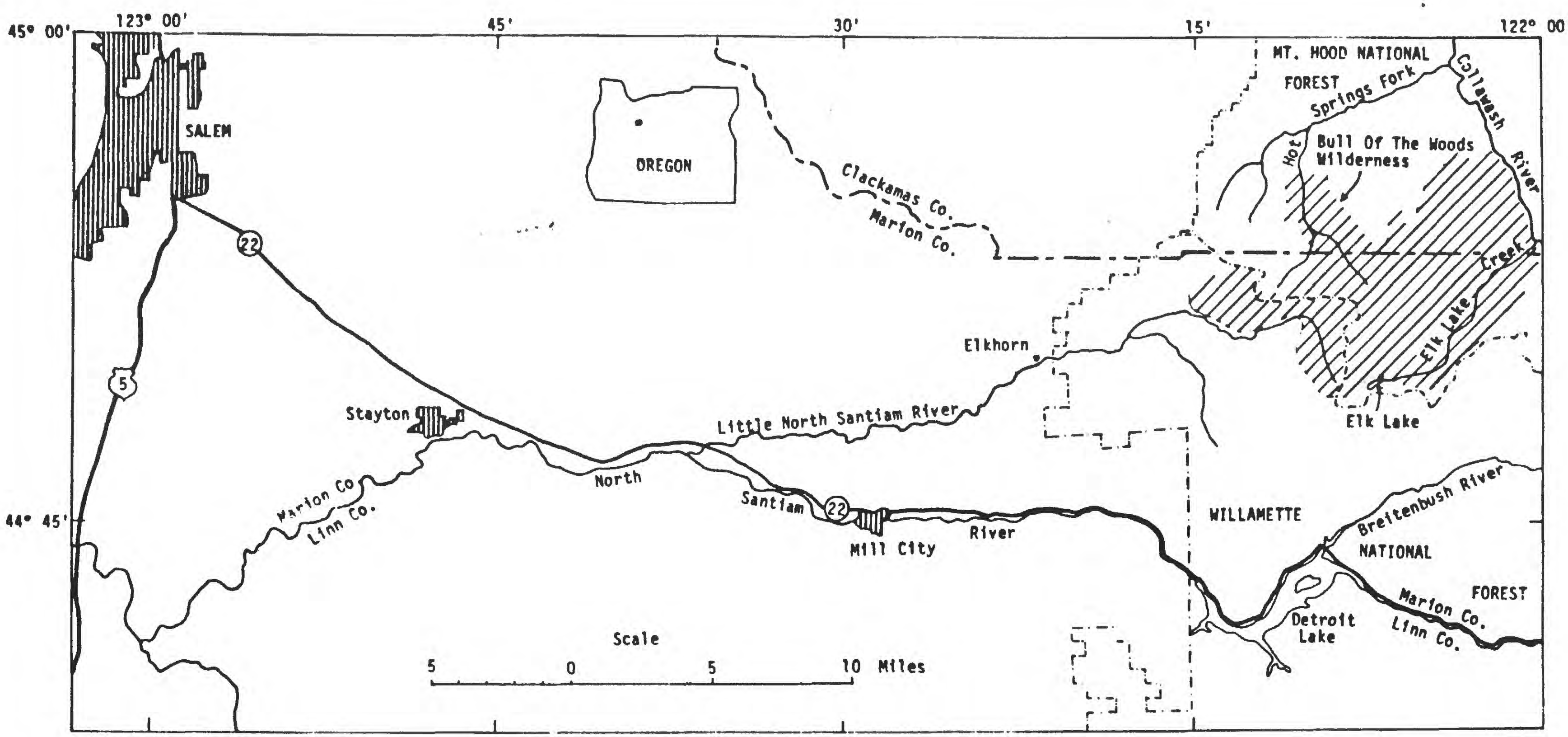


Figure 1.-- Index map showing location of the Bull of the Woods Wilderness, Oregon

Range in Oregon. It also was mapped in broad reconnaissance by Peck and others (1964) as part of a regional study of central and northern segments of the western Cascade Range. Part of the wilderness near Elk Lake was mapped by White (1980) as part of a doctoral dissertation on the geology and geochemistry of volcanic rocks of the Detroit area, western Cascade Range. Hammond and others (1980) prepared a "Guide to the geology of the upper Clackamas and North Santiam Rivers area, northern Oregon Cascade Range," which describes the geology of the wilderness area in general terms; subsequently a geologic map was prepared of the upper Clackamas and North Santiam Rivers area (Hammond and others, 1982). Regional gravity and aeromagnetic maps compiled by Couch and others (1978, 1981, 1982) include the wilderness area.

Ore deposits and metallic mineral occurrences in and adjacent to the wilderness have been studied and reported on by Callaghan and Buddington (1938) and the Oregon Department of Geology and Mineral Industries (1951); these studies have been summarized by Brooks and Ramp (1968). A recent detailed study of the geology and mineralization of the North Santiam mining district, which is contiguous with the wilderness on the southwest and west, was made by Olson (1978). Included in this detailed study are analyses for Ag, Cu, Mo, Pb, and Zn (Olson, 1978, appendix A) of a number of rock chips and stream sediments collected in the mining district.

Location and geography

The Bull of the Woods Wilderness is located in the western Cascade Range about 15 mi west of the Cascade crest and 45 mi east of Salem, Oreg. (fig. 1). The area, which is partly timber covered, consists of about 60 mi^2 including the drainage basins of Battle Ax and Gold Creeks, both tributary of the Little North Santiam River, and Elk Lake, Dickey, Pansy, Hugh, and Nohorn Creeks, and the Hot Springs Fork, all tributary of the Collawash River. Relief in the area is about 3,800 ft, ranging from a high point at Battle Ax (elev. 5,558 ft) to low points adjacent to the Collawash and Little North Santiam Rivers.

U.S. Forest Service primary and secondary log-haulage roads that connect to paved roads on the Breitenbush River, northeast of Detroit, Oreg., and on the Collawash River provide access to the south, east, and north margins of the Bull of the Woods Wilderness. A gravel-surfaced road from Elkhorn, Oreg., on the Little North Santiam River, provides limited access to the North Santiam mining district and to the western part of the wilderness.

A number of well-maintained trails provide access to the wilderness from Elk Lake, Bagby Hot Springs, and from the ends of several logging spur roads.

GEOLOGY

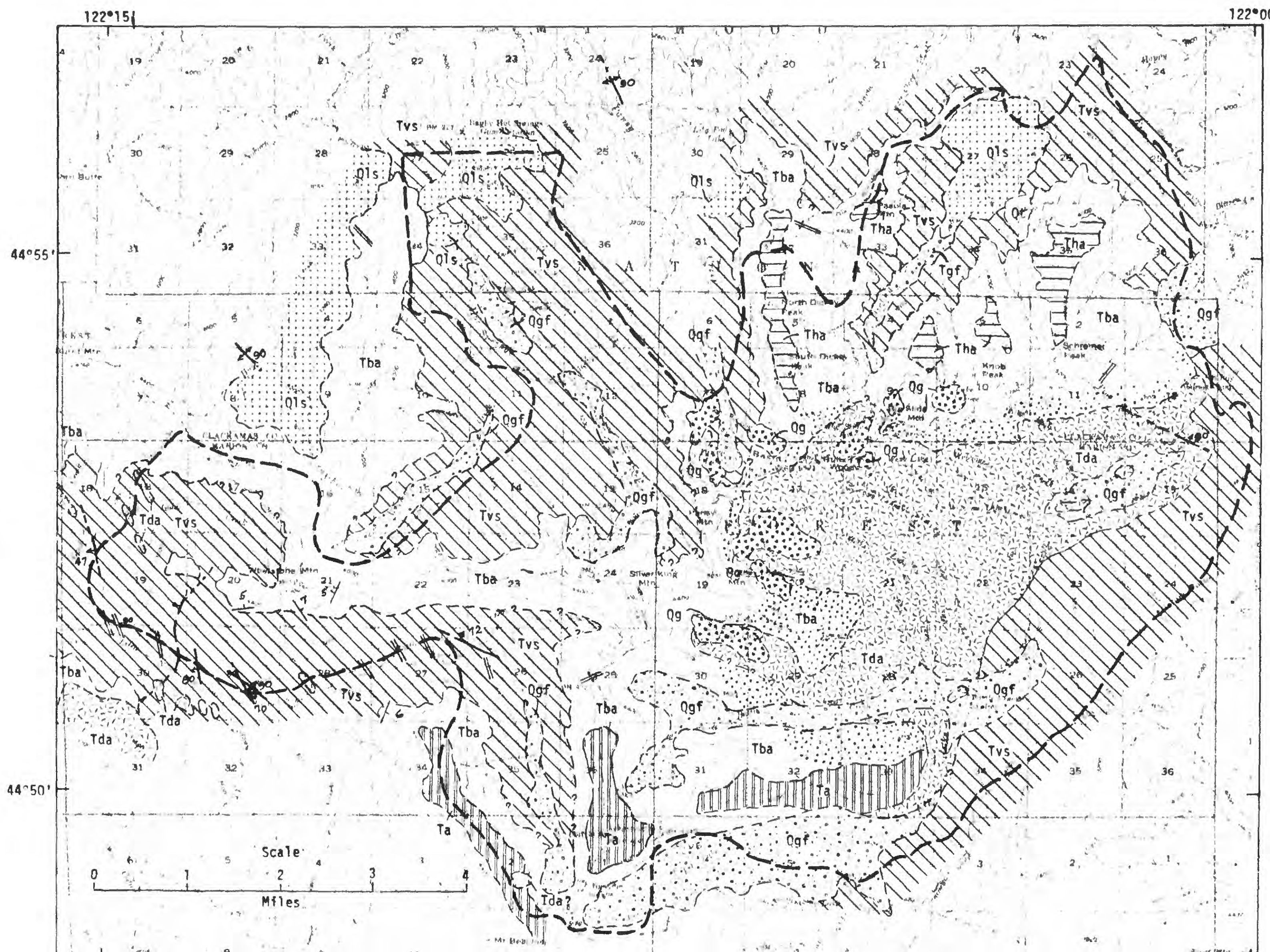
Rocks in and near the Bull of the Woods Wilderness are predominantly Oligocene to upper Miocene flows, breccia, and volcaniclastic deposits that represent part of a faulted and warped, generally monoclinal, sequence most commonly correlated with parts of the Little Butte Volcanics--heretofore named the Little Butte Volcanic Series (Peck and others, 1964)--, the Breitenbush Formation of Hammond and others (1982), or the Breitenbush tuff of Thayer (1939) and the Sardine Formation (Peck and others, 1964). These rocks have been intruded by medium- to small-sized bodies of diorite, quartz diorite, granodiorite, and related fine-grained commonly porphyritic dikes and plugs of andesite and basaltic andesite.

Stratigraphy

The stratigraphy and structures present in the area are characteristic of those found in the western Cascade Range of Oregon. The oldest rocks in the wilderness, of Oligocene and early Miocene age, consist of interlayered sequences of basaltic andesite and andesite flows and breccia, andesitic mudflows (lahars), bedded tuffaceous sedimentary rocks, palagonitic and pumiceous lapilli tuff, and, locally, dacitic or rhyodacitic ash-flow tuff, all commonly assigned to the Little Butte Volcanics or the Breitenbush Formation (fig. 2). In places along the walls of the canyon of Elk Lake Creek, this sequence is dominated by several ash-flow tuffs, and pumice lapilli tuffs. The older, more deeply buried parts of this sequence show evidence of low-grade regional metamorphism, where original constituents are partly altered to green and orange clay minerals (nontronite and saponite), zeolites (stilbite, laumontite, leonhardite, heulandite), secondary silica minerals, calcite, and chlorite. Throughout the region, where these layered rocks have been complexly intruded by small stocks, dikes, and plugs, they locally have been converted to hornfels; adjacent to intrusions they commonly have undergone intense and pervasive propylitic alteration and, in the North Santiam mining district along the southwest and west border of the area, they locally exhibit both phyllic and potassic alteration. The phyllic alteration is characterized by secondary clay minerals and sericite and the potassic alteration by secondary biotite and potassium feldspar.

Potassium-argon ages obtained on samples collected from this sequence short distances outside the wilderness range from about 25 to 13 m.y. (Fiebelkorn and others, 1983). The younger K-Ar dates may, in part, be reset ages that result from the extensive intrusive activity of middle to late Miocene time.

Unconformably(?) overlying the Oligocene and lower Miocene rocks is a sequence of basaltic andesite and andesite flows and breccia, as well as some epiclastic volcanic sedimentary rocks, of middle(?) Miocene age. Both aphyric and plagioclase-, pyroxene-, and hornblende-phyric basaltic andesites and andesites are represented. The epiclastic volcanic sedimentary rocks are composed mostly of the same lithologies as the flows and breccia. In areas north and northeast of Bull of the Woods, white to light buff-colored flows of hornblende andesite or mafic dacite cap ridges, as for example at North and South Dickey Peaks and Pasola Mountain. Many of the basaltic andesite and andesite flows are strongly flow jointed, and, in most places, are either fresh or only slightly altered; older parts of the sequence show the most alteration with vesicles and fractures containing secondary zeolites and calcite. Locally, fractures and flow joints are coated with hematite or secondary clay minerals. Rocks of the sequence occur high on ridges, in places representing caps for major divides between drainages. Invariably they have been assigned either to the Sardine Formation (Peck and others, 1964) or to several middle Miocene formations, including the Andesite of Nohorn Creek, Rhododendron Formation, and pyroxene andesite/diorite of Hammond and others (1982) and the Elk Lake Formation of McBirney and others (1974) and White (1980). Flows of the Andesite of Nohorn Creek have been dated at about 13 m.y., those of the Rhododendron Formation at 12 m.y. (Hammond and others,



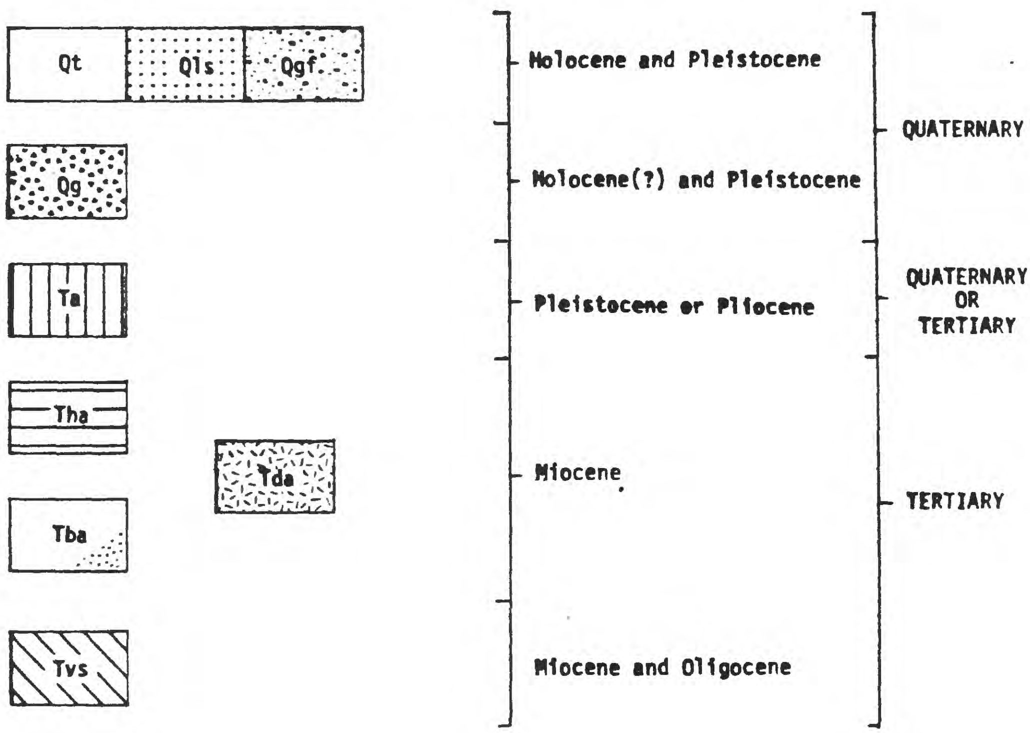
Base from U.S.G.S. topo series
1:62,500 Mill City (1955) and
Battle Ax (1956), Oregon

Geology by G. W. Walker
and N. S. MacLeod, 1984

Figure 2.-- Geologic map of the Bull of the Woods Wilderness, Marion and Clackamas Counties, Oregon

EXLPLANATION FOR FIGURE 2

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qt TALUS (HOLOCENE)--Composed of blocks of andesite or basaltic andesite and andesitic clastics

Qls LANDSLIDE DEPOSITS (HOLOCENE AND PLEISTOCENE)--Unstratified mixtures of tuffs, tuffaceous sedimentary rocks, and intermediate to mafic flow rocks. Occurs mostly in areas where thick sections of flows rest on altered and incompetent fine- to medium-grained clastic rocks

Qgf GLACIO-FLUVIAL DEPOSITS (HOLOCENE AND PLEISTOCENE)--Composed of poorly sorted, angular to subrounded blocks of andesite and dioritic bedrocks, rock flour, and coarse mineral grains derived largely from glacial till. Locally shows some sorting and poorly developed bedding as a result of reworking by streams. Occurs along present day and paleo stream channels

Qg GLACIAL DEPOSITS (HOLOCENE(?) AND PLEISTOCENE)--Unsorted angular blocks mixed with some rock flour. Derived from basaltic andesite, andesite, andesitic volcaniclastic rocks, and dioritic intrusive rocks. Occurs mostly in and adjacent to cirques

Ta BASALTIC ANDESITE AND ANDESITE (PLEISTOCENE OR PLIOCENE)--Plagioclase-phyric basaltic andesite and andesite flows and flow breccia commonly containing fresh or slightly altered olivine and, in places, both hypersthene and augite. K-Ar ages range from 1.24±0.53 to 1.88±0.50 m.y. (Sutter, 1978); may be older inasmuch as dated samples contain high proportion of atmospheric argon and degree of erosion is similar to that of flows and breccia in nearby areas isotopically dated at 3-4 m.y.

Tha HORNBLENDE ANDESITE (MIOCENE)--Flows of white to buff, hornblende- and plagioclase-phyric andesite or mafic dacite that caps ridges north of Bull of the Woods and Schreiner Peak

Tda DIORITE, QUARTZ DIORITE (TONALITE), GRANODIORITE, AND BASALTIC ANDESITE (MIOCENE)--Hypabyssal stocks, altered large dikes, and circular to elliptical plugs. The diorite, quartz diorite, and granodiorite are commonly porphyritic and contain phenocrysts of plagioclase and hornblende; some plagioclase is saussuritized and hornblende is commonly pseudomorphed by chlorite, epidote, and magnetite. Includes near-surface basaltic andesite intrusions that are either aphyric or plagioclase- pyroxene-phyric. Most intrusive rocks, as well as adjoining wallrocks, are propylitized and locally exhibit phyllic and potassic alteration, although parts of some intrusions are relatively unaltered. In roof zones of larger intrusions altered wall rocks occur as screens between plexus of small intrusive dikes and sills and can rarely be distinguished from intrusions. Zones within unit, mostly northwest trending, contain abundant fine-grained pyrite, locally chalcopyrite, some quartz veinlets, and minor amounts of other metallic sulfide minerals. Pyritic zones locally weathered to thin and weakly developed iron and manganese-stained gossans. Age probably mostly middle Miocene as determined by K-Ar dates of 13.4±0.9 on "fresh" granodiorite (Power and others, 1981a, p. 27) and 11.0±0.4 on altered quartz diorite from mineralized tourmaline breccia pipe (Power and others 1981b, p. 3), both samples collected in the North Santiam mining district less than 1 mile from the southwest border of the Wilderness

Tba BASALTIC ANDESITE AND ANDESITE (MIOCENE)--Aphyric and plagioclase- and pyroxene-phyric basaltic andesite and andesite flows and flow breccia. Locally includes andesitic volcaniclastic and mudflow (Lahar) deposits and, in a few places, bedded epiclastic sedimentary rocks. Some flows exhibit well-developed platy flow jointing, with joint surfaces commonly coated with a red iron oxide mineral (hematite?). Coarse stipple pattern indicates areas where unit is complexly invaded by dikes and sills of andesite and microdiorite and both wall rock and intrusions are intensely altered; commonly indistinguishable from altered fine-grained facies of the intrusions. Several potassium-argon ages of this unit from localities both within and a short distance outside the Wilderness range from 11.2±0.8 to 16.5±1.0 m.y. (Laursen and Hammond, 1978; Sutter, 1978; Fiebelkorn and others, 1983), indicating that it is probably mostly middle Miocene in age. Mapped as Sardine Formation by Peck and others (1964); unit includes part of "Andesite of Nohorn Creek," Rhododendron Formation, and "Pyroxene/andesite/diorite" of the "Bull-of-the-Woods complex" of Hammond and others (1982). Andesite of the Rhododendron Formation dated at about 12 m.y. (Hammond and others, 1980)

Tvs VOLCANIC AND SEDIMENTARY ROCKS (MIOCENE AND OLIGOCENE)--Dacitic or rhyodacitic ash-flow tuff, pumice lapilli tuff, palagonite tuff, and tuffaceous sedimentary rocks interlayered with flows, flow breccia, and mudflows (lahars) of basaltic andesite and andesite. Regional metamorphism has converted some of the primary constituent minerals and glass to a host of secondary minerals, including calcite, zeolites (laumontite, leonhardite, stilbite, and heulandite), unidentified clay minerals, and secondary silica minerals. Rocks of this unit were locally converted to hornfels or extensively propylitized adjacent to hypabyssal intrusions of diorite, quartz diorite, granodiorite, and andesite; in places, unit shows evidence of phyllic and potassic alteration and, locally, pervasive silicification. Where intensely altered, commonly indistinguishable from altered fine-grained marginal facies of the intrusive rocks. Includes some rocks originally mapped by Peck and others (1964) as Sardine Formation; represents part of the Breitenbush Formation of Hammond and others (1982)

CONTACT--Dashed where approximately located; queried where uncertain

FAULT--Dashed where approximately located. Arrow shows direction and amount of dip. Bar and ball on downthrown side

VERTICAL FAULT

STRIKE AND DIP OF LAYERED ROCKS

DIKE

STRIKE AND DIP OF INCLINED DIKE

STRIKE AND DIP OF VERTICAL DIKE

(Dike, inclined dike, vertical dike:) Composed of basaltic andesite, andesite, hornblende dacite, and rhyodacite; mostly middle Miocene

PROSPECT OR SMALL MINE

MINE ADIT

APPROXIMATE BOUNDARY OF WILDERNESS

1982; Fiebelkorn and others, 1983), and those of the Elk Lake Formation of McBirney and others (1974) at about 11 m.y. (Sutter, 1978; Fiebelkorn and others, 1983).

Intrusive rocks

Intrusive rocks of dioritic, granodioritic, andesitic, and rhyolitic composition are present in several parts of the wilderness and in areas adjacent on the west. The largest of these intrusive bodies is in the eastern part of the area and is exposed principally along and north of Elk Lake Creek. In some areas the intrusive rocks and wall rocks are complexly intermingled, altered, and poorly exposed, particularly in the roof zone of the intrusive bodies, shown by coarse stipple pattern on figure 2.

Small near-surface intrusions of hornblende diorite, hornblende quartz diorite (tonalite), granodiorite, and andesite cut the Oligocene and lower Miocene volcanic and sedimentary rocks both within and marginal to the wilderness (fig. 2). The intrusive rocks are commonly porphyritic, with phenocrysts of hornblende and andesine or sodic labradorite set in a medium- to finely-crystalline groundmass. Most of the hornblende is in subhedral crystals and is almost invariably altered to biotite, chlorite, and other unidentified alteration products. Potassium-argon dates on separate intrusions in the North Santiam mining district, exposed a mile or less south of the wilderness, indicate a middle Miocene age. One age on "fresh" granodiorite is 13.4±0.9 m.y. and another on altered quartz diorite is 11.0±0.4 m.y. (Power and others, 1981a, 1981b). These ages are similar to ages obtained on several other intrusive bodies in nearby parts of the western Cascade Range, as for example 9.94±0.18 m.y. on the diorite at Detroit dam (Sutter, 1978; Fiebelkorn and others, 1983) and 13.4±1.2 m.y. for quartz diorite at Gold Hill in the Blue River mining district (Power and others, 1981a). Presumably, the large intrusion on Elk Lake Creek, which is undated, is essentially coeval with these other dated intrusives.

Fine-grained facies of the intrusions, mostly in the form of dikes, sills, and plugs, complexly intermingled with altered wall rocks form an irregular and ill-defined roof zone above larger intrusive bodies. Within these zones, the altered intrusions and wall rocks are indistinguishable. Some of the intrusion are steeply inclined sheetlike bodies with a northwest trend, which is characteristic of trends of similar bodies within the entire region, whereas others are nearly equidimensional in plan. Within the adjacent North Santiam mining district localized areas of potassic alteration defined by secondary biotite and orthoclase, also have been recognized (Olson, 1978).

Some andesite or basaltic andesite dikes fed the Oligocene and lower Miocene flows and breccia, but mostly the dikes were the feeders for the middle Miocene basaltic andesite and andesite flows. The older dikes are propylitized and altered, much like the diorite and quartz diorite, but some younger andesite dikes are comparatively fresh and appear to postdate the period of propylitic and phyllic alteration.

The intrusions and locally the wall rocks are extensively and widely impregnated with pyrite, commonly in and adjacent to small shear zones and larger, through-going joints. In a few places the shear zones, as well as irregular small areas of brecciated rock, are mineralized with quartz, pyrite, sericite, and several copper sulfide minerals. Subsequent movement along the shear zones has brecciated the mineralized rock.

The propylitized and pyritized rocks are locally oxidized to form weakly developed and mostly thin gossans. In this deeply dissected region, rapid erosion has prevented the development of extensive and thick gossans and related supergene concentrations of metals.

Unconsolidated deposits

Surficial deposits include glacial till in and adjacent to cirques in higher parts of the wilderness and plastered on canyon walls, as well as extensive glacio-fluvial deposits along present day and paleo-stream channels. The glacio-fluvial deposits were derived both from the reworking of glacial deposits and stream erosion of bedrock. Extensive landslide deposits occur principally in areas where thick and massive sequences of andesite and basaltic andesite flows rest on incompetent beds of altered pumice lapilli tuffs and tuffaceous sedimentary rocks. The landslides are both Pleistocene and Holocene in age; a few landslides are presently active.

Breccia pipes

Olson (1978) recognized several tourmaline-bearing breccia pipes in the North Santiam mining district characterized by angular, highly altered clasts cemented by quartz, sericite, magnetite, specular hematite, sulfide minerals, rarely carbonate minerals, and, locally, potassium feldspar. Host rocks for the pipes include porphyritic andesite flows and, in places, intrusive quartz monzonite and microdiorite. Most of the pipes are elliptical in plan with the long axis of each pipe oriented northwest, generally parallel with other northwest structural trends of the area. One of the larger breccia pipes, that is reported to contain several million tons of highly mineralized rock, is currently being explored by vertical drill holes. The pipe is located south of the Little North Santiam River adjacent to Cedar Creek. Parts of the pipe are pervasively mineralized with copper sulfides (covellite, bornite, chalcopyrite) and pyrite; mineralized parts of the pipe also are reported to contain significant amounts of gold, silver, and molybdenum.

Brecciated and altered rocks at the Mother Lode Group on Mother Lode Creek (fig. 7) may represent surface manifestations of a buried pipe-like body within the Bull of the Woods Wilderness. Altered clasts of diorite(?) are cemented with vuggy quartz, minor sericite, an unidentified clay mineral, pyrite, specular hematite, chalcopyrite, and minor bornite and covellite(?). In surface outcrop some of the cementing material consists of secondary hydrated iron oxide and copper sulfate, carbonate, and silicate minerals. This may represent the surface expression of a poorly exposed breccia pipe or it may be simply mineralized breccia along closely spaced shears. Other than this occurrence, no other potential breccia pipes were recognized within the wilderness.

INTERPRETATION OF AEROMAGNETIC DATA

By Richard J. Blakely

Introduction

The Bull of the Woods Wilderness lies within a terrane of young, relatively unmetamorphosed volcanic rocks that commonly have high magnetic susceptibilities and high remanent magnetizations. Hence, the topographic relief of the Bull of the Woods Wilderness should produce significant anomalies in an aeromagnetic survey, an effect that tends to obscure anomalies caused by deeper magnetic sources (Blakely and others, 1985). An interpretation of aeromagnetic data over volcanic terrane must account for this topographic effect. On the other hand, a lack of correlation between topographic features and observed magnetic anomalies also provides information about the magnetization of near-surface rocks. The absence of an anomaly over a ridge of volcanic rocks, for example, indicates negligible magnetizations for those rocks and may indicate alteration of the magnetic minerals to less magnetic phases. In the following interpretation of aeromagnetic data over the Bull of the Woods Wilderness, I have attempted to determine the topographic effect in order to learn about the magnetic properties of rocks that compose the topographic features of the area and about buried sources.

Analysis

The aeromagnetic data (fig. 3) were collected in 1982 by Oregon State University along east-west flightlines spaced 1 mi apart and along north-south flightlines spaced 5 mi apart. The survey was flown at 7,000 ft constant barometric altitude. Aircraft locations were determined by a ground-based transponder navigation system, and a synchronously operated ground magnetometer was used to correct for diurnal variations and to monitor magnetic storm activity. The International Geomagnetic Reference Field, updated to the date of the survey, was subtracted from the data. Residual anomalies were interpolated to a rectangular grid with grid intersections spaced 0.31 mi apart using standard techniques. These gridded data were then machine-contoured to produce the map shown in figure 3.

Two procedures were implemented to help analyze these data. The first (Blakely and Simpson, 1985) uses the pseudogravity transform of the aeromagnetic data to automatically identify significant apparent magnetic boundaries. These boundaries may reflect edges of buried magnetic sources or abrupt lateral contrasts in magnetization. Figure 4 shows the results of the boundary analysis applied to the aeromagnetic data of figure 3. Sinuous sequences of dots in figure 4 represent apparent magnetic boundaries. It should be noted that topographic features in magnetic terrane also have abrupt magnetic boundaries (with air) and figure 4 should be interpreted with caution.

The second procedure (Blakely and Grauch, 1983) estimates the topographic effect. We first assume a very simple geologic model: The top of the magnetic source corresponds to the topography, the bottom of the source is flat and horizontal, and the magnetization has uniform direction and intensity. Anomalies calculated from this model were compared visually to the observed anomalies in figure 3 in order to assess the topographic effect. For

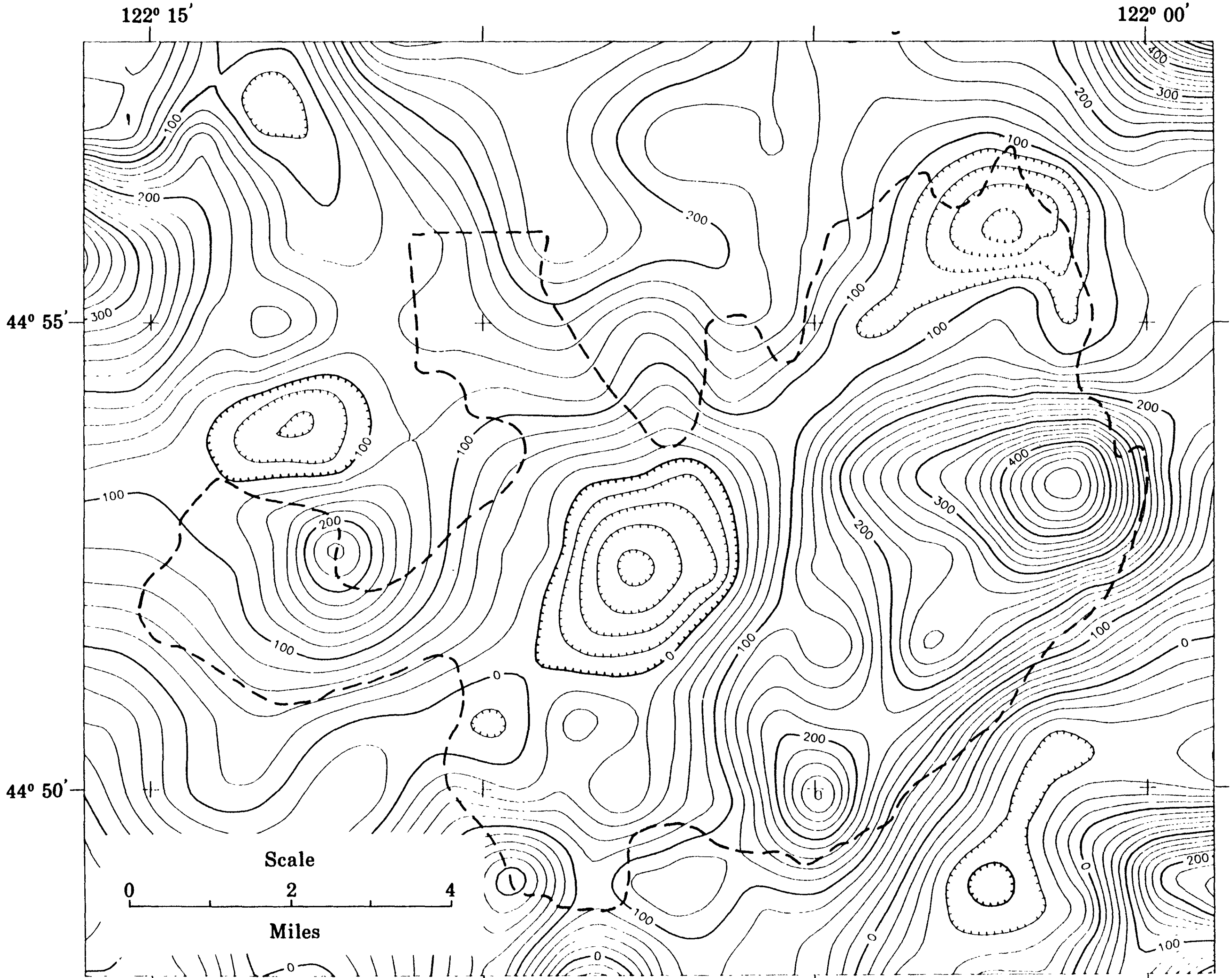


Figure 3.--Aeromagnetic data over the Bull of the Woods Wilderness and surrounding areas. Contours represent intensity of total field anomaly. Contour interval 20 nT. Hachures indicate closed minima. Dashed line indicates approximate Wilderness boundary.

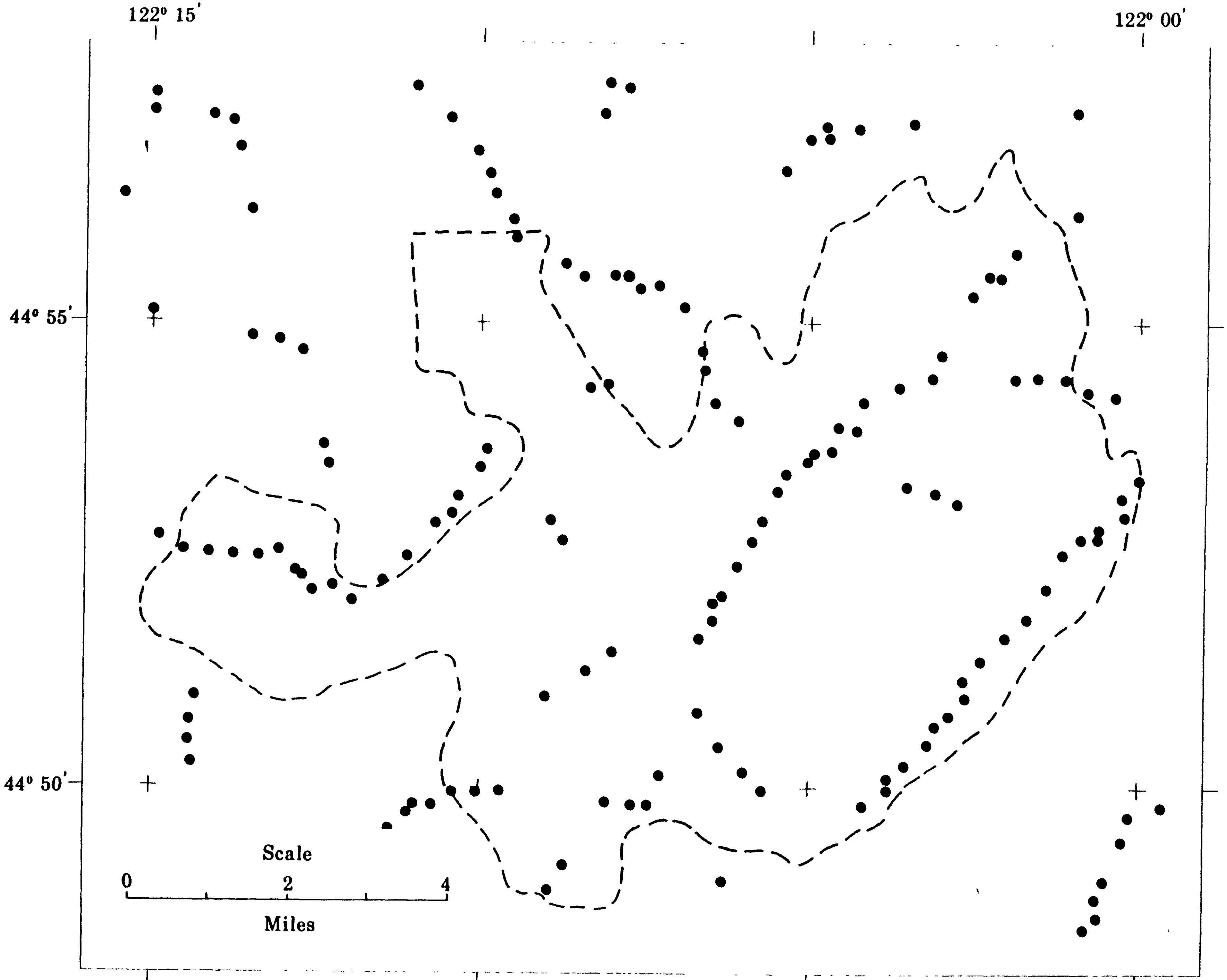


Figure 4.--Results of gradient analysis applied to the aeromagnetic data over the Bull of the Woods Wilderness. Dots represent location of maximum horizontal gradients of pseudogravity anomalies calculated from the aerogmanetic data. Sinuous sequences of dots indicate significant apparent magnetic boundaries (Blakely and Simpson, 1985). Dashed line indicates approximate Wilderness boundary.

example, if the model predicts a positive magnetic anomaly over a ridge and a corresponding anomaly (either positive or negative) is not present in the observed data, we conclude that the ridge is composed of relatively nonmagnetic material.

Interpretation

An interesting regional aspect of the aeromagnetic data in figure 3 is a magnetic trough that extends NE-SW diagonally across the entire area, from the Collawash drainage in the northeast to the Cedar Creek drainage in the southwest. The source of the regional anomaly must be deeper than topographic lows of the area because the anomaly trends across major topographic features, including Silver King Mountain and Bull of the Woods, and across geologic contacts. It may reflect a structural feature beneath this part of the Cascade Range. Alternatively, the magnetic trough and the lack of magnetic topographic expression in this area may result from a metamorphic aureole surrounding the intrusion of diorite and quartz diorite, southeast of the trough.

Figure 5 shows an interpretation of more local features of the aeromagnetic data. Apparent magnetic boundaries are shown by solid lines. Some of these boundaries are a result of major topographic features. The boundary just north of Whetstone Mountain, for example, probably reflects the northern slope of the ridge. Many of the boundaries, however, show no obvious relationship to topography. Perhaps the most interesting of these is the boundary which encloses most of area A (fig. 5) and includes the largest amplitude anomaly of the entire region. The magnetic boundary approximately corresponds to the mapped extent of the intrusion of diorite, quartz diorite, granodiorite, and basaltic andesite in the southeast part of the Wilderness. The southeastern part of the magnetic boundary is displaced to the southeast of the mapped contact between the intrusion and older volcanic and sedimentary rocks. Similarly, the northern part of the magnetic boundary extends roughly 1 mi beyond the mapped contact between the intrusion and older basaltic andesite and andesite flows and flow breccia. These discrepancies between the mapped extent of the intrusion and its magnetic boundaries may indicate the subsurface extent of the intrusion. To the northwest, the magnetic boundary lies roughly 0.5 mi southeast of the intrusion's contact with adjacent roof rocks. Apparently, the zone between the magnetic boundary and the roof rocks is relatively nonmagnetic, perhaps due to alteration of magnetic minerals within the roof zone of the intrusion.

Several major anomalies unrelated to high topographic relief appear in the observed data (fig. 3 and fig. 5). Area A comprises the southeastern portion of the largest amplitude anomaly of the entire map. Although area A spans the contact between the intrusive rocks and older volcanic and sedimentary rocks, the boundary analysis discussed above suggests that this anomaly may be caused primarily by the intrusion. Area A may reflect exceptionally high concentrations of magnetic minerals within this part of the intrusion.

Area B is an anomaly over volcanic and sedimentary rocks. It may be a consequence of relatively high concentrations of magnetite in these shallow rocks or of other magnetic rocks buried at relatively shallow depth. The wide

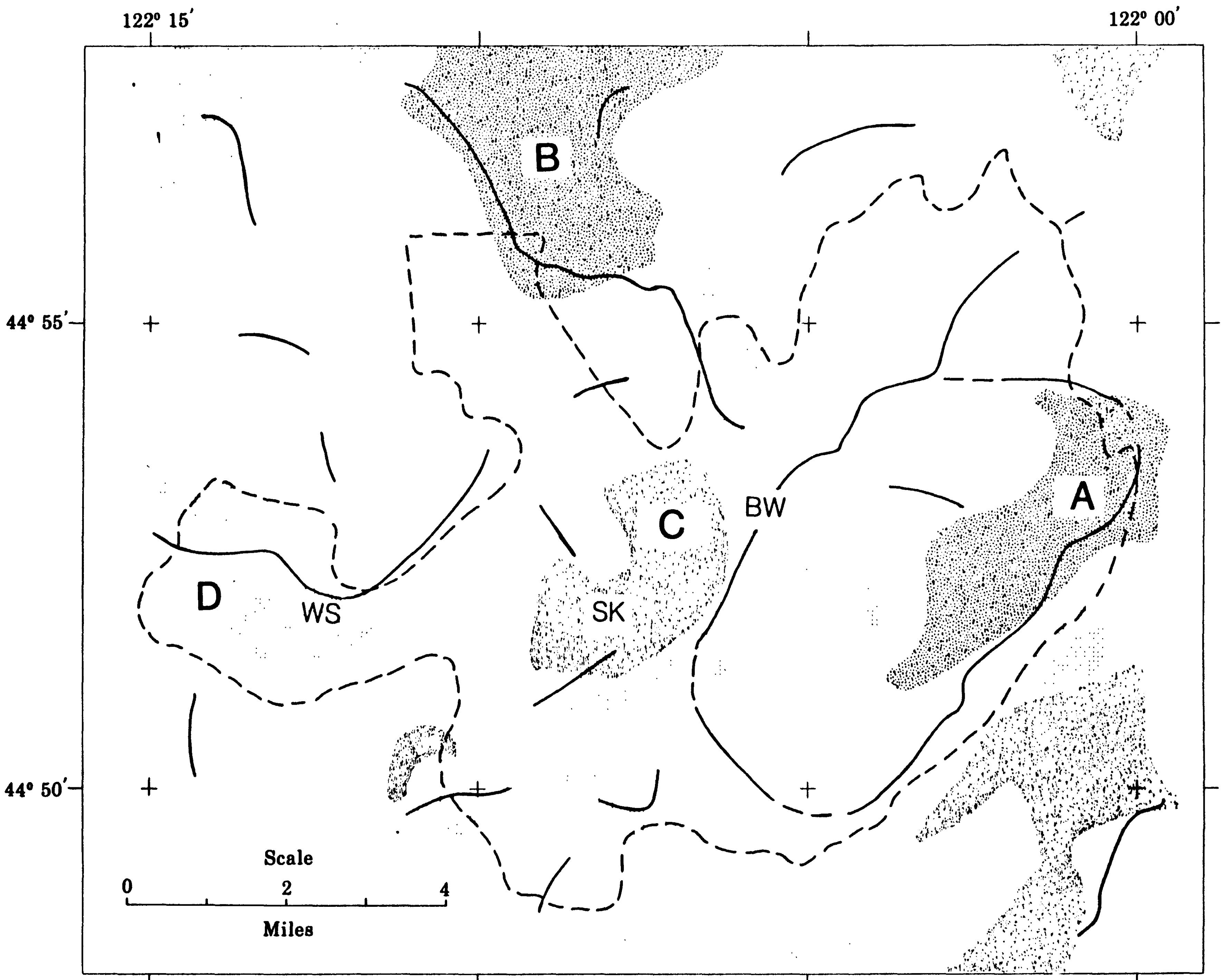


Figure 5.--Interpretation of aeromagnetic data over the Bull of the Woods Wilderness. See legend for explanation of symbols. Dashed line indicates approximate Wilderness boundary. WS = Whetstone Mountain, SK = Silver King Mountains, BW = Bull of the Woods.

EXPLANATION

Magnetic boundaries

Areas of positive magnetic anomalies not related to topography

Areas of negative magnetic anomalies not related to topography

Areas of nonmagnetic topographic relief

gradients of this anomaly and the lack of magnetic topographic expression favors the latter explanation.

Area C is a major negative anomaly. Because it lies over a ridge which includes Silver King Mountain and Pansy Mountain, it is tempting to conclude that the ridge is dominantly magnetized in a reversed direction. The anomaly's shape, however, indicates a deeper and more pervasive source, perhaps a buried, relatively nonmagnetic intrusion.

Figure 5 also indicates parts of topographic ridges that produce negligible magnetic anomalies. These areas include North Dickey Peak, Bull of the Woods, Battle Ax, Whetstone Mountain, and Gold Butte. Area D (fig. 5), for example, includes Whetstone Mountain, a 4969-ft ridge composed of Miocene volcanic material. The topographic effect of Whetstone Mountain should be apparent in figure 3; the absence of an anomaly indicates that the materials composing Whetstone Mountain have low magnetizations in this area compared to other parts of the Wilderness. In most cases, these areas correspond to basaltic andesite and andesite flows and breccias that cap many of the ridges in the area. Apparently, these rocks are relatively nonmagnetic. In the neighborhood of Bull of the Woods, nonmagnetic topography lies within mapped exposures of the intrusion and may be a consequence of alteration of near-surface rocks.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

Although there is no record of production of minerals from the Bull of the Woods Wilderness, small quantities of base and precious metals have been produced from mines in the adjacent North Santiam mining district (Callaghan and Buddington, 1938; Brooks and Ramp, 1968) and some placer gold has been recovered from stream gravels in and adjacent to the district. Several small prospects, presumably located for gold values, are present along the southern margin of the wilderness, about 2 mi east of Elk Lake. Within the wilderness several small prospects, one west of Mother Lode Creek and the other near Pansy Lake, apparently were located for both copper and precious metals. The North Santiam mining districts, originally located about 1877, has a total recorded production (Brooks and Ramp, 1968) for the period 1896 to 1947 of: gold, 454 oz.; silver, 1,412 oz.; copper, 41,172 lb.; lead, 40,700 lb.; and zinc, 110,063 lb., estimated to have a total value in current (1985) dollars of approximately $200,000. Placer gold production apparently is not included in establishing these figures.

Renewed interest in the district in the past decade led to several exploration programs, including geochemical sampling and extensive drilling by large mining interests. Most recent drilling has been directed toward exploring a large, mineralized breccia pipe located adjacent to Cedar Creek, a little more than a mile southwest of the wilderness boundary.

Ore deposits of the North Santiam district are principally associated with veins and brecciated shear zones that contain pyrite, sphalerite, chalcopyrite, galena, minor tetrahedrite, and, in oxidized parts of deposits, some free gold. The veins and breccia zones cut small intrusive bodies of Miocene diorite, quartz diorite, granodiorite, rhyolite, as well as the altered Oligocene and Miocene volcanic and volcanoclastic wallrocks, which are mostly of andesitic to rhyolitic composition. Extensive mineralization also has been recognized in near-vertical, elliptical breccia pipes, commonly with their long axes parallel to the northwest-trending shears and elongate intrusive bodies. Olson (1978) reports that the pipes contain covellite, bornite, chalcopyrite, pyrite, and on the basis of analyses, significant amounts of gold, silver, and molybdenum. In addition to the sulfide ore minerals, the veins and pipes contain secondary copper and iron oxide minerals and different amounts of chlorite, clay minerals, sericite, calcite, quartz, specular hematite, and locally, secondary potassium feldspar.

Available assay data (Oregon Department of Geology and Mineral Industries, 1951; Brooks and Ramp, 1968) suggests that the distribution of metals in the more highly mineralized zones is erratic. Gold values are generally low, mostly well below 0.05 oz per short ton, and silver values are from less than an ounce per ton to 3 or 4 oz per ton. Most properties in the North Santiam district for which assay data are available are reported to contain only traces of gold. Assays for copper, lead, and zinc also are erratic, but values of several percent are common for each of these metals in more highly mineralized parts of vein systems.

Panned concentrates from stream-sediment localities (fig. 6) are composed almost entirely of common rock-forming minerals, principally magnetite, pyroxene, olivine, hornblende, hypersthene, and zircon(?); no metallic sulfide minerals or free gold were recognized in the concentrates. Some reddish-gray grains in the panned concentrates are probably hematite. Several panned concentrates show anomalous amounts of silver, lead, copper, zinc, and several other metallic elements (table 1). Samples obtained downstream from known mines in the North Santiam district and in the central part of the wilderness about 1 mi south of prospects at the Mother Lode Group (fig. 7) are especially anomalous in silver, lead, zinc, molybdenum, and questionably in bismuth and tin. Gold values of most panned concentrates are near the limit of detection (0.05 ppm), using atomic-absorption analytical methods. Several panned concentrates contained highly anomalous amounts of silver. One sample (001C, table 1), from near the confluence of Gold Creek and the Little North Santiam River a short way below the site of an old concentration mill at the Santiam Copper mine, contains more than 10,000 ppm silver and another sample (010C, table 1) collected near the confluence of Battle and Elk Lake Creeks, south of the Mother Lode Group, also contains more than 10,000 ppm silver. Presumably these high silver values are the result of a few grains of some unidentified sulfide mineral, possibly argentiferous tetrahedrite, in a very small volume of panned concentrate, implying a high concentration factor during panning.

Analyses of stream-sediment and rock samples collected from areas within and immediately adjacent to the wilderness (fig. 6; table 1) indicate the presence of anomalous amounts of copper, lead, zinc, gold, silver, mercury, and several other metallic elements. The local concentration of these metals is characteristic of many highly mineralized mining districts, although the analyses also indicate highly erratic distribution of the metals and a lack of consistently high values in any large structures or of local geologic environments that would signify large tonnages of heavily mineralized rock. The highest gold values were obtained from stream sediment samples collected near the confluence of Gold Creek and the Little North Santiam River; one sample contained 1.2 ppm and another 1.3 ppm gold (table 1), or about 0.04 oz per short ton. Rock samples (R85 and R101, table 1) were collected from small dumps adjacent to prospect pits at the Mother Lode Group, centrally located in

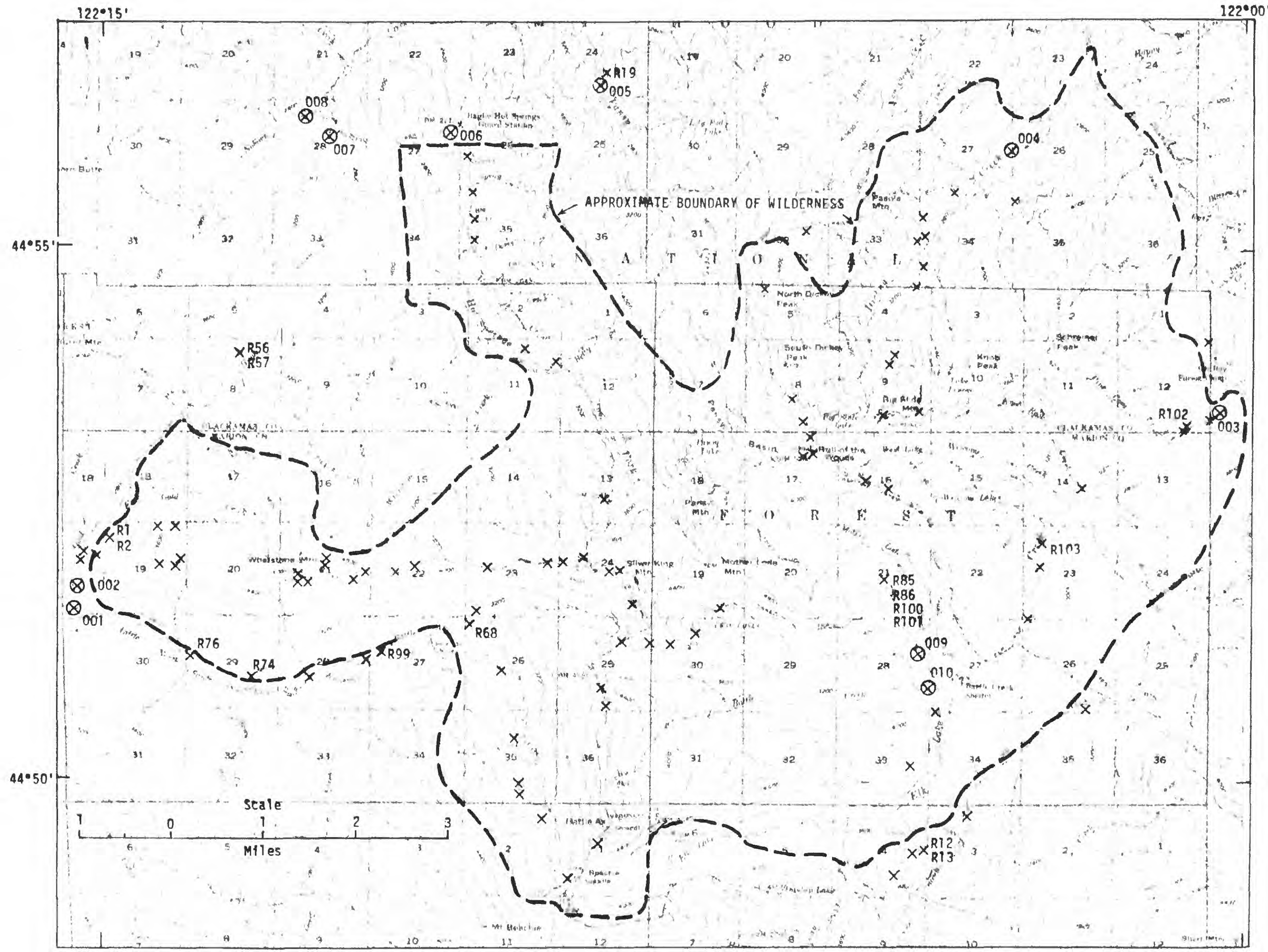


Figure 3.--Index to sample localities. ×, unmineralized rock sample; $\times_{R1}$, mineralized rock sample; $\otimes_{001}$, stream-sediment sample.

Table 1.--Analyses of samples from the Bull of the Woods Wilderness, Oregon[1]

[AA, atomic absorption; ppm, parts per million; numbers in parentheses indicate sensitivity limit of method used; N, not detected at limit of detection; L, indicates detected, but below limit of determination; G, indicates greater than value shown. Analysts: M. S. Erickson; T. A. Roemer]

	Semiquantitative spectrographic analyses (6-step)													
	Percent				(ppm)									
	Fe	Mg	Ca	Ti	Mn	Ag	As	B	Ba	Be	Bi	Cd	Co	Cr
Locality number[2]	(0.05)	(0.02)	(0.05)	(0.002)	(10)	(0.5)	(200)	(10)	(20)	(1)	(10)	(20)	(5)	(10)
R1	10	2	L	0.7	500	.5	N	50	700	N	15	N	20	70
R2	2	2	L	.3	700	N	N	50	500	L	N	N	5	20
R12	2	1	G(20)	.1	700	N	N	L	200	N	N	N	N	50
R13	5	.7	.1	.3	500	15	N	30	700	L	N	N	N	L
R19	1.5	.3	.7	.15	100	N	N	20	700	1	N	N	N	N
R56	3	.7	.3	.5	10	N	N	30	700	N	N	N	N	L
R57	7	1.5	3	.5	300	N	N	10	500	L	N	N	5	20
R68	2	.15	L	.07	100	1.5	N	15	150	N	N	N	5	N
R74	5	.15	L	.15	200	200	L	20	500	N	20	N	N	N
R76	7	2	.2	.5	70	N	N	500	200	N	N	N	15	150
R85	5	.7	L	.2	1,000	50	N	150	300	N	N	N	20	20
R86	5	.7	.07	.15	700	.7	N	G(2,000)	100	N	N	N	15	10
R99	10	3	15	.2	G(5,000)	2	N	20	L	1	N	300	70	15
R100	3	.15	.05	.002	300	20	N	20	N	N	N	N	N	N
R101	15	.03	L	L	100	200	N	30	20	N	50	N	N	N
R102	10	1.5	1.5	1	500	N	N	100	1,000	1	N	N	30	15
R103	7	5	1.5	.3	700	N	N	15	200	L	N	N	30	100
001S	15	3	2	G(1)	1,000	.7	N	50	300	N	N	N	50	200
002S	15	3	3	1	1,000	2	N	50	500	N	N	N	50	100
003S	10	3	3	1	700	N	N	50	300	N	N	N	30	100
004S	10	2	3	1	1,000	N	N	20	300	1	N	N	20	50
005S	10	3	5	1	1,000	N	N	10	300	N	N	N	30	100
006S	20	5	5	G(1)	1,500	N	N	30	200	N	N	N	50	150
007S	15	3	3	1	1,000	N	N	10	300	N	N	N	50	150
008S	15	5	3	1	1,000	N	N	L	200	N	N	N	50	200
009S	10	2	5	.7	1,000	N	N	150	500	L	N	N	30	50
010S	15	3	7	G(1)	1,500	.5	N	100	300	N	N	N	50	100
	(0.1)	(0.05)	(0.1)	(0.005)	(20)[3]	(1)	(500)	(20)	(50)	(2)	(20)	(50)	(10)	(20)
001C	50	.07	3	2	70	G(10,000)	N	50	300	N	G(2,000)	200	200	20
002C	1	.2	5	G(2)	300	2,000	N	20	700	N	G(2,000)	150	L	200
003C	1	.2	2	G(2)	100	700	N	50	1,000	N	200	70	N	50
004C	.7	.15	10	.7	200	15	N	20	G(10,000)	N	50	N	N	L
005C	5	.2	7	.7	70	L	N	20	10,000	N	N	N	L	L
006C	1	.2	10	.5	50	L	N	L	3,000	N	N	N	N	N
007C	1	.1	7	.07	50	L	N	L	200	N	N	N	N	N
008C	1	.3	5	.2	70	L	N	L	10,000	N	N	N	L	N
009C	2	.2	3	G(2)	150	300	N	500	2,000	N	30	150	N	50
010C	.5	.2	2	G(2)	200	G(10,000)	N	700	150	N	N	1,000	10	100

[1]Looked for but not detected: La, Th.

[2]Locality number preceded by R represents mineralized rock specimen; a number followed by S represents a stream-sediment sample that passes through a 1/8-in. sieve; a number followed by C is heavy-mineral concentrate of stream-sediment sample, with magnetic fraction removed.

[3]Sensitivity for some elements on panned concentrates is less than that for stream sediments or rock samples.

Table 1.—Continued

Locality number[2]	Semiquantitative spectrographic analyses (6-step)—Continued (ppm)													
	Cu (5)	Mo (5)	Nb (20)	Ni (5)	Pb (10)	Sb (100)	Sc (5)	Sn (10)	Sr (100)	V (10)	W (50)	Y (10)	Zn (200)	Zr (10)
R1	150	50	N	30	50	N	20	N	N	150	N	15	N	150
R2	15	20	N	50	N	N	10	N	N	100	N	20	200	150
R12	20	20	N	7	N	N	7	N	150	100	N	20	N	N
R13	20	15	N	7	20	N	10	N	100	100	N	20	N	150
R19	L	N	N	10	10	N	L	N	150	L	N	10	N	150
R56	20	15	N	5	20	N	15	N	200	150	N	L	N	100
R57	30	L	N	15	10	N	20	N	1,000	200	N	15	N	150
R68	150	5	N	15	150	N	L	N	N	50	N	N	N	L
R74	2,000	100	N	7	5,000	100	L	N	N	20	N	N	2,000	100
R76	10	N	N	50	30	N	20	N	150	150	N	N	N	100
R85	10,000	N	N	30	30	N	20	N	N	100	N	N	500	100
R86	1,000	L	N	30	L	N	5	N	N	150	N	N	300	50
R99	1,000	7	N	20	200	N	10	N	300	70	N	N	G(10,000)	20
R100	5,000	5	N	5	150	N	N	N	N	10	N	N	500	N
R101	G(20,000)	L	N	10	70	N	N	N	N	L	N	N	200	N
R102	100	N	N	15	L	N	30	N	200	70	N	30	N	150
R103	70	7	N	70	30	N	20	N	500	150	N	10	N	150
001S	200	N	N	70	100	N	20	N	300	500	N	20	500	200
002S	200	L	N	50	150	N	30	20	200	300	N	20	300	150
003S	70	N	N	50	30	N	20	N	500	200	N	20	N	300
004S	50	N	N	30	L	N	20	N	300	200	N	20	N	150
005S	70	N	N	50	N	N	20	N	500	200	N	15	N	100
006S	100	L	N	100	N	N	20	N	300	300	N	15	300	50
007S	70	N	N	50	N	N	20	N	300	300	N	10	N	70
008S	100	N	N	100	N	N	20	N	300	300	N	15	N	100
009S	70	N	N	30	50	N	15	N	1,500	150	N	20	N	100
010S	150	N	N	50	70	N	20	N	1,000	200	N	20	N	150
	(10)	(10)	(50)	(10)	(20)	(200)	(10)	(10)	(200)	(20)	(100)	(20)	(500)	(20)
001C	2,000	500	N	100	2,000	N	L	100	300	100	N	150	15,000	G(2,000)
002C	300	700	50	L	10,000	N	L	G(2,000)	200	300	N	200	10,000	G(2,000)
003C	100	N	N	L	1,000	N	L	70	200	200	N	200	5,000	G(2,000)
004C	1,500	L	N	L	300	N	L	30	1,500	100	N	500	700	G(2,000)
005C	200	L	N	L	N	N	L	N	1,000	70	N	100	700	G(2,000)
006C	1,500	N	N	L	N	N	L	N	1,500	20	N	20	N	G(2,000)
007C	L	N	N	L	N	N	L	N	1,000	L	N	N	N	G(2,000)
008C	30	N	N	L	N	N	L	N	1,000	L	N	50	N	G(2,000)
009C	300	200	N	L	5,000	N	L	N	500	100	N	70	15,000	G(2,000)
010C	300	1,500	N	L	20,000	N	L	N	300	300	150	150	G(20,000)	G(2,000)

Table 1.—Continued

	AA			Detector
	(ppm)			
Locality number[2]	As (5)	Au (0.05)	Sb (1)	Hg (0.02)
R1	35	0.05	N	L0.02
R2	L	N	N	.02
R12	5	N	N	.02
R13	360	.15	9	.08
R19	10	N	2	.10
R56	N	N	2	1.8
R57	N	N	1	.02
R68	5	N	2	N
R74	350	.45	150	.16
R76	N	L	N	L
R85	25	.10	3	L
R86	10	L	1	N
R99	5	N	N	.14
R100	30	.05	7	.02
R101	15	.35	N	L
R102	L	L	N	L
R103	25	N	N	.04
001S	L	1.2	N	.20
002S	25	1.3	N	.30
003S	5	N	N	.28
004S	L	N	N	.16
005S	N	N	N	.14
006S	N	N(.10)	N	.14
007S	N	.10	N	.34
008S	N	N(.10)	N	.50
009S	5	N	N	.30
010S	10	N(.50)	N	.26
001C	15	L	N	.20
002C	190	.35	3	.04
003C	40	L	1	.04
004C	10	N(.06)	1	.50
005C	5	N	1	.02
006C	L	N	3	L
007C	N	N	2	L
008C	N	N	2	.24
009C	15	N	2	.02
010C	45	L	3	.02

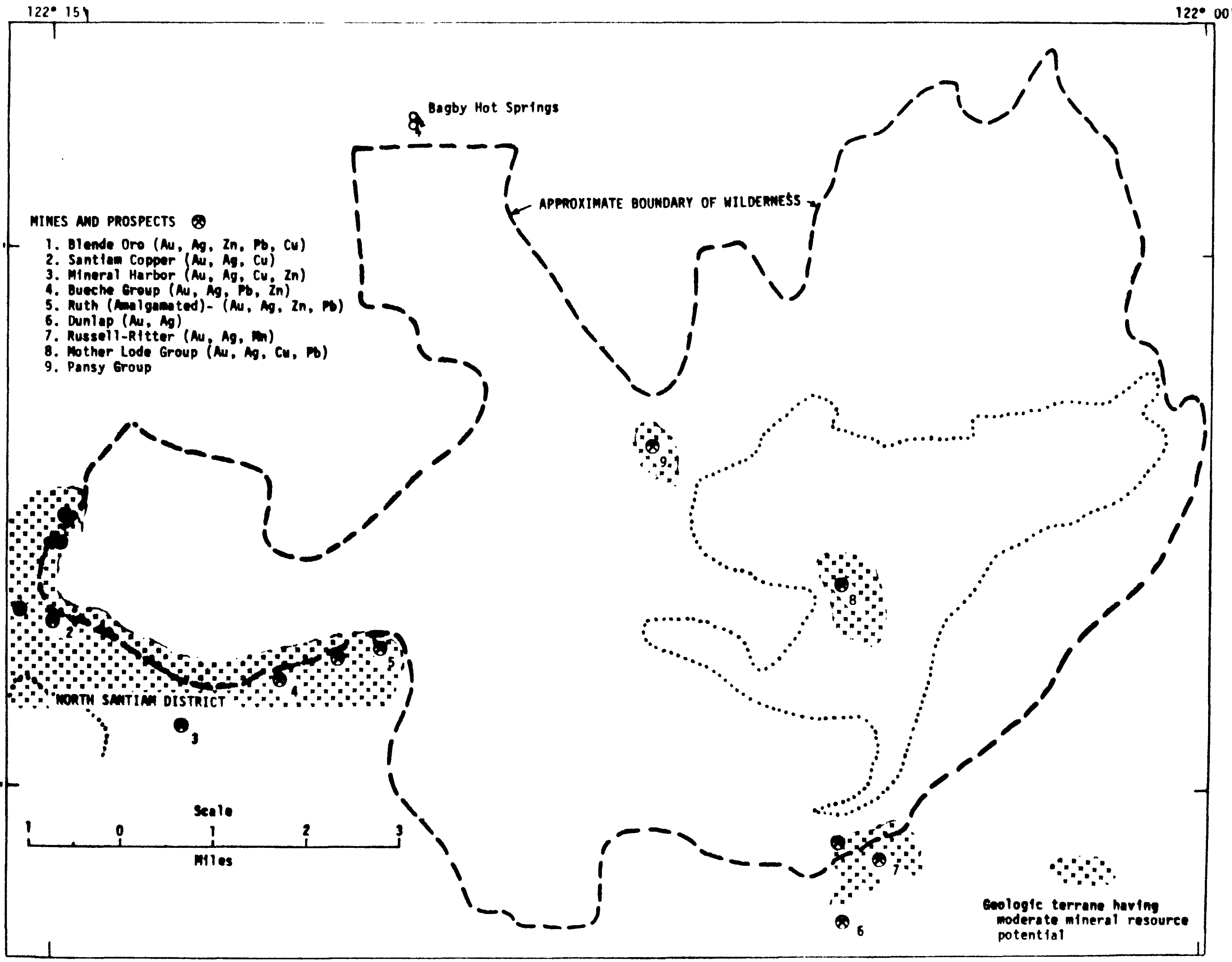


Figure 7.- Mineral resource potential of the Bull of the Woods Wilderness. Outline of larger intrusive bodies shown by dots (······).

the wilderness. The samples consist of brecciated and thoroughly altered rock fragments, presumably part of the large diorite intrusion in which the prospects are located, with interstitial and brecciated quartz, several percent of chalcopyrite, hematite, minor amounts of bornite and covellite(?), and several bright green and blue secondary copper minerals. Analyses (table 1) indicate several thousand ppm copper and minor amounts of other metals. One altered rock sample (R74) collected in a mineralized shear on the north side of the Little North Santiam River and another select specimen (R99) from a dump on the south side of the river contain highly anomalous amounts of copper, lead, and zinc; the first of these samples also is anomalously high in arsenic and antimony and the second in manganese and cadmium.

None of the anomalous values of metals appear to be associated with major structures, specific intrusions or parts of intrusions, volcanic piles, or a particular lithology, except that all the more intensely mineralized areas are either in small shear zones, or, as in the North Santiam district, in breccia pipes. No breccia pipes were identified in the wilderness area, although the brecciated and mineralized rock at the Mother Lode Group is so poorly exposed that it might represent either mineralization in small shears, which is most likely, or possibly surface manifestations of a poorly defined and small pipe. Moreover, because these features are generally small in size, they are unlikely to be seen in aeromagnetic data unless they are associated with unusually high concentrations of magnetic minerals. Because the distribution of metallic elements within the wilderness appears to be highly erratic and shows little correlation with large-scale geologic features or aeromagnetic anomalies, the presence of large base metal deposits or deposits with important gold values seems unlikely. Small deposits of base and precious metals and large tonnages of weakly mineralized rock may be present, particularly in those areas shown as having a moderate resource potential on figure 7.

Additional sampling and physical exploration of areas indentified as having a moderate potential on figure 7 is necessary to fully evaluate their mineral resource potential, but the areas proximity to and geologic similarity with the geology in the adjacent North Santiam district suggests a moderate potential for small deposits of base and precious metals. Some of these areas also have a potential for medium- to large-sized blocks of ground weakly mineralized with copper and probably with gold, although the gold values are likely to be only a small fraction of an ounce per ton. Most of the wilderness away from these known mineralized areas is geologically unfavorable indicating a low potential for mineral deposits.

Energy resource potential

Insofar as can be determined from surface geologic features, there is no evidence that the Bull of the Woods Wilderness contains deposits of mineral fuels, and it likely has only a small potential for the development of geothermal energy. The presence of Bagby Hot Springs on the Hot Springs Fork of the Collawash River less than 0.5 mi north of the wilderness boundary, as well as Austin and Carey Hot Springs about 10 mi northeast of the area on the Clackamas River, and the pesence of somewhat higher than normal heat flow in the region (Riccio, 1978), indicate that the wilderness may have some, as yet, poorly defined potential for geothermal resources. The thermal waters at Bagby Hot Springs are partly developed for recreational bathing. According to

Bowen, Peterson, and Riccio (1978) the temperature of thermal waters at Bagby Hot Springs is 136° F (58° C), at Austin Hot Springs 191° F (91° C), and at Carey Hot Springs 96° F (36° C). There are no thermal springs within the wilderness and this, in addition to the lack within the area of large volumes of Quaternary volcanic rocks with possible residual magmatic heat, indicates that the potential for geothermal energy is probably small.

Conclusions

Minor occurrences of base and precious metals within the Bull of the Woods Wilderness and similarity of its geology with that of the adjacent North Santiam mining district suggest a moderate resource potential for some metallic elements, notably copper, lead, zinc, silver, and possibly gold. Additional geochemical sampling and physical exploration are required to determine whether these or other metals occur in commercial quantities, however. Hot springs and above-normal heat flow in the region indicate that there may be some as yet undefined potential for the development of geothermal energy. Absence of thermal springs in the wilderness and lack of large volumes of young volcanic rocks suggest, however, that the potential for geothermal energy is probably small.

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