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MINERAL RESOURCE POTENTIAL OF THE GOAT ROCKS WILDERNESS AND ADJACENT ROADLESS AREAS, LEWIS AND YAKIMA COUNTIES, WASHINGTON

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STUDIES RELATED TO WILDERNESS

Under the 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 been conducting 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 currently 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 submitted to the President and the Congress. This report discusses the results of a mineral survey of the Goat Rocks Wilderness and adjacent roadless areas in the Gifford Pinchot and Snoqualmie National Forests, Lewis and Yakima Counties, Wash. The Goat Rocks Wilderness (NF032) was established by Public Law 88-577, September 3, 1964. The Goat Rocks Roadless Areas (06036 A, C, D) were classified as proposed wilderness additions during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

MINERAL RESOURCE POTENTIAL SUMMARY

The mineral resource potential of Goat Rocks Wilderness and adjacent roadless areas has been studied by a multidisciplinary team of geoscientists from the U.S. Geological Survey and the U.S. Bureau of Mines. The potential for mineralization in the Goat Rocks study area has been classified based on a study of past mining activity and recent geologic, geochemical, and geophysical studies. A porphyry-copper model (A. S. Brown, 1976) was used to evaluate the observations and to define areas of favorable mineral potential. Two areas (A,B) within the Goat Rocks study area have moderate potential for the occurrence of mineral resources and two areas (C,D) have favorable geologic conditions for mineralization and show geochemical anomalies of base metals. On the basis of available data, areas C and D are defined as areas of low potential for base-metal resources.

Area A, located north of Old Snowy Mountain, is classified as having moderate potential for occurrence of base-metal resources in a porphyry-copper deposit. It has a pronounced color anomaly, hydrothermally altered (phyllic) rocks are exposed at the surface, and geochemical anomalies (copper, molybdenum, cobalt, nickel, lead, silver, and zinc) for a porphyry-copper suite are present in both the altered rocks and the stream sediments. Hydrothermally altered rock is mapped in a volcanic pile within an old volcanic center on the southeast side of a cupola on the Goat Rocks pluton as defined by the gravity data. A pronounced magnetic low is coincident with the geochemical anomaly, suggesting the presence of a hydrothermal system at depth.

Area B, located in the headwaters of the Klickitat (on the Yakima Indian Reservation) and the South Fork of the Tieton River, is also classified as having a moderate potential for the occurrence of base-metal resources in a porphyry-copper deposit. Area B is defined by a pronounced color anomaly, a sizable area of hydrothermal alteration, and a substantial geochemical anomaly similar to that for area A. Field studies were not conducted in the Yakima Indian Reservation, and therefore, the complete outline of the anomaly is not defined by geologic mapping and geochemical studies. Although we classify area B as having moderate potential for the occurrence of base-metal resources in a porphyry-copper deposit, the area is less favorable than area A because area B has no associated magnetic low.

Area C, a large geochemical anomaly along the Clear Fork of the Cowlitz River, is interpreted to represent possible mineralization along the intrusive contact between the Goat Rocks pluton and the Ohanapecosh and Russell Ranch Formations to the east. The geochemical anomalies of a large suite of base metals in the stream-sediments, occurrences of pyrite, cinnabar, and barite in the heavy-mineral suite, and large geochemical anomalies in water samples from these drainages suggest mineralization associated with the emplacement of the Goat Rocks pluton. Area C is classified as an area of low potential for the occurrence of copper, lead, and zinc resources in veins associated with a porphyry-copper deposit.

Area D, defined by a small geochemical anomaly in the stream sediments from the outcrop of the Russell Ranch Formation in the roadless area 06036D, may have volcanogenic massive sulfide mineralization (Franklin

and others, 1981), but such mineralization is not supported by geochemical anomalies in the water samples from these drainages. On the basis of currently available data, we assign a low potential for the occurrence of copper, lead, and zinc resources in volcanogenic massive sulfide deposits associated with the submarine basalts of the Russell Ranch Formation.

Outside the study area, there is a small, inferred resource for coal in the Cowlitz Pass coal field located north of the study area, and potential for coal resources in the Packwood coal field located west of the study area (U.S. Bureau of Mines and U.S. Geological Survey, 1980). However, the coal-bearing rocks do not crop out in, or appear to extend into, the Goat Rocks study area; there is low potential for the occurrence of coal resources in the study area.

A small quarry near Dog Lake, northeast of the study area, is in andesite suitable for building stone for local markets. The Goat Rocks study area has a high potential for building stone resources; however, the demand can be readily supplied from the existing quarry. Abundant sand and gravel deposits suitable for construction purposes exist in the study area, but alternate sources occur closer to local markets.

The potential for geothermal resources in the Goat Rocks study area is low because there are no active hot springs or evidence of Holocene silicic volcanism. A low potential for oil and gas resources in the thick section of pre-Tertiary marine sediments on either side of the Goat Rocks study area is indicated by available data.

INTRODUCTION

The Goat Rocks Wilderness and adjacent Goat Rocks Roadless Areas (06036, A, C, and D) straddle the crest of the Cascade Range in Lewis and Yakima Counties, south-central Washington (fig. 1). The wilderness (82,680 acres) and roadless areas (eight separate units totalling 25,240 acres) lie in the Gifford Pinchot National Forest west of the Cascade crest and in Snoqualmie National Forest east of the crest. The Yakima Indian Reservation borders the southeastern and southern parts of the wilderness. Mount Rainier National Park is about 5 mi north of the area, and the Mount Adams Wilderness about 6 mi south of the area. Elevations range from 2,930 ft along Upper Lake Creek to 8,184 ft at Gilbert Peak. Access to the study area is provided by good unpaved roads leading south from U.S. Highway 12. Travel within the area is facilitated by the Pacific Crest National Scenic Trail and connecting trails.

This report summarizes studies by the U.S. Geological Survey and the U.S. Bureau of Mines, designed to evaluate the mineral potential of the Goat Rocks study area. Studies by the U.S. Geological Survey focused on geology (Swanson and Clayton, 1983), geochemistry (Church and others, 1983 and in press), and gravity and aeromagnetics (Williams and others, 1983). The U.S. Bureau of Mines searched courthouse records (Lewis and Yakima Counties) for mineral lode, coal, and quarry claims, and examined the U.S. Bureau of Land Management and the U.S. Bureau of Mines files and records for information on mineral prospects. Prospects were examined and hydrothermally altered zones were sampled. Analyses of these samples are on file at the U.S. Bureau of Mines, Western Field Operations Center, Spokane, Wash. Areas of mineral potential were evaluated, and resources were classified according to the terminology of U.S. Geological Survey Circular 831 (U.S. Bureau of Mines and U.S. Geological Survey, 1980).

ACKNOWLEDGMENTS

The development of a mineral resource potential summary of a study area is dependent upon the expertise and contributions of many people in addition to the authors. Z. Frank Daneŝ contributed unpublished gravity data. C. A. Finn contributed to the reduction and interpretation of the geophysical data. J. G. Frisken, R. S. Werschky, and W. M. Kemp assisted in the collection of geochemical samples in the field. We also acknowledge the assistance of our helicopter pilot, the late Jack Johnson, whose skills as a pilot made the geochemical sampling a very quick and efficient task. Michael Grube, Mitchell King, Ronald Mayerle, and J. Mitchell Linne assisted the U.S. Bureau of Mines authors with field investigations. Ed Osmond, John Johnson, and Ray Scharf, Gifford Pinchot National Forest, and their staff provided information about access, weather, and trails.

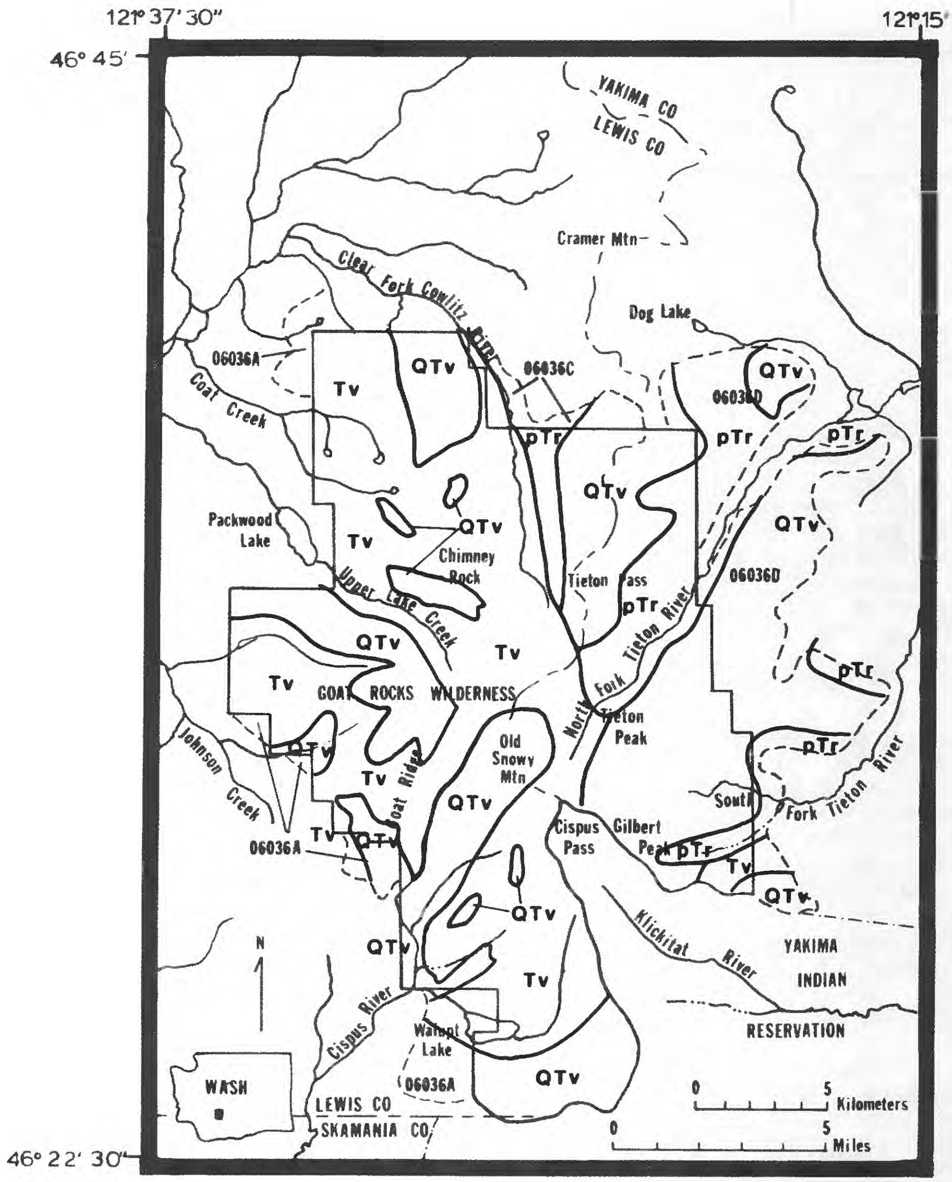
GEOLOGY, GEOCHEMISTRY, AND GEOPHYSICS

Geology

The Goat Rocks study area contains Cenozoic volcanic rocks overlying pre-Tertiary rocks. The oldest pre-Tertiary rocks belong to the Russell Ranch Formation (Simmons, 1950); the main rock types are graywacke, argillite, minor pillow basalt (now greenstone), chert, and thin tuffaceous units. The rocks are intensely deformed, but their metamorphic grade is below the prehnite-pumpellyite facies. Carbonaceous detritus (up to 10 volume percent) and radiolarians of Late Jurassic age (D. L. Jones, USGS, written commun., 1979) are well preserved.

The Ohanapecosh Formation, the thickest of the Cenozoic formations (fig. 1), is of Eocene age (Fiske, Hopson, and Waters, 1963). It rests unconformably on the Russell Ranch Formation, is 7,540 ft to 10,000 ft thick, and consists mostly of altered basaltic and andesitic lava flows and bedded andesitic and dacitic volcaniclastic rocks. The depositional environment of the volcaniclastic rocks is uncertain. Water depths were probably not great. All lava flows appear to be typically nonpillowed, subaerial types with rubbly basal and upper zones and vesicular tops.

Quartz-bearing silicic ashflow tuff, rhyolite, and related volcaniclastic rocks commonly overlie the Ohanapecosh Formation in the northwestern part of the mapped area and are assigned to the Stevens Ridge Formation (fig. 1). The contact is poorly exposed and commonly obscured by intrusions, but the Stevens Ridge Formation appears to dip somewhat less steeply than the Ohanapecosh Formation, and the contact may be an angular unconformity. The Stevens Ridge Formation is a maximum of about 590 ft thick in the



EXPLANATION

QTv	Volcanic and intrusive rocks (Quaternary and Pliocene)
Tv	Ohanapecosh and Stevens Ridge Formations (Eocene)--volcanic and intrusive rocks
pTr	Russell Ranch Formation (pre-Tertiary)--graywacke and argillite
——	Approximate boundary of Goat Rocks Wilderness
- - -	Approximate boundary of adjacent roadless areas
——	Contact
— -	County boundary
—·—	Reservation boundary

Figure 1.--Location map and generalized geology of the Goat Rocks study area, Lewis and Yakima Counties, Wash.

study area. No volcanic vents were found, and all the rocks were probably erupted outside the mapped area.

Thick sequences (up to 2,100 ft) of upper Pliocene high-silica rhyolitic tuff, flows, and breccias, directly overlie the Russell Ranch Formation in the southeast part of the Goat Rocks Wilderness. Flow-banded rhyolite and coarse autobreccia at the base of the section below the eastern ridge of Tieton Peak, between the headwaters of the North and South Forks of the Tieton River, may be part of one or more lava domes in the vent area. Welded tuff and accretionary lapilli tuff in this area are evidence of explosive eruptions. Explosive volcanism and large volumes of rhyolite are commonly associated with the formation of a caldera. Several thick tuff units of Russell Ranch Formation contain abundant blocks and lapilli indicating extensive fragmentation of basement rock consistent with caldera formation, although no definitive field evidence for a caldera has been found.

Many of the high ridges are capped by high-potassium pyroxene andesites of late Pliocene and Pleistocene age (Clayton, 1983). The flows are laterally discontinuous at the core of the Goat Rocks study area; they are intercalated with volcanic breccias and lahars, and locally, are highly altered. Commonly, the flows display primary dips of 10°-20°. Away from the core, thick sequences of shallow-dipping, valley-filling flows are preserved on modern ridges as examples of inverted topography. These features are interpreted as remnants of the Goat Rocks volcano (Ellingson, 1969), a major composite volcano that has been deeply eroded. Volcanic vent areas of different ages may be located by the abundance and orientation of dikes, degree of alteration, and the attitudes of deposits. A radial dike swarm centered on Upper Lake Creek basin cuts the youngest flows west of Old Snowy Mountain. Long, north-northwest-trending pyroxene andesite dikes near Chimney Rock and east-trending dikes northeast to Tieton Peak may be either part of the radial swarm or represent separate fissure systems. Hydrothermal alteration in an area between Cispus Pass and Tieton Peak affects all the older flows and may be associated with intrusion of a pluton near Cispus Pass. Local hydrothermal alteration was observed in Goat Lake cirque and near Heart Lake 1-2 mi west-northwest of Old Snowy Mountain.

Eruption of more than 200 olivine-bearing basalt and basaltic-andesite flows during the late Pliocene and early Pleistocene built a 3 mi wide, 2,300 ft thick, shield volcano centered at Hogback Mountain in the northeast of the wilderness. Basaltic flows from this shield volcano buried several older hornblende andesite domes near the margin of the volcano, and extended about 20 mi down the Tieton River valley. Coarsely porphyritic hornblende dacite, some of which contains biotite and quartz, forms thick dikelike intrusions to the north within roadless area 06036D. The hornblende dacite also occurs as tuffs interbedded with the basalt of Hogback Mountain, and north of the mapped area the unit forms a widespread system of volcanoes and shallow level plutons (Clayton, 1983).

Sparsely porphyritic hornblende andesite flows younger than the domes on Hogback Mountain and the pyroxene andesite of Goat Rocks volcano advanced down ancestral valleys of many streams. The flows are fresh and are overlain by several meters of glacial till, thus the main pulse of andesitic volcanism probably occurred during the late Pleistocene. Volcanic vents occur on Round Mountain (source of the andesite of Clear Fork of the Cowlitz River) and in the Old Snowy Mountain and Ives Peak area (source of extensive flows along the Cispus River and Upper Lake Creek).

During the late Pleistocene, olivine basalt was erupted from Lakeview Mountain shield volcano and several volcanic vents west of Coleman Weedpatch southeast of Walupt Lake; the ridge southwest of Walupt Lake is an eroded remnant of a subglacial volcano (Hammond, 1980) that shows no evidence of younger glaciation and may be as young as 14,000 yrs. Hyaloclastic debris of olivine basalt that caps the ridge in the north part of the wilderness may be the product of a subglacial eruption, probably predating the valley-filling hornblende andesite of Clear Fork of the Cowlitz River.

Several thin layers of tephra produced by Quaternary eruptions of Mount Rainier and Mount St. Helens occur in the area. The most recent tephra, from the May 18, 1980, eruption of Mount St. Helens, forms a layer that blankets the entire area and varies systematically in thickness from about 1/2 in. at the north boundary to about 1 1/2 in. near Walupt Lake (Waitt and Dzurisin, 1981). The bulk composition of the 1980 tephra is dacitic, but the easily leached glassy matrix is rhyolitic.

Intrusive bodies are common in the mapped area. The larger plutons include a microdiorite in the Beargrass Butte (1 1/2 mi northeast of Packwood Lake) area that intrudes the Stevens Ridge Formation and a microdiorite-porphyritic andesite cutting the Ohanapecosh Formation on Goat Ridge. The base of both of these intrusions is roughly concordant with bedding, but each body as a whole cross-cuts its host. Numerous smaller dikes, sills, and small stocks, generally of pyroxene andesite and microdiorite, occur throughout the area. Most of the larger intrusions, and many of the smaller intrusive bodies, show various degrees of propylitic (chlorite-epidote) or phyllic (quartz-sericite-pyrite) alteration. Pliocene and younger dikes and plugs are generally fresh except for devitrification, but areas of hydrothermal activity are marked by quartz veins, and propylitic and phyllic alteration.

Ellingson (1968) recognized a body of quartz monzonite just north of Cispus Pass and named it the Cispus Pass pluton. Geologic mapping suggests that much of what he included in the pluton may instead be altered pyroxene andesite of the Ohanapecosh Formation (Swanson and Clayton, 1983). Further work is necessary to define the extent of the pluton and its alteration halo adequately. A relatively fresh diorite(?) forms prominent cliffs south and west of Cispus Pass and may be related to the Cispus Pass pluton.

Structurally, the Ohanapecosh and Stevens Ridge Formations have been gently folded but evidence of this deformation in the younger rocks is ambiguous. The Russell Ranch Formation is pervasively sheared and locally boudinaged, and is cut by major north-trending faults. The Ohanapecosh Formation is folded along a north-northwest trend and dips away from the uplifted Russell Ranch Formation at angles of 30°-50°. The troughline of a broad syncline in the Ohanapecosh Formation crosses the upper reaches of the Middle Fork of Johnson Creek but is not evident to the north and south beneath Pliocene and younger rocks. The crestline of a major anticline occurs west of the study area in the upper Johnson Creek drainage. Minor warps affect the formation near Chimney Rock and in the headwaters of Upper Lake Creek. Local deformation is common near intrusions, and primary dips in volcanic vent areas complicate the tectonic pattern.

The contact between the Ohanapecosh and Russell Ranch Formations is poorly exposed because of landslides and conceivably could be the Cortright fault of Hammond (1980; the Clear Fork fault zone of Ellingson, 1972). Evidence for significant faulting was not observed. Several small faults, having vertical displacements of less than a few feet, were mapped in the Ohanapecosh Formation. These faults fall into two sets, one with a northeast strike, the other with a northwest strike. Subhorizontal slickensides were observed on most of these faults, but the sense of motion (right or left lateral) was indeterminate.

Geochemistry

A reconnaissance geochemical survey of the Goat Rocks study area was conducted in July, 1981, to contribute to the mineral resource assessment. Several geochemical sample media were investigated; stream-sediment samples, heavy-mineral concentrates panned from stream sediments, water samples from the streams in the study area, and rock samples from both altered and unaltered outcrops were collected. A total of 142 stream-sediment samples, 91 panned-concentrate samples, 135 water samples, and 140 rock samples were analyzed using semiquantitative emission spectrography (Grimes and Marranzino, 1968), aqua regia leach/ICP (Inductively Coupled Plasma) analysis (Church, 1981a, b; Church and others, 1982), atomic absorption, and specific ion chromatography analysis (Miller and Ficklin, 1976; Smee and Hall, 1978). Mineralogical identifications of sulfide minerals in the nonmagnetic, heavy-mineral concentrates were also made. The geochemical interpretation of these results is given in a companion report (Church and others, in press). A listing of the data, single-element plots of selected metals and ions, and statistical summaries of the analytical results are given in Church and others (1983).

Samples of altered rock from the propylitic and phyllic alteration zones were collected to define trace-element signatures of the hydrothermal systems. The U.S. Bureau of Mines also took chip samples of altered rocks from these area.

The presence of a blanket of volcanic tephra from the May 18, 1980, eruption of Mount St. Helens (Waitt and Dzurisin, 1981) complicated the stream-sediment sampling program. Many of the drainages sampled contained a substantial component of volcanic ash. Stream-sediment samples were taken at depth in a high-energy flow regime of the streams to minimize the dilution effect caused by the presence of volcanic ash. The minus-80-mesh stream-sediment samples were analyzed by both direct-current arc emission spectrographic techniques and by aqua-regia leach/ICP methods (Church and others, 1983). Leach studies of an ash sample collected a few days after the May 18, 1980, eruption of Mount St. Helens indicate a negligible contribution of the volcanic ash to any geochemical anomalies defined from the leach data.

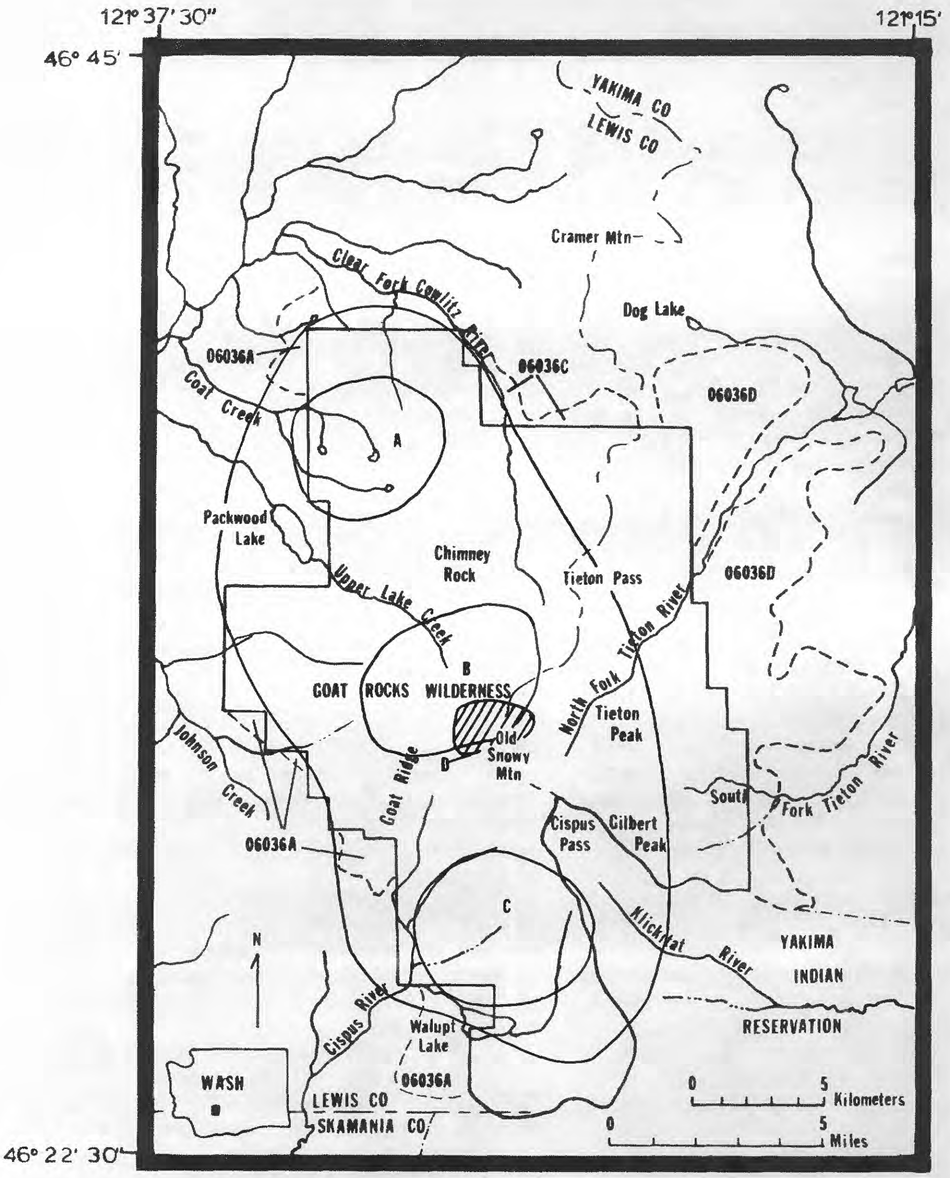
Geochemical anomalies in the stream-sediment sample media defined by the aqua-regia leach/ICP analysis data represent the acid-soluble component in the stream sediments, that is, the primary oxide or sulfide minerals and the hydromorphic coatings on grain surfaces. Spectrographic analyses of the nonmagnetic, heavy-mineral concentrates result in an enhancement, by factors of 5 to 10, of anomalies for copper, lead, zinc, manganese, cobalt, molybdenum, nickel, and barium over those obtained from aqua-regia leach/ICP analysis of the stream sediments. Several additional chalcophile elements are sufficiently enriched in the heavy-mineral concentrates that they can also be detected (arsenic, silver, bismuth, antimony, tin, and mercury). These geochemical data, coupled with the elemental and ion concentrations measured in the water samples and the mineralogy of the nonmagnetic, heavy-mineral concentrates, define suites of elements indicative of base-metal mineralization.

Geophysics

Geophysical investigations included gravity and aeromagnetic surveys (Williams and others, 1983). The interpretation of the gravity data indicates a large, central, positive gravity anomaly (fig. 2) and three smaller, superimposed, positive anomalies. The large anomaly is about 16 by 7 mi and has an amplitude of about 16 mgals. The anomaly appears to delineate a large pluton that lies directly beneath and apparently fed the Goat Rocks volcano. The source of this positive gravity anomaly is interpreted to be the dense plutonic rocks intruding less dense, older volcanic and sedimentary rocks of the Ohanapecosh and Russell Ranch Formation. On the basis of model calculations of density contrasts, Williams and others (1983) concluded that the top of the main body of the pluton appears to be at a depth of about 5,000 ft.

The three smaller positive anomalies are about equally spaced, and each is roughly circular, with a diameter of 3 mi (see fig. 2). The anomalies have approximately equal amplitudes and are an additional 6 mgals greater than the main gravity high. These smaller anomalies appear to delineate shallow intrusive cusps, or cupolas, rising above the main pluton and appear to represent the shallow intrusive bodies that crop out irregularly and are mapped as andesitic and basaltic-andesitic intrusions (Swanson and Clayton, 1983).

The aeromagnetic survey indicates anomalies that, in general, reflect the terrain of the area. Topographic highs produce magnetic highs in undeformed, normally magnetized rock; topographic lows produce magnetic lows. Significant deviations from this pattern may delineate subsurface geology. Zones of mineralization may be indicated by localized magnetic lows, where the magnetic minerals present in the hydrothermally altered area have been attacked. Only one such area is defined by aeromagnetic data (fig. 2, area D). This magnetic low is about 2/3 by 1 1/3 mi in size, and has an amplitude of about 300 gamma. The magnetic anomaly is located on Old Snowy Mountain and coincides with a large zone of hydrothermally altered rock.



EXPLANATION

—— Approximate boundary of Goat Rocks Wilderness

--- Approximate boundary of adjacent roadless areas

Figure 2.--Map showing the outline of the buried Goat Rocks pluton based on the gravity survey (Williams and others, 1983); the three cupolas on the pluton are designated A, B, and C. The location of the magnetic low (D) inferred to be related to hydrothermal alteration is indicated by the crosshatched area.

MINES, PROSPECTS, AND MINERALIZED AREAS

During the study, the U.S. Bureau of Mines examined courthouse records for the location of mining claims filed in the Goat Rocks study area. Three lode mining claims and one coal claim were found; none are active (fig. 3). There is no record of development or production from these claims (Peters and Linne, 1981; Close, 1982).

Field investigations were made of the claim areas, along with an examination of the coal claims in the Packwood coal field located west of the study area. Field examination of the hydrothermally altered areas north of Cispus Pass were also made. Thirty chip samples from across the altered zones were collected to determine if there was any mineral potential. The rock samples were checked for radioactive and fluorescent minerals and were analyzed for concentrations of metals using semiquantitative emission spectrography; gold, silver, copper, lead, and zinc contents were analyzed by fire assay and atomic absorption methods. Fifty-four concentrates panned from stream sediments were collected to evaluate the area for placer potential.

Two lode mining claims have been staked in the Goat Rocks Wilderness. The Mosquito lode was located near Walupt Lake in 1934, and the Glacier lode was located near Packwood Glacier on the west side of Old Snowy Mountain in 1939 (fig. 3, nos. 1 and 2). These claims are apparently abandoned; there are no location notices or evidence of assessment work. However, the Glacier lode claim, located in a hydrothermally altered zone, was examined during this study. A third claim, the Windy Point No. 1 claim, staked in the roadless area (06036D) at the headwaters of the South Fork of the Tieton River, also showed no evidence of mining activity (fig. 3, no. 3).

In 1913, lode deposits were discovered near Bumping Lake 15 mi north of the Goat Rocks study area (Simmons and others, 1974). These gold-, silver-, and copper-bearing deposits occur along breccia or shear zones associated with a granitic pluton of late Oligocene age (Clayton, 1983) and crosscutting rhyodacite dikes and sills of late Miocene to Pliocene age (Clayton, 1983). No similar deposits were found in the Goat Rocks study area.

Coal was discovered in the Spiketon Formation (Gard, 1968) in the Cowlitz Pass and Packwood coal fields (fig. 3, nos. 4 and 5) in the early 1890's. According to Smith (1911, p. 156), interbedded coal and shale are best exposed in 600 ft of workings near the summit of the ridge between Coal and Lake Creeks. The beds strike N. 5° E. and dip 30° W., away from the study area.

A coal claim, the Buckeye claim, located in the southeast corner of the Goat Rocks Wilderness, was filed in 1890 (fig. 3, no. 6). The exact location of the claim is uncertain, but it is thought to be near the contact of the Ohanapecosh and the Russell Ranch Formation or in the volcaniclastic sediments on the south branch of the South Fork of the Tieton River. No outcrops of the coal-bearing Spiketon Formation were found in the study area.

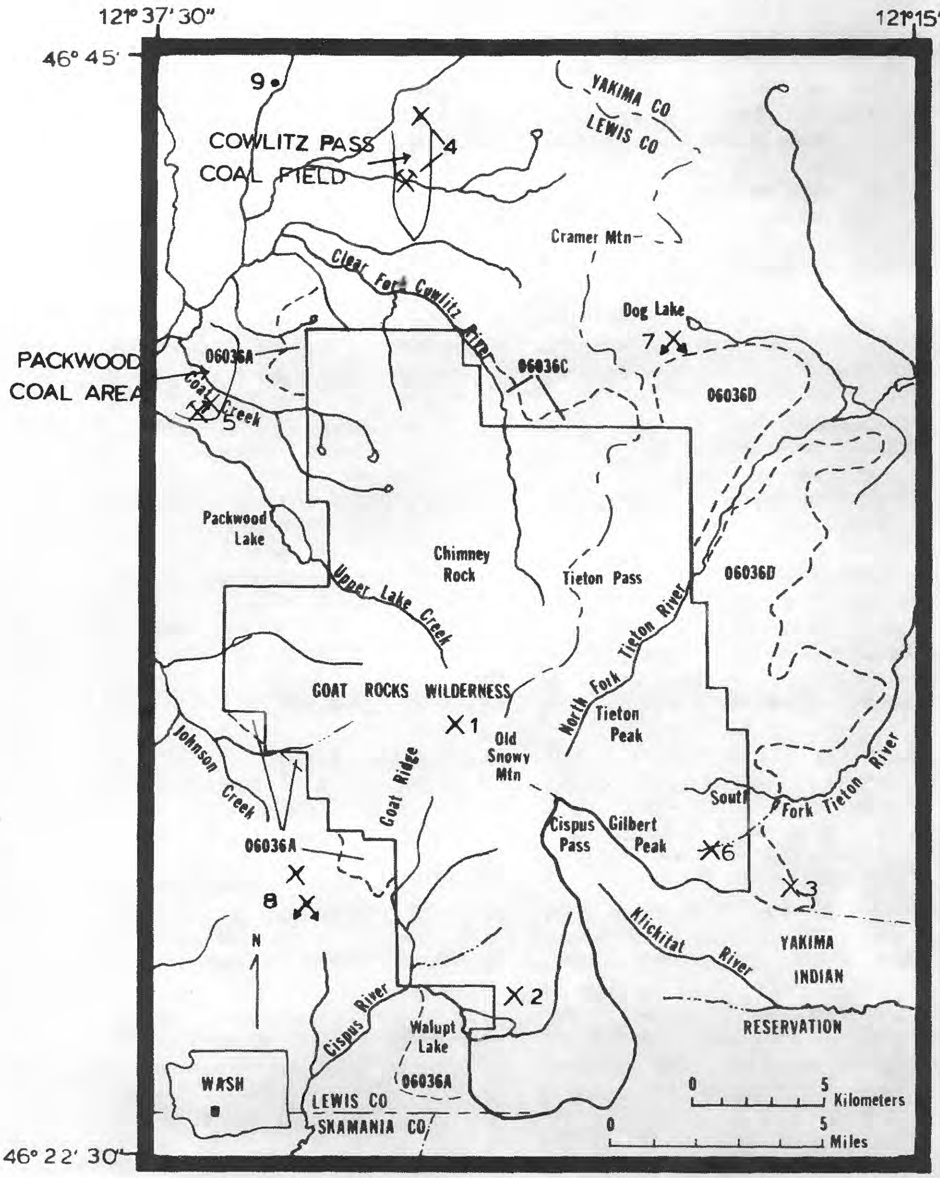
Stone is the only mineral commodity mined in the vicinity of the Goat Rocks study area; there is no record of mining activity within the wilderness or adjacent roadless areas. Near Dog Lake and along Johnson Creek, 1 mi north and 1 mi west of the wilderness, respectively, are building stone and road metal quarries of andesite and basalt which are exploited on a small scale as needed (fig. 3, nos. 7 and 8). The volcanic rock (andesite) is characterized by horizontal and vertical sets of fracture planes, intersecting at right angles, and provides an easily produced building stone suitable for masonry purposes. Similar deposits probably occur within the Goat Rocks study area.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

The potential for mineral resources in the Goat Rocks study area is based on an evaluation of mining records and claim activity, as well as the geologic, geochemical, and geophysical data. The classification of mineral resources for known deposits found in the study area was made according to the terminology of U.S. Geological Survey Circular 831 (U.S. Bureau of Mines and U.S. Geological Survey, 1980). The classification of the mineral potential of an area, however, represents an integration of measurable data and the subjective evaluation of the degree to which those data, and the interpretation of the geologic conditions inferred, represent a known mineral deposit type. We use three terms, high, moderate, and low, to define areas having the potential for mineral resources within the Goat Rocks study area. An area having a high potential for mineral resources is one in which most of the geologic criteria outlined in applicable mineral deposit models are met and a deposit of that general type and age exists in the western cordillera. An area having a moderate potential is one in which the geologic criteria permit a particular deposit type but in which the geochemical or geophysical evidence for mineralization is less well defined; however, a reasonable chance for the occurrence of concealed mineral deposits exists. All other areas have a low potential either because we do not have sufficient geologic data or understanding to define a mineral deposit model, or because the data do not indicate geologic conditions favorable for ore accumulations. An area of low potential may include areas of concealed mineralization as well as areas of dispersed mineral occurrences.

Three areas of possible mineralization, probably related to a porphyry-copper deposit (areas A, B, C; fig. 4) have been recognized. Area A is the hydrothermally altered area near Old Snowy Mountain, area B is the hydrothermally altered zone in the headwaters of the Klickitat River, and area C is a widespread geochemical anomaly along the Clear Fork of the Cowlitz River. Other, smaller scale geochemical anomalies exist within the Goat Rocks study area but they will not be discussed here because the data do not indicate favorable geologic conditions for the occurrence of mineral resources.

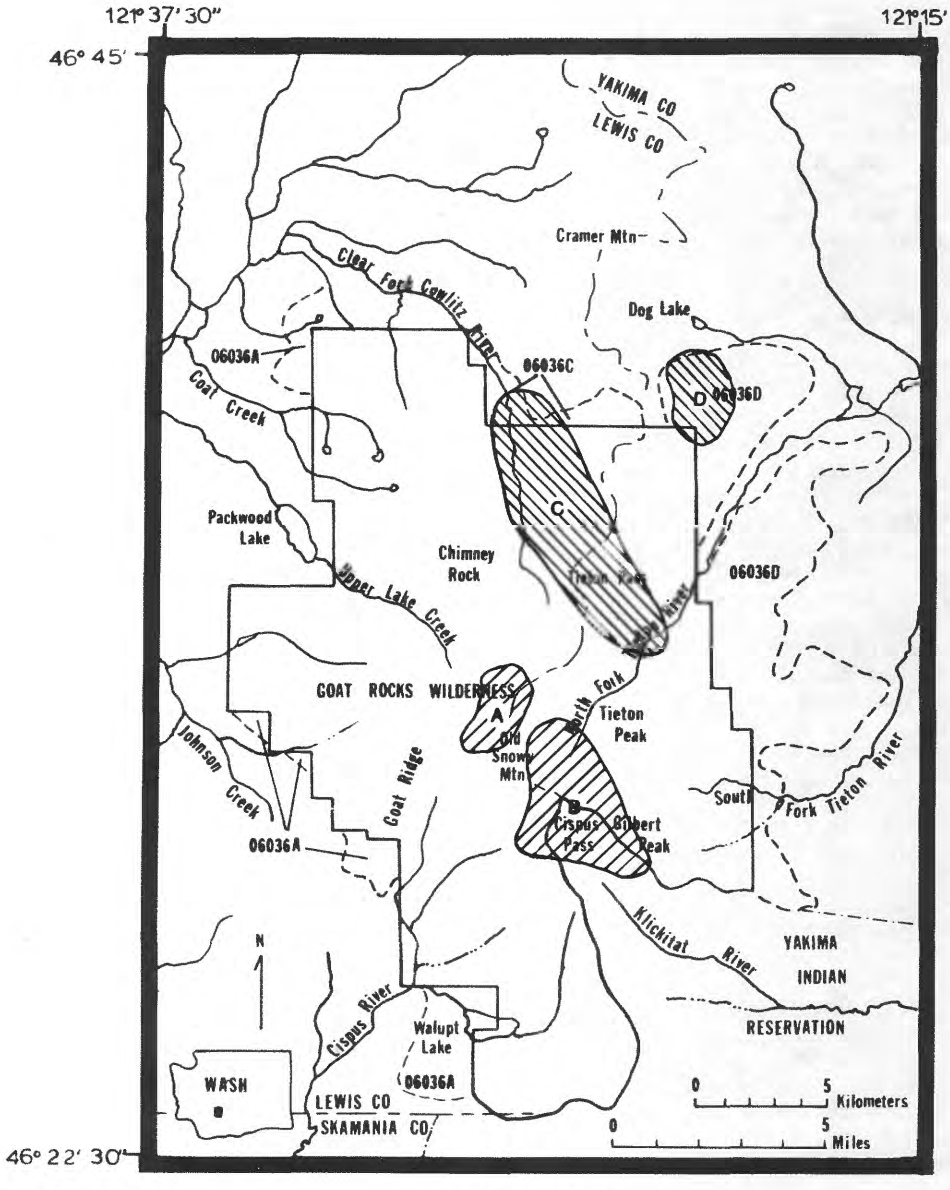
Porphyry-copper mineralization in the Cascade Range (Hollister, 1979) represents a southern extension of the porphyry-copper province of British Columbia. Grant (1969) defined the essential features of the mineralization, alteration, geometry, and geochemical signatures of the plutonic porphyry-copper deposit typical of the Cascade Range. A. S. Brown (1976) reviewed the general features of the three specific porphyry-copper deposits. Briefly summarized, porphyry-copper mineralization is associated with calc-alkaline plutons of granitic to dioritic



EXPLANATION

—— Approximate boundary of Goat Rocks Wilderness	1- Glacier lode claim
- - - Approximate boundary of adjacent roadless areas	2- Mosquito lode
Mine	3- Windy Point No. 1 claim
X Prospect	4- Cowlitz Pass coal field prospects
Gravel pit or quarry	5- Packwood coal field prospects
	6- Buckeye coal claim
	7- Dog Lake stone deposit
	8- Johnson Creek quarries
	9- Ohanapecosh hotsprings

Figure 3.—Map showing the locations of mineral prospects, coal claims and fields, and stone and gravel quarries within and near the Goat Rocks study area, Lewis and Yakima Counties, Wash.



EXPLANATION

—— Approximate boundary of Goat Rocks Wilderness

- - - Approximate boundary of adjacent roadless areas

(diagonal hatching) Areas of moderate potential for base-metal resources

(reverse hatching) Areas of low potential for base-metal resources

Figure 4.—Map showing areas favorable for mineral resources of the Goat Rocks study area, Lewis and Yakima Counties, Wash.

composition, often porphyritic, that have been intruded into continental margin terranes. Regional structures (Grant, 1969; Brown, 1976; Hollister, 1979) control the location of plutons, which are typically emplaced at shallow depths. The rocks they intrude are commonly brecciated and fractured; alteration patterns are symmetric about the deposit and have definite, identifiable zonation. Commonly, the potassic alteration shell for the Cascade porphyry-copper deposit is small (Grant, 1969; Hollister, 1979). Peripheral hydrothermal veins and breccia pipes are common indicators of mineralization. Geochemical anomalies of potassium, copper, lead, zinc, molybdenum, tungsten, gold, silver, arsenic, mercury, and manganese, as well as other metals may occur (Grant, 1969). A pyritic halo is common and barite is often present.

Metallic resources

Area A, Packwood Glacier-McCall Basin, is located beneath the Packwood Glacier on the west and extends north and east into the McCall Basin in the headwaters of the North Fork of the Tieton River (fig. 4). The Glacier lode claim was staked in this area just west of Packwood Glacier. The volcanic rocks that crop out here have been brecciated and show extensive propylitic alteration, silicification, and associated pyrite deposition. The boundaries of this area approximate the phyllic alteration zone. This zone of altered rock lies on the southeast side of the radial dike swarm associated with a period of activity of the Goat Rocks volcano. Extensive brecciation appears to have occurred during late-stage volcanic and intrusive activity, and there are at least two stages of dike injection; both sets of dikes contain disseminated sulfides. The area has a pronounced color anomaly caused by oxidation of pyrite.

Geochemical data from the aqua-regia-leach fraction of stream sediments collected from the area indicated anomalies of copper, cobalt, manganese, nickel, lead, and barium. Water samples had anomalous sulfate (presumably from the oxidation of pyrite), copper, and fluoride. Pyrite was ubiquitous in the nonmagnetic, heavy-mineral concentrates; anomalous values were found for barium, lead, cobalt, nickel, copper, zinc, molybdenum, arsenic, antimony, tin, bismuth, mercury, niobium, and boron in the heavy-mineral concentrates. Samples of altered rocks and pyrite-rich zones contained anomalous concentrations of leachable lead, cobalt, nickel, copper, molybdenum, manganese, arsenic, niobium, and zinc.

The presence of aqua-regia-soluble magnesium, chromium, and aluminum in rocks is interpreted to be from the clays present in the hydrothermally altered zone. The anomalous concentrations of phosphorous can be indicative of a high-level exposure of a hydrothermal alteration zone (Chaffee, 1982). Chip samples collected from area A by the U.S. Bureau of Mines had values as high as 1.1 ounces of silver per ton and lesser amounts of copper (50 ppm), lead (103 ppm), and zinc (104 ppm). The samples typically contained less than 0.2 ppm silver, and averaged 26 ppm copper, 31 ppm lead, and 52 ppm zinc.

The altered area is approximately coincident with magnetic low (fig. 2) and the southeastern area of the central gravity high and is interpreted to be a venting zone of the Goat Rocks volcano. The magnetic low defines a zone of hydrothermal alteration where magnetite has been attacked locally and where the magnetization of the rocks has been reduced. This zone of relatively weak magnetization is about 2/3 by 1 1/3 mi in size; its depth is difficult to determine. Area A is considered to have a moderate potential for the occurrence of base metal resources in a porphyry-copper deposit. Metal contents of surface samples are too low to warrant a tonnage and grade estimate. Further evaluation, however, cannot be made without additional detailed sampling and subsurface exploration.

Area B, informally named Glacier basin, is a second area of hydrothermal alteration in the vicinity of Cispus Pass near the headwaters of the Klickitat and the South Fork of the Tieton River. Mapping has delineated zones of alteration similar to those found in area A. The central altered area is an extensive phyllic altered zone with ubiquitous pyrite and quartz veins surrounded by a zone of disseminated pyrite showing argillic alteration.

The approximate boundary of the argillic alteration zone is used to define the outline of area B (fig. 4). Outside of area B is a poorly defined zone of propyliticaily altered rocks containing sporadic, small veins of pyrite with silicified margins. Area B extends into the headwaters of the Klickitat River on the Yakima Indian Reservation; the boundaries of the alteration zone were not mapped in the Reservation itself, but are approximate. Widespread propylitic alteration of Pliocene and lower Pleistocene(?) volcanic rocks indicate extensive hydrothermal activity. The area formed beneath an earlier volcanic vent system centered southwest of Cispus Pass. Interpretation of the gravity data (fig. 2) suggests a cupola on the Goat Rocks pluton underlying this vent area. A small outcrop of Cispus Pass pluton is present in the southern part of area B. No dike swarm is present in this alteration area, nor is there an associated magnetic low.

Geochemical sampling indicated anomalous leachable cobalt, molybdenum, nickel, copper, lead, and zinc in the stream sediments collected from drainages in the Goat Rocks Wilderness surrounding this anomaly. Fluoride, sulfate, copper, and molybdenum anomalies were measured in the water samples collected from these drainages. Pyrite was ubiquitous in the nonmagnetic, heavy-mineral concentrates, and cinnabar was identified in the sample from the headwaters of the southern tributary of the South Fork of the Tieton River. Metal anomalies from the heavy-mineral concentrates included lead, cobalt, barium, nickel, copper, zinc, mercury, bismuth, boron, niobium, and arsenic. Samples of altered rock contained anomalous concentrations of manganese, cobalt, nickel, copper, molybdenum, lead, arsenic, zinc, and niobium; one sample contained anomalous silver. Leachable magnesium, chromium, aluminum, and high, but sporadic distributions of phosphorous were also detected in the samples of altered rock. Chip samples collected from area B by the U.S. Bureau of Mines contained maximum values of 30 ppm copper, 200 ppm lead, and 120 ppm zinc. Average values were less than 0.2 ppm silver, 16 ppm copper, 54 ppm lead, and 43 ppm zinc.

No magnetic low was observed in association with area B although, admittedly, it was not as readily visible in the magnetic data due to the steep relief of the terrain. Our data suggest that area B has a moderate potential for the occurrence of base-metal resources in a disseminated porphyry-copper deposit. Further evaluation of area B cannot be made without additional sampling, subsurface exploration, and access to exposures in the headwaters of the Klickitat River on the Yakima Indian Reservation.

Area C, Clear Fork of the Cowlitz River, is outlined by a widespread geochemical anomaly along the Clear Fork of the Cowlitz River and small south-draining tributaries of the North Fork of the Tieton River (fig. 4). Area C is underlain by the Ohanapecosh Formation with beds dipping about 40° west-southwest. Rock exposures in this area are poor, landslides are common, and the area is covered with brush. The gravity data suggest a subsurface contact between the Goat Rocks pluton and the sediments to the east (figs. 1 and 2), but the nature of this contact, be it an intrusive contact or a fault, could not be discerned during geologic mapping (Swanson and Clayton, 1983).

Evidence of mineralization along this contact can be seen in both the geochemical and the mineralogical data. Anomalous metals in stream-sediment samples were leachable copper, cobalt, manganese, barium, zinc, lead, nickel, and molybdenum. Water samples contained anomalous fluoride, chloride, copper, and molybdenum. Pyrite was ubiquitous in the nonmagnetic, heavy-mineral concentrates. Barite was identified in four samples: two from tributaries along the North Fork of the Tieton River, and two from the upper reaches of the Clear Fork of the Cowlitz River. Two of these same sites, and two others from the Clear Fork of the Cowlitz River, also contained cinnabar. Metal values in the nonmagnetic, heavy-mineral concentrates indicated anomalous values for lead, barium, cobalt, copper, zinc, nickel, boron, arsenic, tin, niobium, and mercury. A few samples of altered rock collected in area C contained anomalous levels of leachable zinc, manganese, molybdenum, arsenic, and lesser amounts of lead.

Indications of mineral resources in area C are ambiguous. If the contact between the sedimentary rocks and the pluton is intrusive, mineralization could occur along the intrusive contact, along fractures in the intruded sedimentary rocks, along the truncated bedding planes of the Russell Ranch and Ohanapecosh Formations, or along the unconformity between the Russell Ranch and the Ohanapecosh. The lack of a magnetic anomaly neither suggests nor precludes a large-scale hydrothermal system. No mineralized veins were seen in the area during the field evaluation of the geochemical anomalies or during the geologic mapping. Area C (fig. 4) is classified as having a low potential for the occurrence of base-metal resources in hydrothermal veins associated with a porphyry-copper system.

Several localized geochemical anomalies exist in drainages in the Goat Rocks study area, but they have not been designated in this report as areas of potential for mineral resources. The strong geochemical anomaly in the stream sediments from the outcrop belt of the Russell Ranch Formation east of Hogback Mountain, area D, in roadless area 06036D may suggest a volcanogenic massive sulfide deposit (Franklin and others, 1981). The Russell Ranch Formation is dominantly a marine sedimentary unit containing some submarine basalts. No field studies of this anomaly were made, because no sulfate anomalies were detected in the water samples; no zinc anomalies and only small anomalies of leachable barium and lead were seen in the stream-sediment sample medium. Area D has low potential for the occurrence of copper, lead, and zinc resources in volcanogenic massive sulfide deposits within the Russell Ranch Formation.

Coal resources

Outside the study area, coal, discovered along Summit Creek in the Cowlitz Pass coal field, occurs in beds of the Spiketon Formation (Gard, 1968, p. 11) and similar rocks also occur in the Packwood coal field (Culver, 1919, p. 125). The formation is discontinuous, but where present, it consists of as much as 3,600 ft of repeated arkosic sandstone, carbonaceous siltstone, mudstone, and anthracite coal beds. Maximum thickness of the coal-bearing beds exposed in the Packwood coal field occurs in 600 ft of workings near the summit of the ridge between Coal and Lake Creeks, west of the Goat Rocks study area. Only 3 ft of the 18-foot-thick coal-bearing section contains pure coal. The beds dip steeply away from the study area (strike N. 5° E., dip 30° W.) and the coal-bearing units do not crop out in the study area. Attempts were made to mine coal in the Cowlitz Pass coal field, but the coal proved too shaly to be used for fuel (Green, 1947, p. 14). Beikman and others (1961, p. 103) estimated that the Summit Creek area contains an inferred coal resource of less than 4 million tons. No coal or outcrops of the Spiketon Formation were found in the vicinity of the Buckeye coal claim (fig. 3, no. 6) or elsewhere in the Goat Rocks study area. It is unlikely that there are any significant coal resources in the Goat Rocks study area.

Stone resources

The only mineral commodity produced in the vicinity of the Goat Rocks study area is stone. Small amounts of andesite-flagstone are intermittently quarried from deposits at Dog Lake (fig. 3, no. 7). Basalt and andesite are periodically produced from quarries along Johnson Creek for construction and maintenance of macadam-surfaced logging roads (fig. 3, no. 8). Similar stone deposits occur in the study area; however, demand can be met more readily from existing quarries. Abundant alluvial deposits along streams draining the study area contain sand and gravel suitable for construction, but alternate sources are closer to local markets.

Geothermal resources

The Cascade Range contains a number of hot springs associated with Recent volcanic activity (Washington Department of Natural Resources, 1982). Muffler (1979) classified the Cascade Range as an area of potential geothermal resources. However, there are no hot springs within the Goat Rocks study area and the most recent volcanism found in the area, the basaltic flows from a subglacial volcano near Walupt Lake, occurred about 14,000 years ago. The nearest hot springs are the Ohanapecosh hot springs located about 5 mi north of the Goat Rocks study area (fig. 3, no. 9). Emplacement of the Goat Rocks pluton may have occurred throughout the lifetime of the Goat Rocks volcano, from about 3 m.y. to less than 1 m.y ago. A single fission track age of 1 m.y. has been obtained for the Cispus Pass pluton (Clayton, 1983). No heat flow measurements were made during the study. The lack of Holocene silicic volcanic activity and absence of hot springs suggest that the Goat Rocks study area has a low potential for geothermal resources.

Oil and gas resources

Specific investigations for oil and gas potential were not made for this study; however, there is cumulative evidence that oil and gas may exist in the study area. Drilling indicates marine sedimentary rocks beneath the Columbia River Basalt Group just west of the study area (Lewis, 1982), and oil and gas are currently being produced from Eocene marine sedimentary rocks in the Mist field about 40 mi north of Portland, Oreg. W. D. Stanley (unpub. data, 1983) presented the results of a regional magnetotelluric study across the north-central Cascade Range in Washington; the study included an east-west cross section north of the Goat Rocks study area. The implications for oil and gas potential cannot be dismissed. Stanley interprets his data to reflect a sedimentary section as much as 6 mi in thickness just east of the study area. Stanley's interpretation is supported by the gravity data from the work of Williams and others (1983), which suggests that low-density sediments occur on both the east and west sides of the Goat Rocks pluton to a depth of several thousand feet. The marine Russell Ranch Formation may also be underlain by a thick series of pre-Tertiary marine sedimentary rocks that strike N. 20°-30° W. and pass very near the present location of the Clear Fork of the Cowlitz River. If a marine sedimentary section underlies the Russell Ranch Formation, this melange may contain numerous structural and stratigraphic traps on either side of the Goat Rocks pluton. The lack of data concerning the presence of adequate marine source rocks, the effect of the thermal aureole surrounding the Goat Rocks pluton, and the nature of the geologic contact between the pluton and the sedimentary rocks precludes a definitive evaluation of the potential for oil and gas resources in the study area. Further definition of the oil and gas potential can only be addressed by subsurface exploration methods and possibly by drilling. On the basis of available data, the oil and gas potential of the Goat Rocks study area is low.

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