UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geology and mineral resource potential map of the Diamond Peak Wilderness, Lane and Klamath Counties, Oregon

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STUDIES RELATED TO WILDERNESS AREAS

Under the provisions of the Wilderness Act (Public Law 88-577, Sept. 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 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 of the Diamond Peak Wilderness (NF017), Deschutes and Willamette National Forests, Lane and Klamath Counties, Oregon. The Diamond Peak Wilderness was established by Public Law 88-577, September 3, 1964.

SUMMARY

Diamond Peak Wilderness contains no identified metallic mineral resources or mineral fuels. No historic or active mining activity is known within the wilderness. Two cinder cones in or partly in the wilderness, Red Top Mountain and Crater Butte, contain substantial cinder resources, but future demand for the deposits is not anticipated because numerous other sources are nearby. The area has a low potential for geothermal resources.

INTRODUCTION

Diamond Peak Wilderness covers 36,637 acres (57 mi^2) in the Deschutes and Willamette National Forests, Lane and Klamath Counties, Oregon (fig. 1). The U.S. Geological Survey and U.S. Bureau of Mines conducted a mineral survey of the wilderness in the summers of 1980 - 1982. Geological, geochemical, and geophysical studies by the Geological Survey, and detailed examinations of known or suspected mineralized areas by the Bureau of Mines were used to evaluate the mineral resource potential of the area.

Diamond Peak Wilderness is located along the crest of the Cascade Range 56 mi southwest of Bend and 20 mi southeast of Oakridge, Oregon. The area is most easily reached from Oregon State Highway 58, and is bounded on the north and east by the Southern Pacific Railroad right-of-way, on the south by the unpaved Emigrant Pass road, and on the west by a network of Forest Service gravel roads. Logging operations are ongoing along the western boundary.

The dominant geographic feature in the wilderness is Diamond Peak, 8,748 ft in elevation. Although total relief in the wilderness exceeds 4,000 ft, the terrain is characterized by gentle to moderate slopes. Streams flowing west from the crest of the Cascade Range are moderately incised whereas east-flowing streams form broad drainages between volcanic landforms. All of the wilderness except the higher parts of Diamond Peak is forested with hemlock and fir.

The Diamond Peak area is included in a regional reconnaissance map of the High Cascades (Williams, 1957), but no detailed geologic maps of the area exist. Aeromagnetic and gravity maps of the central Cascade Range

(Couch and others, 1978; Pitts and Couch, 1978) include the Diamond Peak area.

GEOLOGY

Diamond Peak Wilderness and the crest of the Cascade Range are part of the High Cascade physiographic province of Oregon. The province is an elongate belt of upper Cenozoic lava flows and vents. The major Cascade peaks are Pleistocene stratovolcanoes built upon this belt. Some of these volcanoes are homogeneous accumulations of mafic flows and pyroclastic rocks; others include rocks ranging in composition from basalt to rhyodacite.

Diamond Peak is a Pleistocene stratovolcano formed dominantly of basaltic andesite flows and pyroclastic rocks (fig. 2). The volcano has a youthful form, although glacially modified, and its lavas have normal remanent magnetization. As there is no indication of post-glacial (less than 10,000 years) activity, the volcano is probably extinct. Adjacent stratovolcanoes at Mount Yoran and Lakeview Mountain are similar in composition to Diamond Peak but are older and more deeply dissected. Flows from Mount Yoran have a K/Ar age of 0.33 ± 0.07 m.y. (J. G. Smith, oral commun., 1982). These stratovolcanoes are built of poorly bedded pyroclastic rocks with minor interbedded flows, and are laced by dikes and sills that radiate from one or more high level plugs or volcanic necks. The flanks are composed of numerous lava flows.

Redtop Mountain and Crater Butte are cinder cones formed of accumulations of red to black lapilli, scoria, and bombs. The early ejecta are variably altered to palagonite -- yellowish orange clays derived from basaltic glass.

The lavas throughout the wilderness are fresh olivine basaltic andesite and basalt. Individual flows range from 6 to 30 ft thick and are separated by flow breccias. Most rocks are slightly porphyritic, containing a few percent olivine and plagioclase, with more or less clinopyroxene. Plagioclase is more abundant higher in the lava sequence of Diamond Peak and small prisms of hypersthene occur in the latest lava flows from that volcano. No silicic rocks occur in the wilderness.

Repeated glaciations have dissected the volcanoes, scoured the upland surfaces, and deposited lateral and ground moraines over much of the middle and lower elevations. The glacial drift occurs as unsorted, unstratified deposits of angular to sub-rounded pebbles and angular blocks in a poorly indurated matrix of sand and rock flour. The clasts possess negligible weathering rinds, consistent with a late Pleistocene age (Cabot Creek glaciation of Scott, 1977); older tills occur beyond the limits of the wilderness. Holocene glacial episodes have been responsible for pro-talus ramparts in some of the cirques on Diamond Peak.

An air fall pumice deposit up to 32 in. thick mantles the wilderness. The deposit consists of ash and lapilli up to one-half inch in size, with small proportions of plagioclase, pyroxene, and hornblende crystals. This pumice is part of the extensive Mazama ash deposit erupted about 6,845 ^{14}C years ago from the caldera at Crater Lake National Park (Williams, 1942; Bacon, 1983). No volcanic rocks in the wilderness are younger than the Mazama ash.

Although the lavas are unaltered, trace amounts of specular hematite, and less commonly malachite, occur locally in fractures within the flows. The mineralization is scattered and rare, discontinuous

within any single fracture, and is not associated with any other kind of rock alteration or veining. In all cases, the mineralization along the fractures occurs within one half mile of a vent and is caused by volcanic exhalative processes. The vents are unaltered except for trace amounts of clays, probably the result of fumarolic activity. Intrusive rocks are unaltered.

MINERAL RESOURCES

The Diamond Peak Wilderness contains no known mining claims or active mines, nor any identified resources of metallic minerals. The only indications of base- or precious-metal interest near the wilderness are old placers, mostly along Crescent Creek east of the wilderness; there is no known production from these placers. The nearest significant mining (lead, zinc, copper, gold, silver) occurred in the Bohemia mining district, in the Western Cascades 20 to 25 mi due west of Diamond Peak (Brooks and Ramp, 1968); metallic mineral resources are not known to occur in the High Cascade physiographic province in Oregon.

As part of this mineral investigation, stream-sediment samples were analyzed for 31 elements, including base and precious metals. Sample locations are shown on Figure 1 and analytical data are listed in Table 1. Two samples of sand- and silt-size sediment were collected from stream bottoms at most sites, one of bulk sediment, the other a pan-concentrate of the heavy-mineral fraction of the sediment. Each sample was dried, sieved to minus-80 mesh, and split. The heavy minerals in the pan-concentrate sample were further concentrated by settling in bromoform (specific gravity, 2.8) and separated into magnetic and nonmagnetic fractions. Stream sediment and nonmagnetic heavy-mineral

concentrate samples were then pulverized before analysis by standard semiquantitative emission spectrography; some concentrate samples did not yield enough material for analysis. All of the analyzed samples contain only trace abundances of metallic elements, similar to those commonly found in unaltered volcanic rocks.

Small quantities of angular flour gold, in amounts ranging from 0.00001 to 0.0002 oz per cubic yard, were recovered from 15 of 17 placer gravel samples collected by the U. S. Bureau of Mines from streams draining the wilderness (Moyle and Rumsey, 1982). This gold content, from 3 to 60 parts per billion, is about 1000 times lower than economic values that existed in 1983. Similar traces of gold were found in many streams in other parts of the High Cascades province which suggests the gold is derived from dispersed sources in the volcanic rocks rather than being related to surficial or buried mineral deposits. Assay results of a sample of slightly altered basaltic andesite from the eastern flank of Diamond Peak indicates a trace gold and 0.005 percent copper.

Immediately west of the wilderness, alteration has affected Miocene silicic lava flows and a shallow intrusion. Pyrite is present in minor amounts, but X-ray diffraction studies of the clays in the alteration zone failed to show any sericite or other signs of potassium metasomatism. No gold, silver, or copper was detected in a sample analyzed from the alteration zone. The alteration likely developed around an old hot spring or solfatara. North of the wilderness at the Willamette Pass quarry (fig. 1), a small malachite-bearing fracture zone in basaltic andesite flows contains 0.4 oz per ton silver.

There has been no rock or cinder production from the Diamond Peak Wilderness. An estimated 670,000 cubic yards of crushed stone, pit-run materials, and rip-rap have been produced from seven quarries outside the western and northern boundaries of the wilderness (Table 2). More than 87,000 cubic yards of available existing reserves remain at the active quarries (Cindy Pack, U.S.F.S., written commun., 1980). An additional 510,000 cubic yards is available at the Willamette Quarry (Table 2, no. 1) but may not be produced owing to environmental constraints. New crushed stone sources are presently being developed west of Diamond Peak Wilderness at this time (Robert White, U.S.F.S., oral commun., 1980).

Two pyroclastic cones along the boundaries of the wilderness contain cinders suitable for road construction and other common uses. Redtop Mountain, which is mostly within the wilderness, has a maximum volume of 83 million cubic yards, and Crater Butte, which is mostly outside the wilderness, contains a maximum of 37 million cubic yards, assuming base levels of 6,400 ft and 6,500 ft, respectively (Moyle and Rumsey, 1982). The volume that would be of industrial interest, however, is probably considerably less. Furthermore, cinder and rock material are very abundant in the Cascade Range outside the wilderness.

Hydrocarbon deposits (oil, natural gas, coal) are not known to occur in the region and are highly unlikely in the Diamond Peak Wilderness, which is underlain by a very thick sequence of volcanic rocks.

The Diamond Peak Wilderness is located in the High Cascade physiographic province, a region formed of young volcanic rocks and which

may locally contain geothermal energy resources capable of producing electric power or lower temperature resources for uses such as in agriculture and direct heating. Hot springs occur marginal to the province, mostly along valley bottoms near the contact between the Western Cascades and High Cascades. They are interpreted to represent lateral flow of hot water from sources beneath the High Cascades (Blackwell and others, 1978).

No thermal springs occur in the Diamond Peak Wilderness. The nearest hot springs occur along Salt Creek (McCredie Springs; 163°F), Salmon Creek (Wall Creek Springs; 106°F), and Hills Creek (Kitson Hot Springs; 111°F), 10 to 18 mi northwest of the wilderness boundary, and a warm spring occurs near Summit Lake, south of the boundary (Waring, 1965; Riccio, 1978; Bowen and Peterson, 1970; Bowen and others, 1978; Brown and others, 1980). The geochemistry of the waters from these springs does not indicate high temperature sources (Mariner and others, 1975, 1980; Brown and others, 1980), but cold meteoric water probably has diluted the thermal water during lateral subsurface flow.

Temperature gradients in drill holes at scattered localities near the boundary between the Western Cascades and High Cascades suggest that heat flow increases significantly under the High Cascades (Blackwell and others, 1978). Shallow heat flow holes drilled in older rocks of the Western Cascades a few miles west and northwest of the Diamond Peak Wilderness had bottom hole temperatures of 50° to 70°F at depths of less than 500 ft and temperature gradients of 104° to 226°F/mi (Brown and others, 1980; Woller, 1982). No deep holes have been drilled in the Diamond Peak Wilderness.

On the basis of the local geology, there is no reason to suspect that geothermal resources are more likely in the wilderness than in other nearby parts of the High Cascades. If they are present, they probably occur at substantial depth. At these depths the volcanic rocks may have very low porosity and permeability and, even if temperatures are high, fluids may not be present in sufficient quantity for geothermal energy production. Exploitation of low-temperature geothermal resources that may occur beneath the wilderness is probably not viable due to the distance to the nearest points of use. In summary, available evidence fails to substantiate the presence of geothermal resources, and if they do occur they are probably at considerable depth.

MINERAL RESOURCE POTENTIAL

The Diamond Peak Wilderness contains no identified metallic mineral resources and there is no evidence of a potential for their occurrence. Cinder cones partly in the wilderness contain an estimated total of 120 million cubic yards of volcanic cinder suitable for construction material, but voluminous alternative sources are present nearby outside of the wilderness.

Anomalous heat flow values associated with the High Cascade physiographic province, and warm springs near the wilderness, indicate an undefined, but low, potential for geothermal energy.

REFERENCES CITED

Bacon, C. R., 1983, Eruption history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal Volcanology and Geothermal Research (in press).

Blackwell, D. D., Hull, D. A., Bowen R. G. and Steele, J. L., 1978, Heat flow in Oregon: Oregon Department Geology and Mineral Industries Special Paper 4, 42 p.

Bowen, R. G., and Peterson, N. V., 1970, Thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 14, scale 1:1,000,000.

Bowen, R. G., Peterson, N. V., and Riccio, J. F., 1978, Low- to intermediate temperature thermal springs and wells in Oregon: Oregon Department Geology and Mineral Industries Geological Map Series GMS-10, scale 1:1,000,000.

Brooks, H. C., and Ramp, Len, 1968, Gold and silver in Oregon: Oregon Department Geology and Mineral Industries Bulletin 61, 338 p.

Brown, D. E., McLean, G. D., Woller, N. M., and Black, G. L., 1980, Preliminary geology and geothermal resource potential of the Willamette Pass area, Oregon: Oregon Department Geology and Mineral Industries Open-File Report O-80-3, 65 p.

Couch, R. W., Gemperle, M., and Connard, G. G., 1978, Total field aeromagnetic anomaly map, Cascade Mountain Range, central Oregon: Oregon Department Geology and Mineral Industries Map Series GMS-9, scale 1:125,000.

Mariner, R. H., Presser, T. S., Rapp, J. B., and Willey, L. M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U. S. Geological Survey Open-File Report, 27 p.

Mariner, R. H., Swanson, J. R., Orris, G. J., Presser, T. S., and Evans, W. C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U. S. Geological Survey Open-File Report 80-737, 50 p.

Moyle, P. R., and Rumsey, C. M., 1982, Summary report - mineral resources of the Diamond Peak Wilderness and proposed addition, Lane and Klamath Counties, Oregon: U.S. Bureau of Mines Open-File Report MLA23-82, 10 p.

Pitts, G. S., and Couch, R. W., 1978, Complete Bouguer gravity anomaly map, Cascade Mountain Range, central Oregon: Oregon Department Geology and Mineral Industries Map Series GMS-8, scale 1:125,000.

Riccio, J. F., 1978, Preliminary geothermal resource map of Oregon: Oregon Department Geology and Mineral Industries Map Series GMS-11, scale 1:500,000.

Scott, W. E., 1977, Quaternary glaciation and volcanism, Metolius River area, Oregon: Geological Society America Bulletin, v. 88, p. 113-124.

Waring, G. A., 1965, Thermal springs of the United States and other countries of the world--a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Williams, Howel, 1942, The geology of Crater Lake National Park, Oregon: Carnegie Institute Washington Publication 540, 162 p.

_____, 1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Department Geology and Mineral Industries Map, scales 1:125,000 and 1:250,000.

Woller, N. M., 1982, Geology of the Swift Creek area, in Geology and geothermal resources of the Cascades, Oregon, G. R. Priest and B. F. Vogt, editors: Oregon Department Geology and Mineral Industries Open-File Report 0-82-7, p. 135-151.

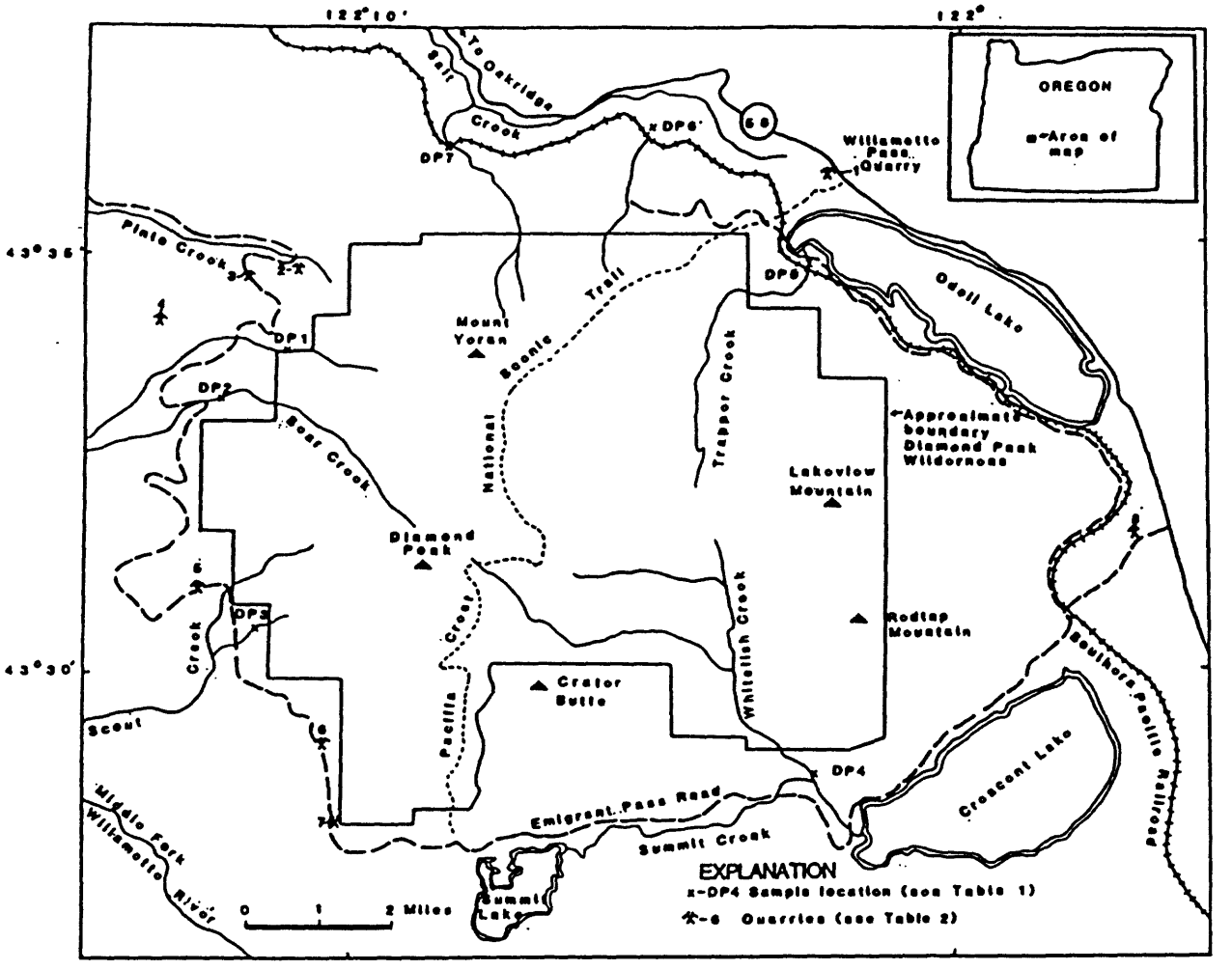


Figure 1. Location of the Diamond Peak Wilderness (NF017), Cascade Range, Lane and Klamath Counties, Oregon.

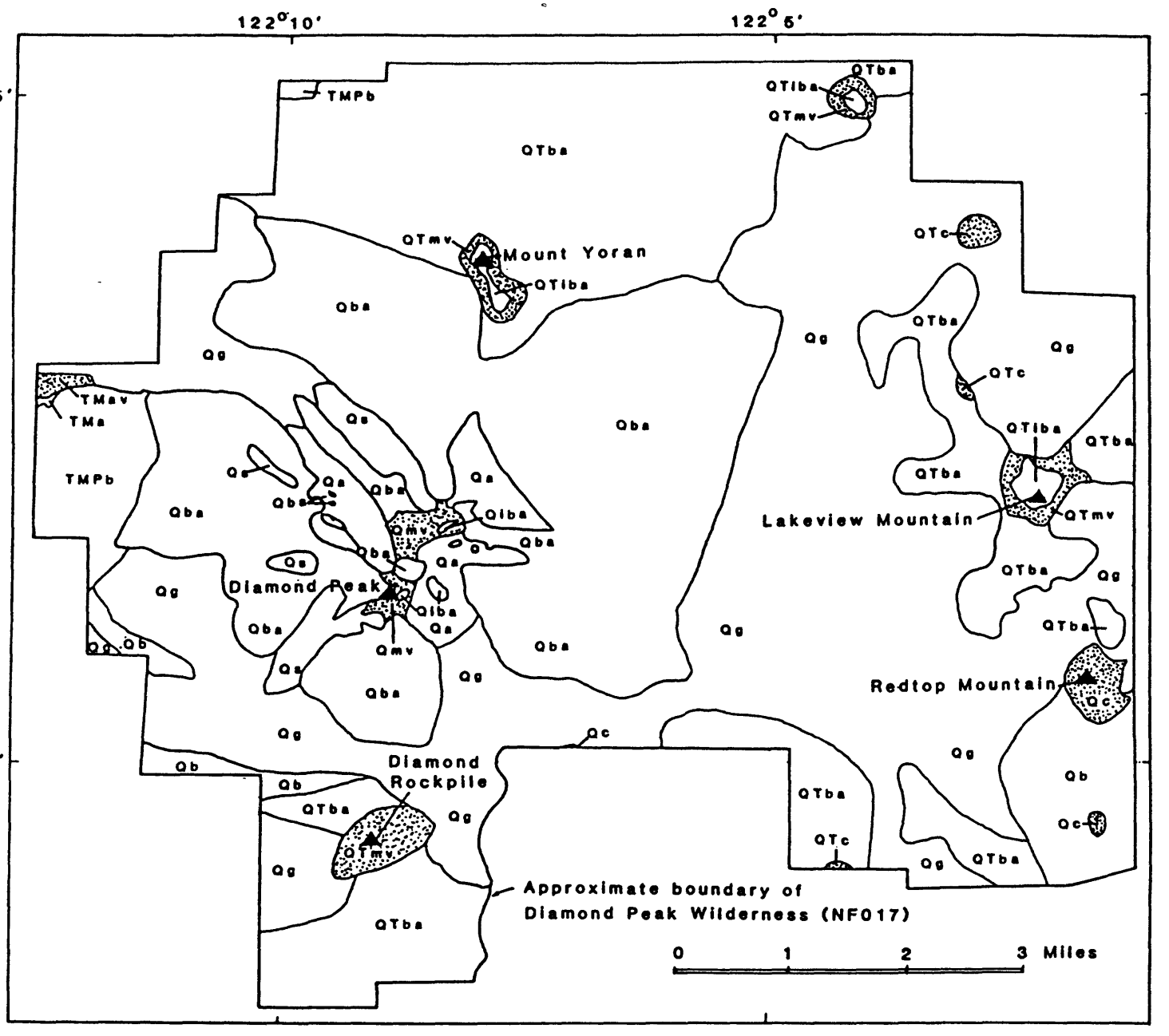
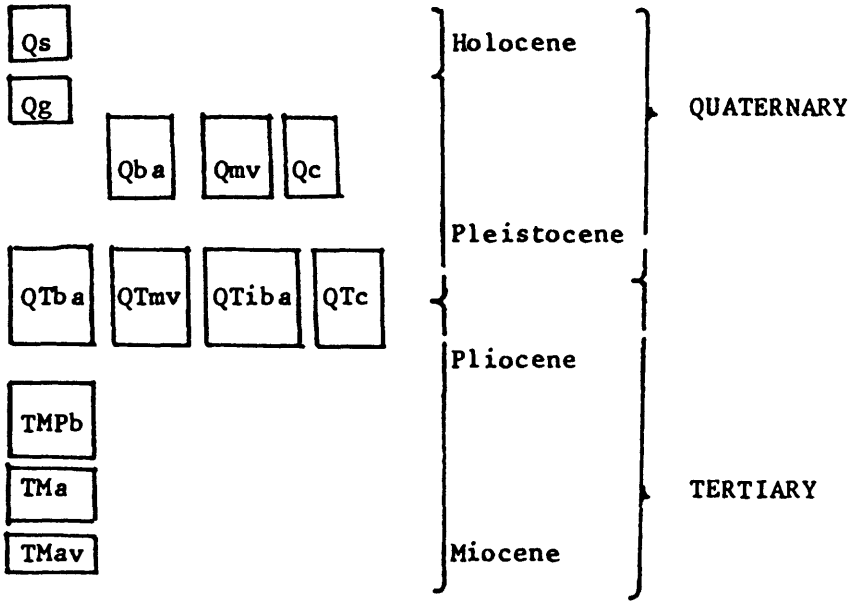


Figure 2.--Geologic map of the Diamond Peak Wilderness, Oregon. Geology by David R. Sherrod, 1981, 1982.

EXPLANATION

(Geologic map unit symbols may not necessarily conform to U.S. Geological Survey standards)

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qs SURFICIAL DEPOSITS (HOLOCENE)--Coarse to fine, poorly sorted, angular, unconsolidated rubble that forms talus cones, rock glaciers, and neoglacial moraines around Diamond Peak. Mostly younger than the Mazama ash

MAZAMA ASH (HOLOCENE) Not shown on map--Pumiceous ash and lapilli up to 1/2 in. in diameter, of slightly porphyritic pale gray dacite. Deposit occurs as a blanket 30 in. thick in south part of area and 12 in. in north; thickens abruptly eastward from Cascade crest. Completely buries older units in trough between Lakeview Mountain and Diamond Peak. Derived from climactic eruption of Mount Mazama

(Crater Lake), 45 mi south of Diamond Peak (Williams, 1942). Age about 6,845±50 ^{14}C years (Bacon, 1983)

Qg GLACIAL DRIFT (PLEISTOCENE)--Unsorted, unstratified deposits of sub-angular to sub-round cobbles and boulders in a matrix of poorly indurated rock flour; clasts have negligible weathering rinds. Occurs as ground moraines and lateral moraines. Probably formed during the Cabot Creek glaciation of Scott (1977)

Qba BASALTIC ANDESITE, BASALT, AND ANDESITE (PLEISTOCENE)--Medium gray to dark gray, vesicular to massive, slightly porphyritic lavas and grayish red flow breccias. Phenocrysts of olivine, 1-2 percent; plagioclase, 1-5 percent; clinopyroxene, 0-1 percent; hypersthene, 0-1 percent; and magnetite, 0-1 percent. Age younger than approximately 700,000 years, on basis of normal magnetic polarity and association with vents that are only moderately eroded. Correlative flows 3 miles west of the wilderness have yielded a K/Ar age of 0.17±0.48 m.y. (Woller, 1982)

Qc CINDER DEPOSITS (PLEISTOCENE)--Red to black basaltic cinders and scoria that form cinder cones. Includes some basaltic agglutinate, palagonitic lapilli tuff and tuff breccia, and minor intrusions and flows. Age less than approximately 700,000 years, on basis of youthful morphology and association with flows of normal magnetic polarity

Qmv MAFIC VENT COMPLEX OF DIAMOND PEAK (PLEISTOCENE)--Mafic pyroclastic rocks, dikes, sills, small plugs, and lava flows. Composition varies from olivine basalt to two-pyroxene olivine basaltic andesite. Age less than

approximately 700,000 years, on basis of youthful morphology and association with flows of normal magnetic polarity

QTba BASALTIC ANDESITE, BASALT, AND ANDESITE (PLEISTOCENE AND PLIOCENE)--Petrographically similar to unit Qba but generally more eroded; derived from deeply eroded vents or buried vents. Consists of rocks with normal and reversed magnetic polarity. K-Ar ages of 0.98±0.34 m.y. for flow west of Mount Yoran and 0.77±0.21 and 0.92±0.46 m.y. for flows southwest of Diamond Peak are reported by Woller (1982). Upper part may be as young as unit Qba; lower part may be older than 2 m.y.

QTc CINDER DEPOSITS (PLEISTOCENE AND PLIOCENE)--Similar to unit Qc but more deeply eroded. Includes vents associated with lavas included in unit QTba

QTmv MAFIC VENTS (PLEISTOCENE AND PLIOCENE)--Similar to unit Qmv but more deeply eroded. Includes vents that erupted lavas with both normal and reverse magnetic polarity. Age same as unit QTba

QTiba MAFIC INTRUSIONS (PLEISTOCENE AND PLIOCENE)--Dikes and plugs of very fine grained basalt or basaltic andesite. Intrudes unit QTmv. Consists of rocks with normal and reverse magnetic polarity

TMPb OLDER BASALT AND BASALTIC ANDESITE (PLIOCENE AND UPPER MIOCENE)--Light-gray to dark-gray olivine basalt and minor basaltic andesite flows and breccias that form dissected

ridges lacking the constructional landforms of the younger volcanic rocks. Similar in field appearance to units Qba and QTba but commonly slightly more weathered in appearance, contains more abundant olivine phenocrysts, and is dusted with abundant magnetite microphenocrysts. Woller (1982) reports K/Ar ages for correlative flows west of the area of 5.53 ± 0.34 m.y. and 4.32 ± 0.40 m.y.

TMa OLDER ANDESITE (MIOCENE)--Andesite flows and breccias; underlies unit TMPb in western part of area

TMav OLDER ANDESITE OR BASALTIC ANDESITE VENT DEPOSITS (MIOCENE)--Poorly-bedded to well-bedded tuff, lapilli tuff, and tuff breccia. Underlies unit TMa

CONTACT - Approximately located

VENT DEPOSITS

Table 2. Quarries and cinder deposits near Diamond Peak Wilderness, Oregon.

Map No. (fig. 1)	Name	Product	Historic Production (est.)(cubic yards)	Remaining Resource (est.)(cubic yards)
1	Willamette Pass	Crushed stone and glacial overburden	Pre-1975 - 500,000 1978 - 25,250 Post-1978 - 40,000	24,750 (plus 510,000 encumbered resources)
2	Notch Lake	Crushed stone	Pre-1974 - 10,000	5,000
3	Hemlock Butte	Stone: pit run	Pre-1974 - 10,000	3,000
4	Lone Ridge	High quality crushed stone (BC-3, BC-8)	1975 - 49,000 1977 - 8,000 1979 - 6,300	Unknown but substantial
5	Pioneer Gulch #2	Stone: pit run and 3 ft rip rap	Pre-1973 - 11,000 1973 4,000	15,000
6	Spatter Cone	mixed lava and cinder pit run	Pre-1974 1,200	4,000
7	Beaver Creek	Stone: pit run	Pre-1974 5,000	10,000
8	Unknown (inactive)	Common borrow: pumice, glacial till	3,000-5,000	Unknown
--	Red Top Mountain	Cinders	None	83,000,000
--	Crater Butte	Cinders	None	37,000,000

1 - 8 are near the wilderness; deposits at Red Top Mountain and Crater Butte are partly in the wilderness.

Table 1. Analytical data for stream-sediment samples from the Diamond Peak Wilderness, Oregon. Analyses are by G. W. Day, U. S. G. S., Denver, Colorado. (Fe, Mg, Ca, and Ti in percent; all other elements in parts per million; N, not detected; L, detected, but below limit of determination; * identifies non-magnetic heavy-mineral fraction of pan-concentrate sample)

Field No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr
	percent				ppm													
DP1B	5	7	5	.5	2000	70	500	30	70	100	N	70	50	20	700	200	20	100
DP2B	10	10	10	.7	2000	50	500	50	100	100	N	100	30	20	700	200	30	150
DP3A*	.2	5	.5	.5	200	L	500	N	N	10	N	20	30	N	2000	50	N	200
DP3B	7	3	5	.7	2000	100	700	30	100	100	30	70	70	20	700	200	30	200
DP4A*	1	1	5	.5	500	L	1000	N	70	20	N	20	700	N	5000	200	N	3000
DP4B	7	10	5	.5	1500	70	500	50	150	100	N	100	70	20	500	200	30	150
DP5B	10	10	10	1	3000	70	700	30	150	100	N	70	70	30	700	300	30	200
DP6B	10	10	20	1	3000	70	700	50	200	100	N	150	50	30	700	300	30	150
DP7B	10	10	10	1	2000	70	500	70	300	100	N	200	30	30	700	300	30	100
Lower limit of detection:	.05	.02	.05	.002	10	10	20	5	10	5	20	5	10	5	100	10	10	10

Analyzed for but below limit of detection (indicated by ppm in parentheses): antimony (100), arsenic (200), beryllium (1), bismuth (10), cadmium (20), gold (.1), molybdenum (5), silver (.5), tin (10), thorium (100), and tungsten (1).