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GEOCHEMICAL STUDIES OF ROCKS, WATER, AND GASES AT MT. HOOD, OREGON

Harold A. Wollenberg, Richard E. Bowen,
Harry R. Bowman, and Beverly Strisower

February 1979

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

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February 1979

1) Lawrence Berkeley Laboratory, Earth Sciences Division
2) Consultant to State of Oregon, Department of Geology and Mineral Industries

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ABSTRACT

Mt. Hood, a composite andesitic volcano, located near Portland, Oregon, is one of several large eruptive centers which dominate the Cascade Mountains of the western United States. As part of a program of geologic, geophysical and geochemical studies to examine Mt. Hood's geothermal resource potential, samples of warm-and cold-spring water, water from a geothermal test well in Old Maid Flat, fumarolic gases, and rocks were collected and analyzed for major chemical constituents and trace elements.

The only warm-spring area on Mt Hood is Swim Springs, located on the south flank. Orifices at Swim were sampled repeatedly with little overall change noted in water chemistry between summer and winter. Oxygen and hydrogen isotope data and mixing calculations based on analyses of Swim Springs and numerous cold springs, indicate that a large component of the warm water at Swim is from near-surface runoff. Chemical geothermometry suggests that temperatures at depth in the Swim Springs system are within the range 104-170°C; the temperature of unmixed hot water may exceed 200°C. Higher-than-background chloride contents and specific conductances of cold springs on the south flank of the mountain suggest that there is a small component of thermal water in these sources.

A geothermal model of Mt. Hood is proposed wherein snow- and glacier-melt water near the summit comes in close proximity to the hot central "neck" of the mountain, manifested by the summit-crater fumaroles. The hot water migrates down-slope, mixing with cold water along its path; a small portion of the mixed warm water surfaces at Swim Springs.

We were surprised to detect the platinum-group element, iridium in warm and cold spring waters and in a sample of altered andesite. Iridium is generally considered to be associated with basic to ultrabasic igneous rocks; its association with an andesite volcano is believed to be without precedent.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the following people for their valuable assistance on this project:

- Personnel of the State of Oregon's Department of Environmental Quality for use of earlier chemical analyses of waters in the Mt. Hood region;
- Jerry Black and Joseph Riccio of the State of Oregon's Department of Geology and Mineral Industries for assistance in collecting water samples;
- James Robison of the U.S. Geological Survey for aid in collecting samples and guidance on the hydrologic setting of Mt. Hood;
- Alfred Truesdell and Nancy Nehring of the U.S. Geological Survey for isotope analyses and analyses of constituents of fumarolic gases;
- David Johnson of the U.S. Geological Survey for aid in sampling and analyses of fumarolic gases;
- Steven Flexser of Lawrence Berkeley Laboratory for assistance in X-ray fluorescence analyses and Alan Smith of Lawrence Berkeley Laboratory for gamma-ray spectrometric analyses of radioelements.
- To Orah Goldman, the authors' thanks for many careful typings of text and tables.

This work was done under the auspices of the U.S. Department of Energy.

I. INTRODUCTION

Large volcanoes together with numerous smaller eruptive centers along the Cascade Mountains from Northern California into British Columbia (Figure 1) are evidence of a tremendous release of thermal energy along this zone. The geologic history of the Cascade Range indicates that eruptions and mountain building have taken place over a long period, and continue into the present. Mount Hood, located 80 km east of Portland (Figure 2), has a volcanic history similar to many of the other Cascade volcanoes. It has high-temperature fumaroles near its summit and a warm spring area on the south flank. These recognized thermal manifestations along with the mountain's accessibility and proximity to Portland, Oregon's main energy consuming region, make it a desirable location for the study and development of geothermal energy.

Over the past two years, a multidisciplinary study of the geologic, geochemical and geophysical features of Mount Hood that relate to the location of geothermal energy has been under the direction of the Oregon Department of Geology and Mineral Industries (DOGAMI) with funding from the U.S. Department of Energy. Earlier studies (Wise, 1968, 1969) described the geologic and tectonic framework of the region. Detailed geochemical and geophysical investigations are being conducted in the same area. A separate but related program of potential volcanic hazards of Mount Hood is being conducted concurrently by the U.S. Geological Survey (USGS) under the direction of D. R. Crandell.

Technical support of the geochemical studies of Mount Hood is supplied by the Earth Sciences Division of Lawrence Berkeley Laboratory (LBL). Geophysical studies consist of gravity and aeromagnetic surveys by Oregon State University, aerial infrared surveys by the USGS, and electrical

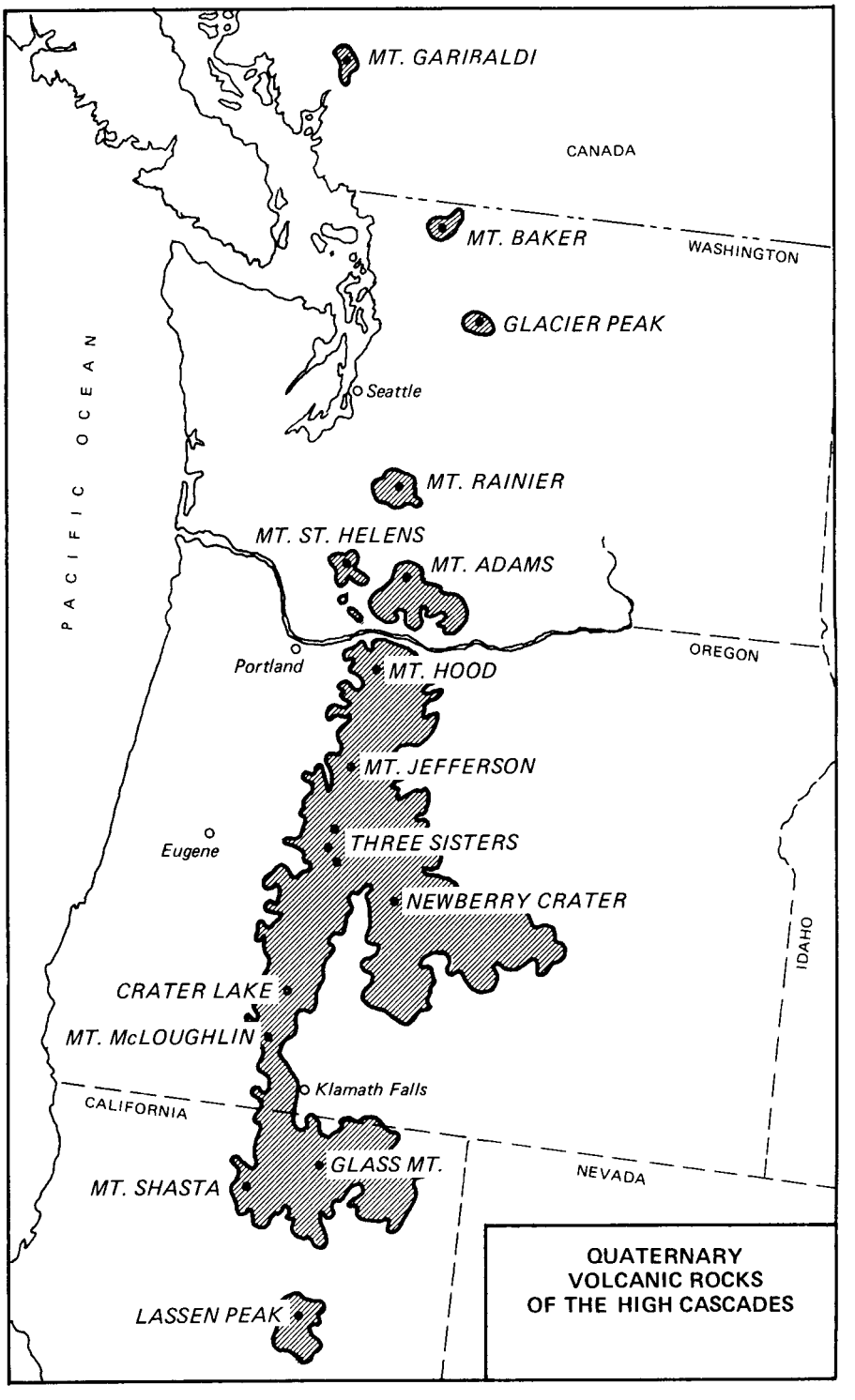


Figure 1. Regional geologic setting of Mt. Hood.

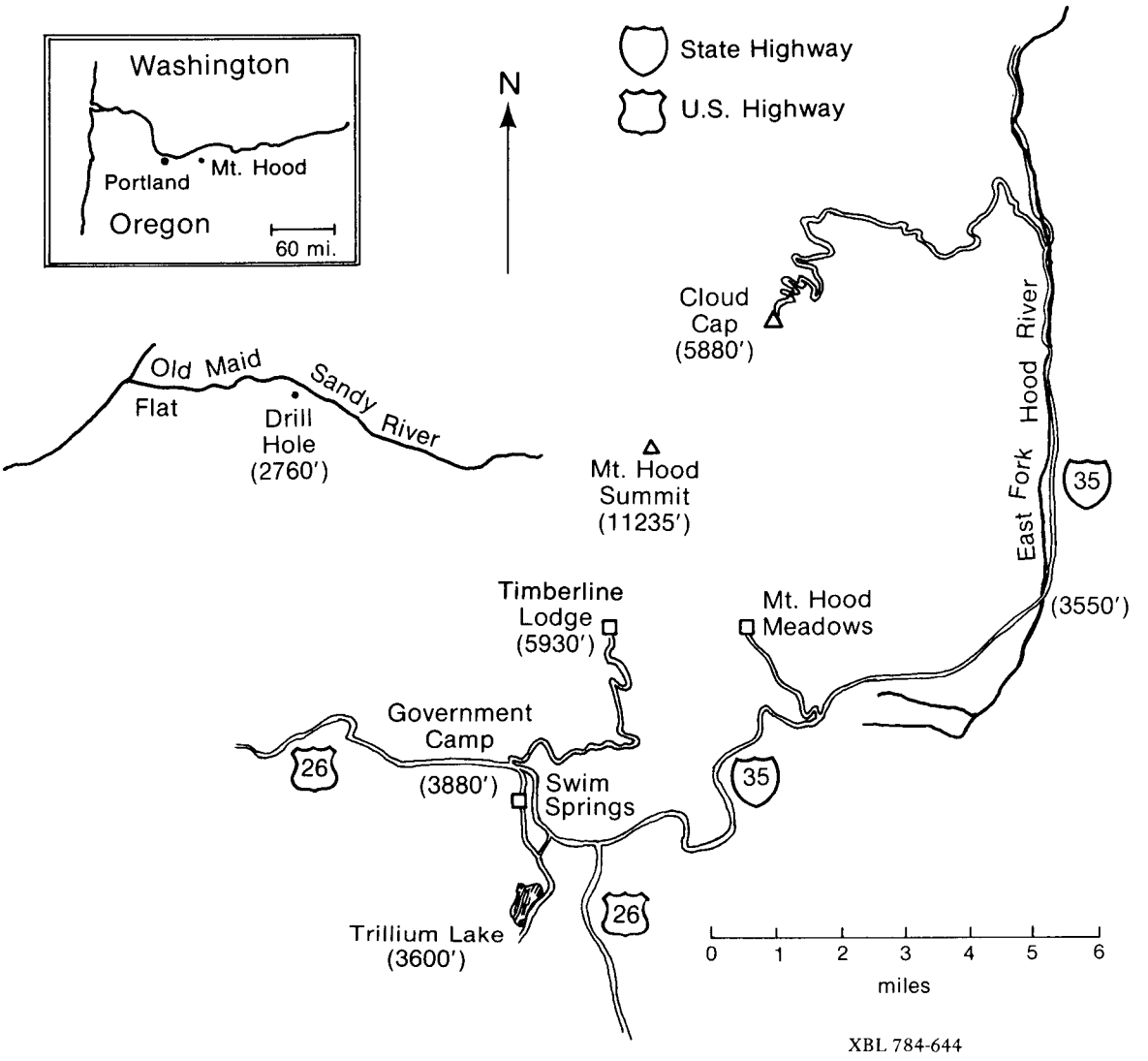


Figure 2. Location map, Mt. Hood area.

measurements by LBL (Goldstein and Mozley, 1978). Sampling and chemical analyses of rocks, gases, and ground waters in the area, including the fumaroles and the thermal and cold springs, has been a joint project between DOGAMI, USGS, and LBL. Suites of rocks typical of the area, both fresh and hydrothermally altered, have been analyzed to discern possible changes produced by the alteration. Selected water samples have been analyzed for oxygen and hydrogen isotope ratios to help determine the pathways water takes from its meteoric origin into and through the mountain's hydrologic system.

Analyses of waters from geothermal areas have proven to be very effective exploration tools. Truesdell (1975), in a comprehensive review, pointed out that several elements gave indications of minimum subsurface reservoir temperatures. The ratios between sodium, potassium, and calcium (Fournier and Truesdell, 1974) along with the silica content of warm-spring water may be definitive. A knowledge of silica contents and temperatures of cold and warm spring waters may be used to determine the amount of mixing of nonthermal waters and the reservoir temperatures before mixing.

This report emphasizes the presentation of analytical data obtained prior to October 1978. Since sampling and analyses have continued beyond that time, interpretative comments in this report are necessarily brief and should be considered as preliminary. A more detailed interpretation of the data awaits the results of continuing field sampling and laboratory analyses.

A. Geologic Setting

The regional setting of Mt. Hood is shown in Figure 1. Mt. Hood is a composite andesitic stratovolcano rising approximately 2500 meters above the surrounding terrain. It is largely Pleistocene in age with the main body of the cone constructed prior to the onset of Fraser Glaciation, about 20,000 years ago (Wise, 1968). Renewed volcanism took place about 12,000

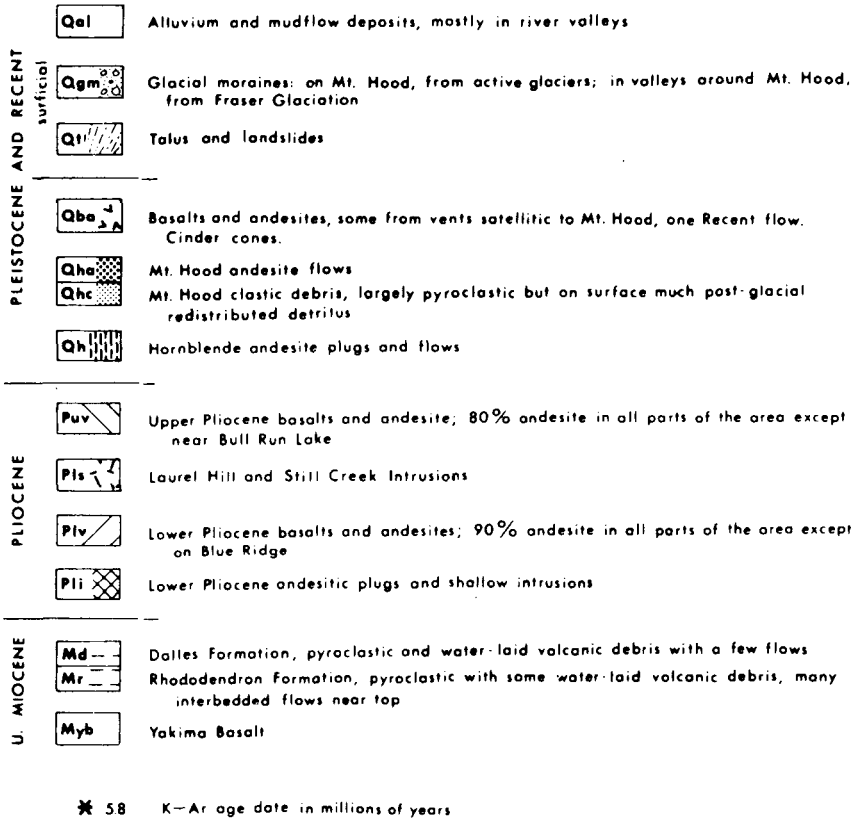
years ago with the extrusion of several domes near the summit (Crandell and Rubin, 1977). Further episodes of extrusions near the summit about 1,600 years ago produced a series of hot avalanches that culminated in the collapse of the south rim of the crater which then topped the mountain. The collapse of the south crater wall resulted in a large debris fan that covers the south flank of the mountain (Wise, 1968). The most recent major eruption took place about 220 years ago from the Crater Rock area. At that time a series of hot avalanches cascaded down the east and west sides of the mountain, carrying incandescent debris several miles down the valleys (Crandell and Rubin, 1977). Historical eruptions were reported in 1859 and 1865 (Folsom, 1970).

Mount Hood is located along a linear trend with most of the other Cascade volcanoes of Oregon and Washington. Thayer (1937) and Callaghan (1933) have associated the lineation with a fault zone they recognized along the western edge of the High Cascades. Allen (1965) believes that the volcanoes are concentrated in a graben formed by the Hood River-Green Ridge faults on the east and the unnamed faults of Thayer and Callaghan on the west. The western fault has not been recognized in the Mount Hood area but recent drilling on the west side of Mount Hood at Old Maid Flat shows there is significant displacement of the Columbia River Basalt that may be caused by faulting.

The local geologic setting of Mount Hood is illustrated in Figure 3 (Wise, 1968). The predominant surficial material is clastic debris, of andesitic character. A plug dome of hornblende andesite, Crater Rock, was extruded about 2,000 years ago. The extensive lava flows which predated the clastic debris were predominantly hornblende andesite, while more recent extrusions on the north and northeast flanks were of olivine basalt and olivine andesite.

GEOLOGY OF THE MT. HOOD AREA, OREGON

Explanation



⊘ *Surface water samples*

○ *Cold spring samples*

⊕ *Well samples*

● *Warm spring samples*

▲ *Rock samples*

0 1 2 miles

0 1 2 3 kilometers

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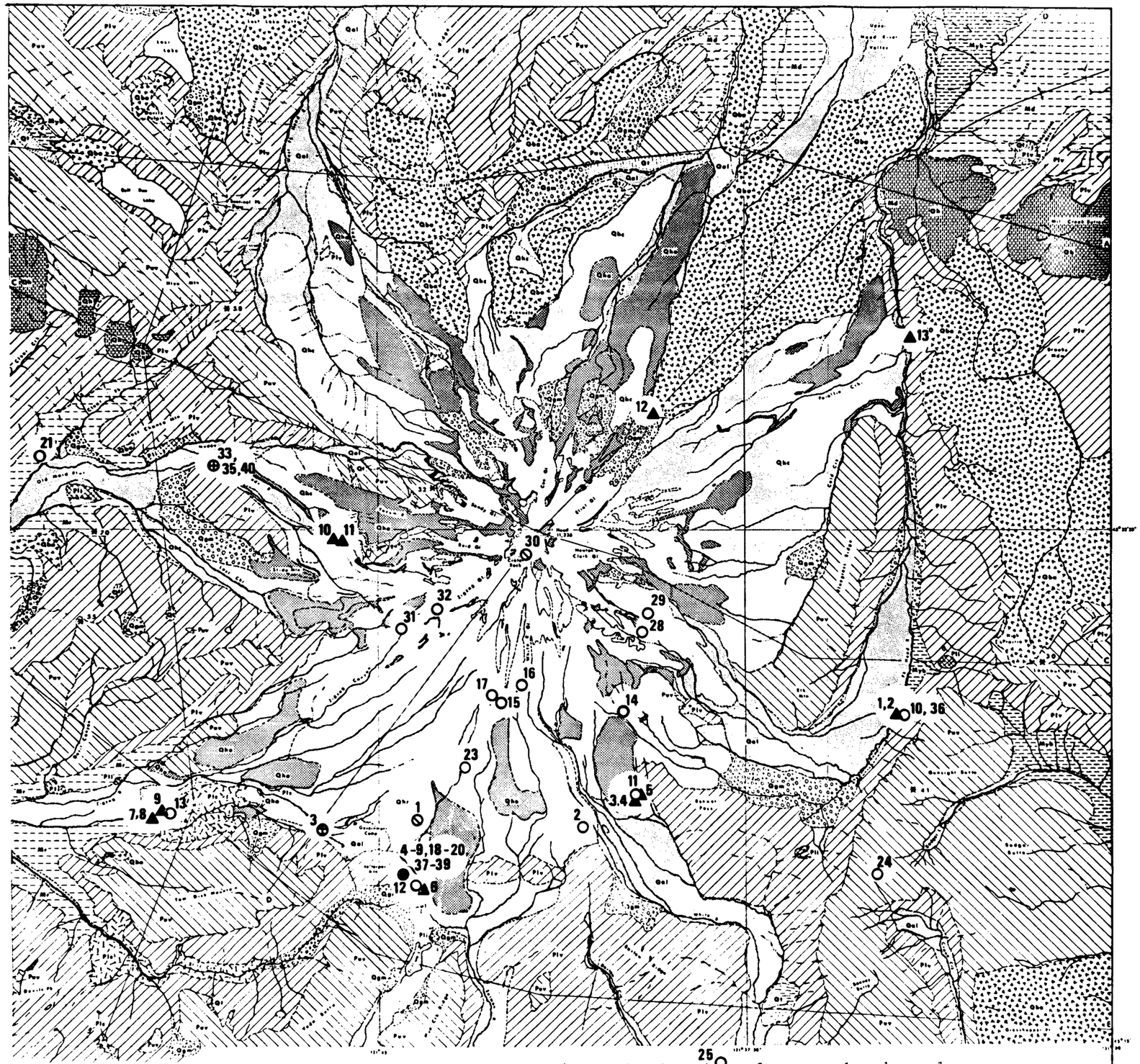

Figure 3. Local geologic setting of Mt. Hood (after Wise, 1968), showing locations of water and rock samples. XBL 788-2661

B. Hydrologic Setting*

Mt. Hood lies along the axis of the Cascade Range, and receives most of its precipitation during the fall and winter from storms that originate in the north Pacific and move southward and eastward across the range. The average annual precipitation is about 102 cm at Portland and increases to the east, to a maximum near the crest of the range. Records of the National Weather Service show that at Government Camp (Figure 2) the average is about 230 cm. Precipitation decreases rapidly to the east and is only 25 cm within 50 km of the crest.

Precipitation falling above an altitutde of about 1,500m on Mt. Hood is inferred to be within a recharge area, and ground water tends to move downward (Figure 4). The transition from recharge to discharge area is manifested by a band around the mountain where springs tend to discharge, and below which perennial streams are common. Above the band, many streams are intermittent; in smaller channels there is runoff only during spring, from melting snow.

At depths ranging to at least 250m in the vicinity of Timberline Lodge, ground water occurs in perched zones between or within andesite flows. The warm water emanating at Swim Springs may have circulated deeper than some of the perched zones, probably originating at elevations higher than Timberline Lodge. The water comes to the surface at Swim, where there is an abrupt flattening of the topographic slope (Figure 4); Mt. Hood andesite flows tend to dip down the mountain, and some permeable zones may intersect the land surface here. The Swim area also lies near a contact between Mt. Hood andesite flows or andesite debris and pre-Mt. Hood andesite and basalts (Wise, 1968); these older rocks are less permeable and may tend to direct ground water to the surface.

* Written in consultation with James Robison, U.S. Geological Survey, Menlo Park, California.

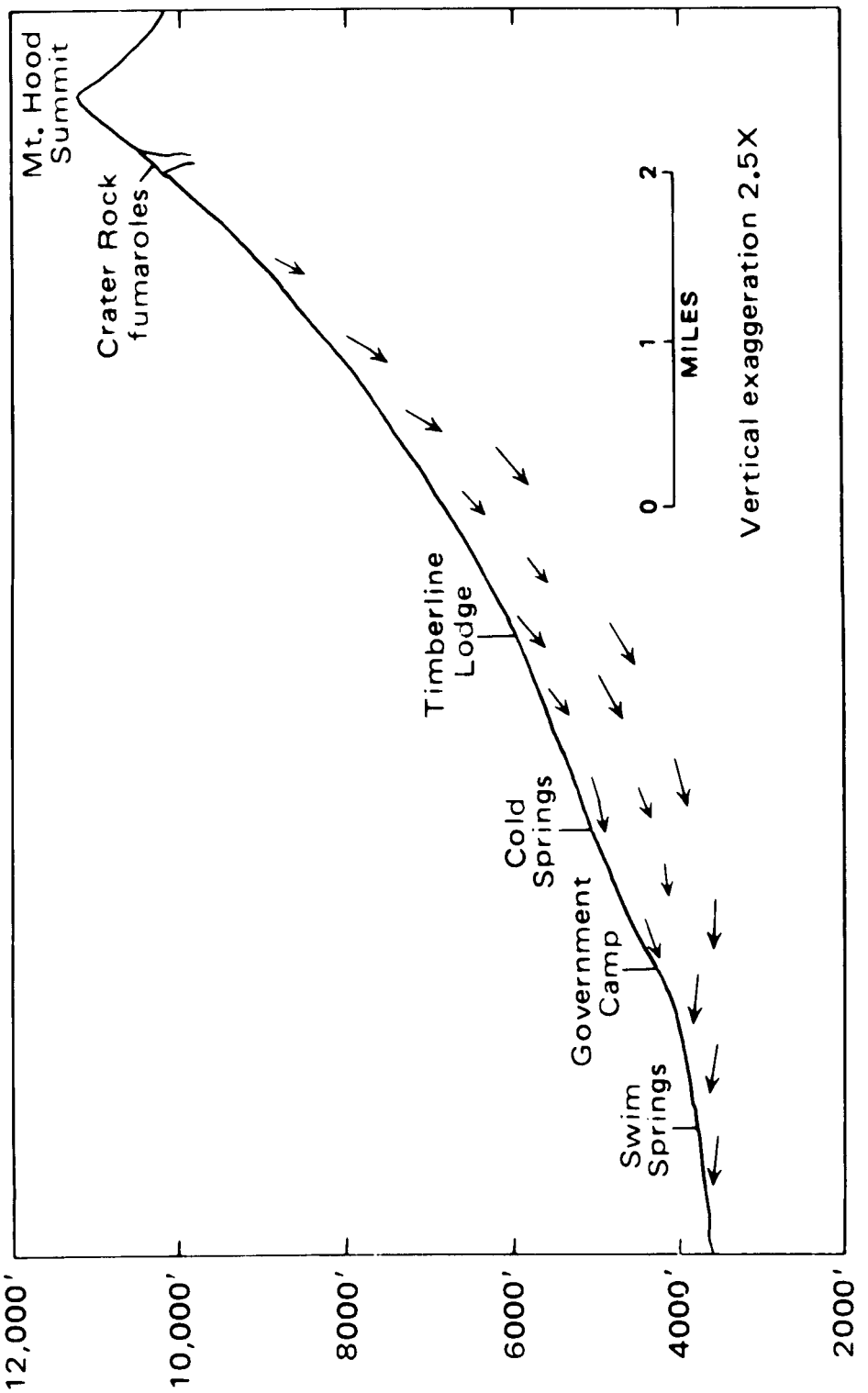

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Figure 4. Inferred ground water movement on Mt. Hood.

Distribution of runoff of streams draining Mt. Hood corresponds to that of precipitation. Records of a gauging station on Salmon River, 7 miles southeast of the summit of Mt. Hood (east of Trillium Lake near highway U.S. 26) show an average runoff of about 80 cm per year for the drainage area above the gauge. Sandy River has a runoff of 178 cm above a gauge 30 km west of the summit, and the West Fork of the Hood River has a runoff of 203 cm above a station 26 km northeast of the summit. The greatest runoff in the Mt. Hood area is reflected at a station on Bull Run River, 29 km northwest of the summit, where the average is more than 305 cm. The component of any deeply-circulating ground water in most of the springs is probably very small because the runoff is large.

II. SAMPLING AND ANALYSES

Techniques used by LBL to sample waters and rocks and to analyze them for major and trace elements have been detailed in papers by Bowman and others, (1975), Hebert and Bowman (1975), and Wollenberg (1975). In this section we shall briefly describe those techniques and the techniques to determine oxygen and hydrogen isotope ratios and constituents of fumarolic gases.

A. Water

Water samples were collected at the locations shown in Figure 3; locations are referenced by latitude and longitude in Table 1. Samples included waters from cold springs and wells, the Swim Warm Springs on the south flank of the mountain (the distribution of orifices at Swim is detailed in Figure 5), and the well drilled for geothermal water on the western flank of Mt. Hood in Old Maid Flat. Samples were collected for laboratory radiometry, X-ray fluorescence, neutron activation, and mass-spectrometric analyses. For analyses of major and trace elements, sampling was done by inserting a 1/4-inch diameter tygon tube into a spring. The water was drawn

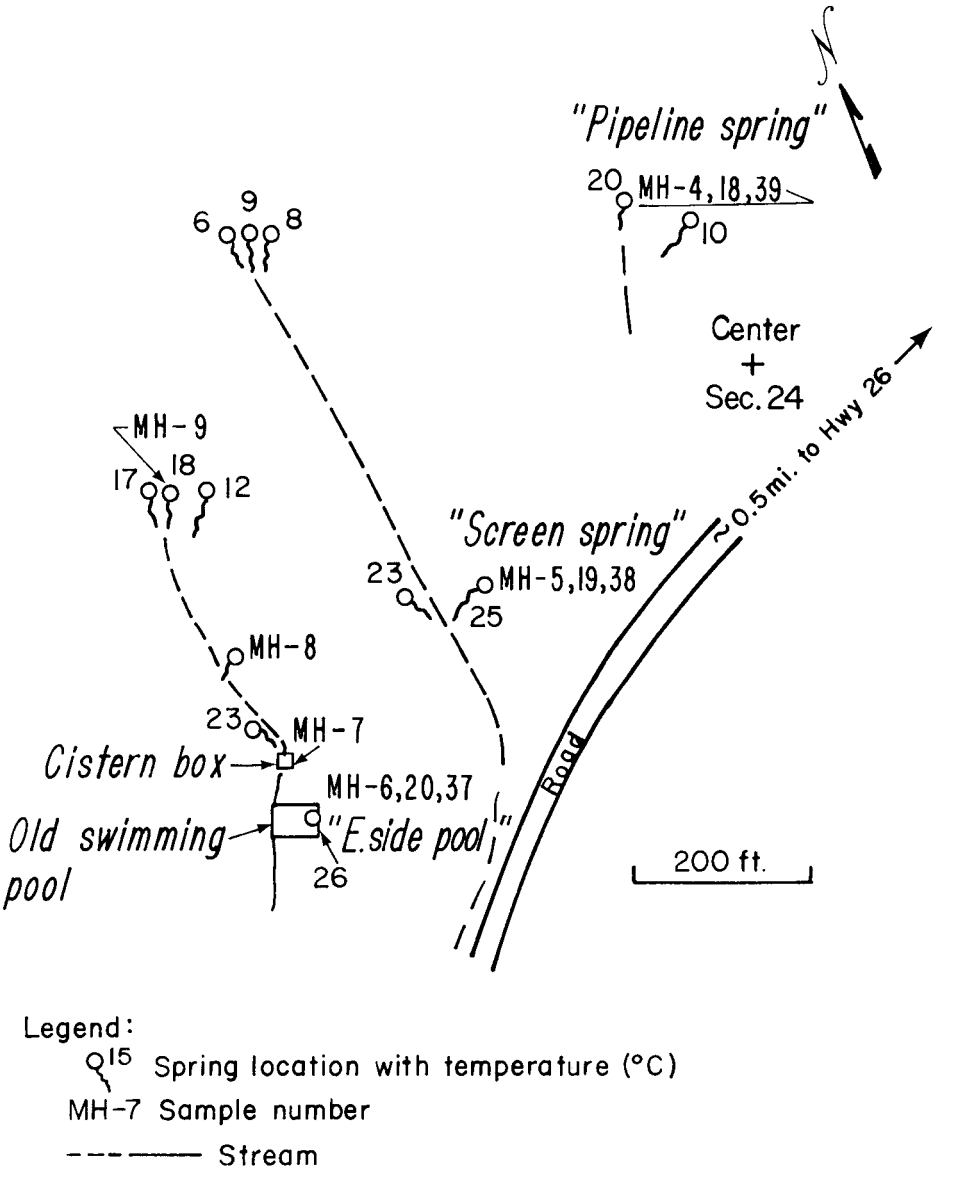
Table 1

DESCRIPTION AND LOCATION OF WATER SAMPLES

MH-1	Still Creek, crossing with Timberline Road, 0.4 mi. N. of Highway 26 junction. 45°18.1′N, 121°43.8′W.
MH-2	Spring, White River outwash; streambed strongly iron-stained. 45°18.2′N, 121°40.4′W.
MH-3	Ski Bowl, artesian well head. 45°18.1′N, 121°46.0′W.
MH-4	Swim area, "Pipeline Spring." 45°18.0′N, 121°44.6′W.
MH-5	Swim area, "Screen Spring." 45°17.9′N, 121°44.5′W.
MH-6	Swim area, east side of old swimming pool. 45°17.9′N, 121°44.6′W.
MH-7	Swim area, cistern box upstream from pool. 45°17.9′N, 121°44.6′W.
MH-8	Spring, swim area, ~100m upstream from cistern box. 45°18.0′N, 121°44.6′W.
MH-9	Swim area, northernmost spring on west branch creek. 45°18.1′N, 121°44.7′W.
MH-10	Robin Hood Quarry, small spring in central bench. 45°20.1′N, 121°34.1′W.
MH-11	Spring, roadcut on north side of Highway 35. 45°18.6′N., 121°39.6′W.
MH-12	Spring, roadcut/quarry, north side of Highway 26, 1/3 mi. NW Trillium L. turnoff. 45°17.4′N, 121°44.0′W.
MH-13	Spring, roadcut on Highway 26, above Laurel Hill Quarry. 45°18.4′N, 121°49.6′W.
MH-14	Spring, Mt. Hood Meadows below Timberline Trail. 45°20.3′N, 121°40.1′W.
MH-15	Salmon River Canyon Springs. 45°19.9′N, 121°42.2′W.
MH-16	Spring, White River Canyon. 45°20.1′N, 121°41.9′W.
MH-17	Spring, from andesite flow. 45°20.1′N, 121°42.9′W.
MH-18	"Pipeline Spring." Same location as MH-4.
MH-19	Swim area, "Screen Spring." Same location as MH-5.
MH-20	Swim area, "East side of Pool." Same location as MH-6.

Table 1 (continued)

MH-21	"Iron Spring" near bridge over Clear Creek. 45°23.5'N, 121°51.5'W.
MH-22	Slightly artesian well, Clear Creek picnic ground. 45°21.4'N, 121°56.2'W.
MH-23	Spring area below Timberline Lodge. 45°18.9'N, 121°42.9'W.
MH-24	Spring at Camp Windy. 45°24.7'N, 121°32.8'W.
MH-25	Clinger Springs. 45°16.4'N, 121°45.9'W.
MH-28	Spring on Timberline Trail, 5700 feet elevation. 45°20.0'N, 121°39.6'W.
MH-29	Cold Spring. 45°21.7'N, 121°39.6'W.
MH-30	Runoff, small lake in crater area. 45°22.1'N, 121°41.9'W.
MH-31	Spring, base of lava flow, Zigzag Canyon. 45°20.9'N, 121°44.1'W.
MH-32	Spring, base of Mississippi Head. 45°21.2'N, 121°43.6'W.
MH-33A	Old Maid Flat, NWNG Co., test hole, artesian flow, 4 days after cessation of drilling. 45°23.4'N, 121°48.5'W.
MH-33B	Old Maid Flat, NWNG Co. test hole, artesian flow, second sampling, several days later. Same location as MH-33A.
MH-35	Old Maid Flat, NWNG Co., test hole, artesian flow, sample after well had been shut-in for ~1 week. Same location as MH-33A.
MH-36	Robin Hood Quarry, same spring as in MH-10 sample.
MH-37	Swim area, east side of large pool. Same location as MH-6.
MH-38	Swim area, "Screen Spring." Same location as MH-5.
MH-39	Swim area, "Pipeline Spring." Same location as MH-4.
MH-40	Old Maid Flat, NWNG Co., test hole, artesian flow for ~36 hours following MH-35 sampling. Same location as MH-33A.



Location map, sampling sites and other springs in Swim Warm Springs area, (Sec.24, T3S., R. 8 1/2 E.)

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Figure 5. The distribution of water sources at Swim Warm Springs.

through a 0.45 micron filter, using a hand-operated vacuum pump; the apparatus is shown in Figure 6. Most often, the water was introduced to the filter directly from the spring, but occasionally conditions required that samples be obtained in bottles and then filtered by pumping from the bottle in the field or laboratory. Generally, 500-ml "Nalgene" bottles were used to collect and store the samples. At the sampling site the pH of the water was measured using a color comparitor set and specific conductance measured by a portable electronic unit. Chloride contents were estimated on-site by immersing "Quantab" strips in spring or well waters.

In the laboratory the water samples were evaporated in the original collecting bottles at 80°C, and aliquots of each were taken for both neutron activation analysis and X-ray fluorescence analysis. In general, the X-ray fluorescence measurements determined the major element abundances, while neutron activation was used for the trace and minor elements. Some elements were determined by both methods so that cross-checks could be made.

For neutron activation, evaporates from water samples were made into pellets and irradiated, along with a composite standard pellet, in the TRIGA Research Reactor at the University of California, Berkeley. Nearly all elements in the samples have their counterparts in the standard, and the abundances are determined by comparing the gamma rays emitted from the unknowns with the gamma-ray spectra of the standards. This method is capable of quantitatively analyzing nearly 50 elements in a sample.

The X-ray fluorescence technique used in this study was developed by Hebert and Street (1974). In this method the evaporates were mixed with $LiBO_2$ and fused into glass discs. The major elemental abundances were determined by comparing these samples (indirectly) with USGS standard rock DTS, spiked with MgO, NaCl, $CaSO_4$ and K_2CO_3.

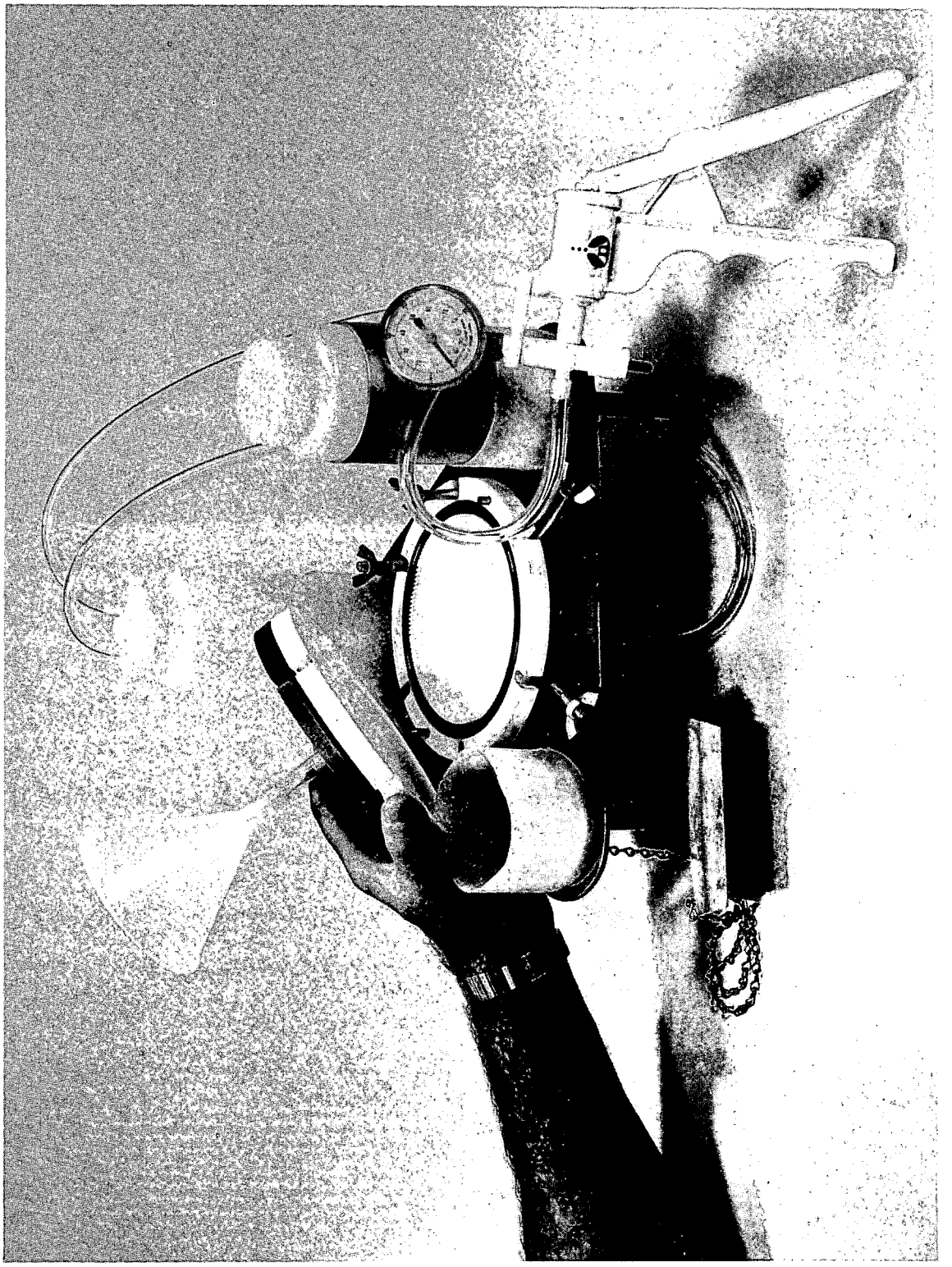

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Figure 6. The filtering apparatus and hand pump used to collect samples in this study.

The precision of the neutron activation method depends mainly on the statistics of gamma-ray counting of the activated samples; for most elements analyzed precisions were of the order of a few percent of the abundance. Precisions and accuracies of X-ray fluorescence determinations of major elements were also a few percent of element abundances.

Samples for laboratory determination of ^{222}Rn were usually collected by filling "Nalgene" bottles with the spring water directly from the pools. This minimized radon loss which might occur if the water were drawn through the filter system. Bottles were immediately sealed, lids taped, and samples transported to the laboratory for gamma-ray pulse-height analyses. The time of sampling was noted to account for the radioactive decay of ^{222}Rn (3.8-day half-life) between sampling and gamma counting. With a reasonably short interval between sampling and counting, the sensitivity of this method is of the order of a few tens of pCi per liter of ^{222}Rn.

Samples for oxygen and hydrogen isotope determinations were obtained by filling 50 ml glass bottles directly with spring water. The bottles were tightly capped, taped, and sent via the U.S. Geological Survey, Menlo Park office, to the analytical laboratories at Saclay, France, where oxygen-16/oxygen-18 ratios and deuterium/hydrogen ratios were measured by mass spectrometry.

B. Rocks

Rock types sampled included altered and relatively fresh andesite and basalt from the flanks of Mt. Hood, a felsic dike in the Hood River Valley, and granodiorite and diorite from the Laurel Hill intrusive. Locations are shown in Figure 3, and listed in Table 2. Samples, each of the order of a kilogram, furnished adequate material for gamma spectrometric determination of uranium and thorium. At several locations gamma-ray counting rates were measured with a portable sodium-iodide crystal.

Table 2

DESCRIPTION OF ROCKS AND LOCATION OF SAMPLES

Mount Hood Rocks:

1. Felsic dike, Robin Hood Quarry
2. Basalt, Robin Hood Quarry
3. Altered Mt. Hood andesite breccia
4. Felsite dike, chloritized, with sulfide minerals
5. (pre?) Mt. Hood andesite
6. Platy Mt. Hood andesite
7. Granodiorite (?), Laurel Hill intrusive
8. Diorite (?), Laurel Hill intrusive

} Laurel Hill Quarry

9. Altered diorite (?), Laurel Hill intrusive
10. Pliocene hornblende andesite, Sandy River
11. Altered andesite, Sandy River
12. Microporphyritic olivine andesite, Cloud Cap
13. Pliocene hornblende andesite, Hood River Canyon (Polallie Campground)

Neutron activation and X-ray fluorescence techniques for analysis of rock samples have been described, respectively, by Perlman and Asaro (1969) and Hebert and Street (1974). Crushed rock samples were pulverized and powders pelletized for reactor irradiation, and fused with lithium borate into glass discs for X-ray fluorescence. With these techniques 25 to 30 elements were determined with precisions of less than 5%; a number were determined to better than 1%.

C. Gases

Gas samples were obtained from fumaroles in the summit crater area of Mt. Hood. Three fumaroles were sampled, one of which was most likely a fumarole sampled previously by Ayres and Creswell (1951). The samples were collected by inserting the end of an $\sim$1.5m-long stainless-steel tube into the fumaroles and allowing the gas to pass into evacuated 300 ml glass bottles containing $\sim$100 ml of 4N NaOH solution. The filled bottles were transported to the laboratory of Dr. A. H. Truesdell, U.S. Geological Survey, Menlo Park, California, where they were analyzed by wet chemical methods for CO_2 and H_2S and by gas chromatography for other constituents. Sampling and analytical procedures have been described in detail by Truesdell and Nehring (1978).

III. RESULTS

Analytical data on water, rock, and gas samples are presented and preliminary interpretations discussed.

A. Water Analyses

1. Major and Trace Elements

For the purposes of this discussion, results of analyses of element contents of water are divided into two groups: those from the Swim Warm

Springs and those from the predominantly cold-water sources elsewhere in the Mt. Hood region. Three analytical laboratories are represented in this study: the Lawrence Berkeley Laboratory, the Central Laboratory of the U.S. Geological Survey, Denver, and the State of Oregon's Division of Environmental Quality.

a. Swim Warm Springs

Results of chemical analyses from successive samplings of Swim Warm Springs are presented in Tables 3a and 3b. Locations of individual orifices are shown on the map, Figure 5. Spring temperatures and the abundance of major and trace elements generally follow a geographic distribution, with the southernmost spring, "East side of pool," being warmest and having the highest chemical contents. Element abundances and temperatures are progressively lower in the "Screen" and "Pipeline" springs, which are respectively up-slope from the "East side of pool" spring. The up-slope decrease of temperature and element content is repeated in the sample sequence MH6 through MH9, from orifices along the small stream entering the pool from the northwest. The successive decreases of temperature and element content suggest that the water at "East side of pool" is the least diluted by mixing with near-surface cold waters. This suggestion is supported by data shown in Figure 7, where major- and trace-element contents are plotted against sodium. In most cases there is a linear relationship between element abundances, with the warmer springs having higher contents. Least-squre linear regression coefficients exceed 0.96 for Na versus Rb, Cs, Cl, Br and K. The strong linear correlations indicate appreciable mixing between warm and near-surface cold waters. The geochemical mixing model, discussed more fully in section III-e, indicates that over 90% of the water emanating at Swim is near-surface cold water.

Table 3a

SWIM WARM SPRINGS

	Successive Samplings										Single Sampling		
Spring	"PIPELINE"			"SCREEN"			"E. SIDE OF POOL"						
Sample	MH-4	MH-18	MH-39	MH-5	MH-19	MH-38	MH-6	MH-20	USGS	MH-37	MH-7	MH-8	MH-9
Date	6/2/77	8/22/77	2/22/78	6/2/77	8/22/77	2/22/78	6/2/77	8/22/77	8/22/77*	2/22/78	6/2/77	6/2/77	6/2/77
pH	7.5	7.5	7.5, 7.5	7.5	7.4	7.5, 7.1	7.5	7.1	7.3	7.3	7.5	7.4	7.5
Temp. °C	22	21.8	21.6	25	23.5	25.5	26	24.1	26.5	26.2	20	21	19
Sp. Cond.			820			1000			1300	1160			
									*(Robison)				
					mg/ℓ								
B	2.0	1	0.5	1.0	3	0.5	3.0	2	0.15	0.5	1	2	0.2
Na	92	84	92	95	101	105	120	114	120	126	86	62	36
Mg	34	36	38	36	30	43	40	40	51	50	30	20	13
SiO_2	75	70	75	75	91	78	80	71	92	88	70	80	60
S	54	54	58	62	65	72	63	68	~80	74	52	48	26
Cl	110	110	102	120	125	135	140	140	170	154	95	80	25
K	7.5	6	7	8	7	8	9.2	7.2	12	9	7.2	6.4	3.6
Ca	50	52	53	55	62	60	60	58	64	64	42	41	19
					µg/ℓ								
Mn	<4	<0.7	3	<5	<4	<3	<7	<5	50	<3	<6	<?	<1
Fe	70	35	(50	27	50	<12	47	<50	220	<25	18	14	14)
Ba	15	26	21	27	28)	22	37	24		27)	17	21	11
Mo	4	<2	3	3	<1.6	<5	4	<4		<7	4	5	2
Rb	17	15	17	18	19	20	23	23		23	16	14	7
Cs	0.25	0.26	0.25	0.31	0.32	0.33	0.38	0.34		0.4	0.25	0.20	0.10
Co	<0.03	<0.03	-	<0.06	<0.03	-	<0.06	<0.03		-	<0.02	<0.02	<0.02
Sb	<0.05	<0.04	<0.06	<0.03	<0.03	<0.02	<0.03	<0.05		<0.1	<0.03	<0.06	<0.02
Cr	<0.7	<0.3	<0.5	<0.7	<0.5	<1	<0.7	<0.1		<5	<0.5	<0.5	<0.4
Zn	<10	1.5	2	<10	2	3	<10	4		3	<10	<5	<5
Ag	<0.06	<0.05	<0.2	<0.06	<0.14	<0.1	<1	<0.2		<0.1	<0.1	<0.06	<0.03
Ce	<0.6	-		<0.6	-			<0.9	-		<0.7	<0.6	<0.3
Sm	0.087	0.03	<0.06	≤0.047	0.06	<0.06	0.105	0.139		<0.06	0.09	0.075	0.03
Eu	<0.011	<0.004	<0.005	<0.013	<0.006	<0.005	<0.014	<0.006		<0.006	<0.012	<0.015	<0.005
U	0.87	0.8	1.1	1.2	0.8	1.2	1.4	1.6		1.3	0.45	0.6	0.2
Ir	<0.0013	<0.0001	<0.0010	≤0.0015	<0.0001	<0.0014	≤0.0012	<0.0001		0.007	≤0.0013	≤0.0012	<0.0003
As	<8	<2	<5	<8	<3	<5	<8	<36		<5	<8	<5	<3
Br	200	134	180	220	180	220	270	280		240	180	148	48
W	<2	<1	<2	<1.5	<1	<2	≤4	<7		<2	<1	<2	<1
Sc	0.02	<0.01	0.022	0.02	0.018	<0.009	0.03	<0.01		0 015	0.014	0.012	0.010
Hf	<0.10	<0.05	<0.006	<0.12	<0.03	<0.03	<0.9	<0.07		<0.03	<0.6	<0.06	<0.010
Th	<0.02	<0.02	<0.005	<0.02	<0.02	<0.015	<0.05	<0.04		<0.10	<0.012	<0.012	<0.010
^{222}Rn (picocuries/ℓ)	172						156			161		186	

Table 3b

SWIM WARM SPRINGS

(Analyses in milligrams per liter, by
State of Oregon, Department of Environmental Quality)

Location*	Pipeline	Screen	E. Side of Pool	E. side of Pool	W. side of stream 50'N of cistern
Date	12/2/76	12/2/76	8/13/76	12/2/76	11/4/75
pH	7.3	7.3	8.1	7.5	7.4
T (C°)	20	25	26.1	25.6	--
Conductance	871	1190	1265	1300	907
Alkalinity (total as $CaCO_3$)	116	157	74	179	121
Hardness (as $CaCO_3$)	253	310	357.0	357	258.2
B	0.28	0.40	0.32	0.32	0.34
Na	79.0	114.0	98.0	136.0	79.0
Mg	29.0	44.0	28.0	48.0	40.0
SiO_2	55.4	71.6	65.5	72.3	52.1
SO_4	149.0	193.0	227.0	205.0	181.1
Cl	103.0	139.0	160.0	161.0	90.0
K	6.0	10.0	10.2	11.7	9.2
Ca	42.0	57.0	27.0	60.0	46.0
Mn	<0.05	<0.05	<0.05	<0.05	0.10
Fe (total iron)	0.05	<0.05	0.2	<0.05	<0.05
As	<0.005	<0.005	<0.005	<0.005	0.04
F	0.15	0.23	0.27	0.23	0.20
PO_4 (soluble ortho.)	0.09	0.08	0.10	0.09	0.12
Al	<0.01	<0.02	<0.02	<0.02	<0.01
Nitrogen (NH_3)	0.06	0.09	<0.01	0.05	0.03
Nitrogen (nitrite)	<0.02	<0.02	<0.02	<0.02	<0.01
Nitrogen (nitrate)	0.04	0.04	<0.02	0.03	0.01
Li	0.08	0.12	0.12	0.13	0.09
HCO_3	141	191	90	218	148

* Refer to map, Figure 5.

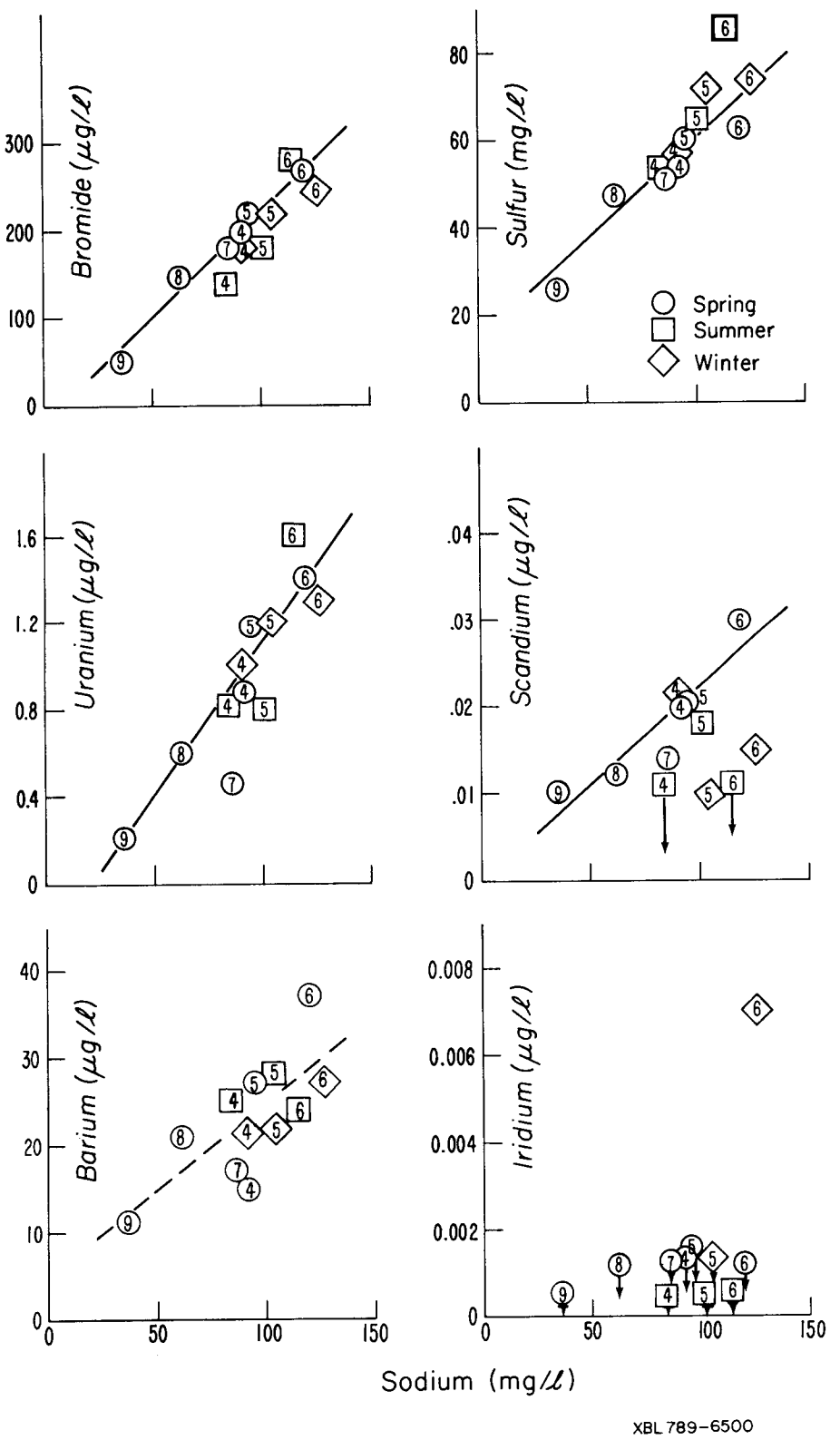


Figure 7a. Major- and trace-element contents of water from Swim Warm Springs, plotted against sodium.

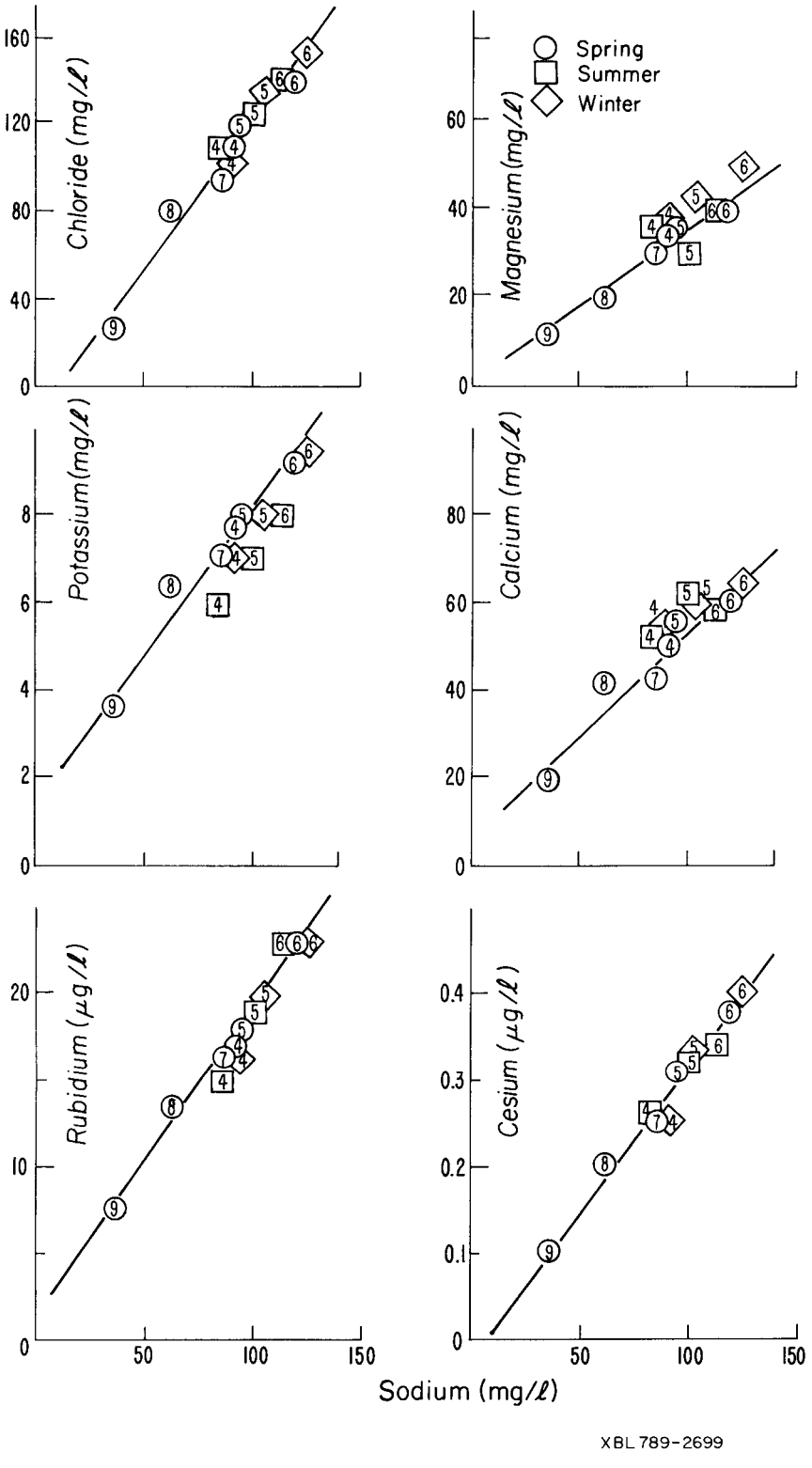


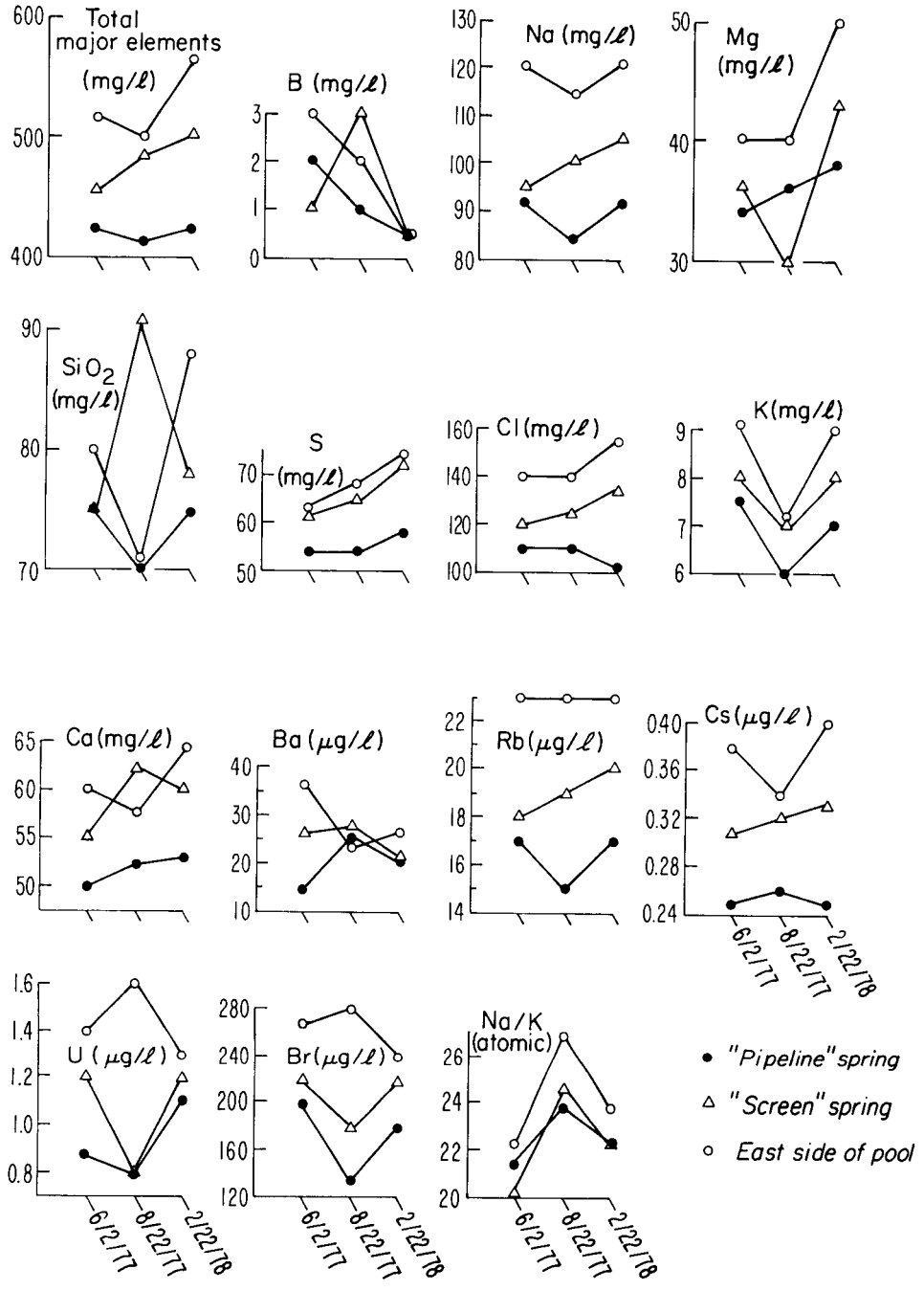
Figure 7b. Major- and trace-element contents of water from Swim Warm Springs, plotted against sodium.

The variation with time of element contents of three orifices at Swim is illustrated in Figure 8. Significant winter increases were observed in Mg and S at all three orifices, while Cl, Cl/B, Ca and Cs were greater in the winter at two of the orifices, and SiO_2, Na, Rb, and U were greater at one (but not necessarily the same) orifice. There were significant winter decreases in B at all three orifices, and in Cl, Ba, U and Br at one or another orifice. It was expected that winter samplings would yield higher contents because the surface runoff would be diminished. However, this was not substantiated because of the increase of some elements and decrease of others in the winter, with respect to the summer samplings.

The presence of the platinum-group element, iridium (0.007 µg/ℓ), in the winter sample from "East side of pool" is of interest, especially because it was not detected in the summer samples from that orifice. There were no other differences of this order in trace element abundances between summer and winter samplings. Iridium was also detected, in lower concentrations, in two cold-water sources: the iron-rich spring in White River Valley (MH 2), and the outflow of the small lake in the summit crater (MH 30). Silver is present along with iridium in these and other springs, and in the summit crater lake. A search of geochemical literature reveals that this is the first evidence of a platinum-group element being detected in geothermal or surface fresh waters.

b. Cold Springs and Wells

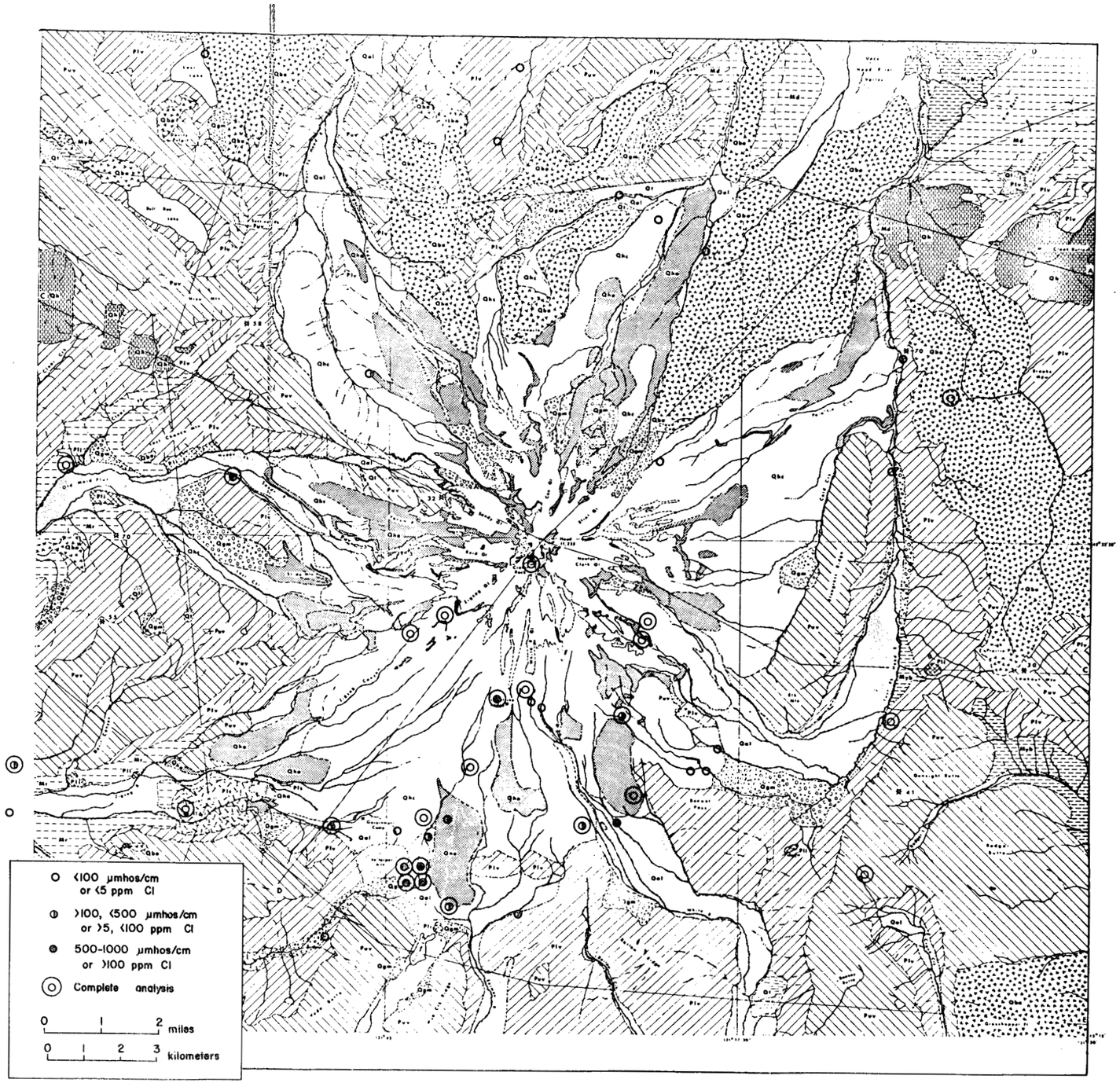
Results of specific conductance and chloride contents, measured in the field, are shown on Figure 9. Springs and surface waters sampled in the drainages of Still Creek, Salmon River, White River and the spring at Mt. Hood Meadows have greater abundance of Cl, and higher specific conductance than springs sampled to date on the north flank of Mt. Hood. Waters from 22 cold sources, 20 of them springs, were analyzed for major and trace elements; results of analyses, pH, and temperature measurements are listed in Table 4. With a few exceptions, the cold springs issue from andesite;



Variation in major and trace-element contents from successive samplings of three orifices at Swim Warm Springs 6/2 and 8/22/77, and 2/22/78.

XBL 789-6505

Figure 8. Element content variations with time at the three orifices at Swim Warm Springs.



XBL 792-8468

Figure 9. Specific conductance and chloride content of waters plotted on the geologic map of Mt. Hood (after Wise, 1968).

Table 4a

Sample	MH-1	MH-2	MH-3	MH-10	MH-11	MH-12	MH-13
Date	6/1/77	6/1/77	6/2/77	6/3/77	6/4/77	6/4/77	6/4/77
pH	6.9	∿6.2	8.5	∿7.5	∿6.7	∿6.9	6.5
Temp. °C	4.5	3.5	7	7	3	5	10
			mg/ℓ				
B	3	0.5	0.2	0.5	0.3	0.2	0.5
Na	3	2.2	16	6	1.2	7	2
Mg	<0.5	<1	4	5	1	2	<0.6
SiO_2	-	-	-	-	-	30	-
S	-	-	-	-	-	3	-
Cl	1	1	2	<0.2	<0.1	5	<0.2
K	<0.7	1	2	<0.2	<0.4	1	<0.4
Ca	3	2	17	50	<0.01	0.11	0.15
			µg/ℓ				
Mn	0.7	27	2	<0.2	<0.1	1.5	4
Fe	30	2400	22		10	110	155
Ba	0.7	4	2.3	<2	5.6	3	1
Mo	0.37	0.2	3	13	≤0.06	0.02	<0.1
Rb	2.2	0.7	1.2	2	1	4	0.3
Cs	0.05	0.02	0.02	0.66	0.01	0.10	0.02
Co	0.02	0.36	<0.01	0.05	<0.02	0.05	<0.02
Sb	<0.03	0.01	0.11	2.4	<0.01	<0.01	0.02
Cr	<0.2	<0.2	<0.1	<0.3	<0.1	0.55	0.33
Zn	20	<5	120	<1	<1	8	3
Ag	<0.02	0.5	<0.03	<0.02	0.005	2.4	0.1
Ce	<0.04	0.17	< 0.2	<0.03	0.02	0.1	0.1
Sm	0.003	0.012	-	0.02	0.0018	0.012	0.009
Eu	<0.001	0.0019	<0.002	<0.004	0.0004	0.003	0.002
U	0.023	0.012	0.077	0.08	0.005	0.05	0.008
Ir	≤0.00005	0.00031	<0.00010	<0.0002	<0.0001	≤0.0002	<0.00001
As	<0.2	<4	1.4	12	<0.2	<1	<0.1
Br	2	1	3	<4	<2	6	7
W	<0.05	-	<0.2	<0.6	<0.07	<0.3	<0.1
Sc	0.031	0.023	<0.003	0.020	0.0027	0.030	0.05
Hf	<0.03	0.01	<0.03	<0.019	0.004	<0.009	<0.004
Th	<0.003	0.008	<0.005	≤0.008	≤0.0015	≤0.009	0.012

Table 4b

	Sample	MH-14	MH-15	MH-16	MH-17	MH-21	MH-22	MH-23	MH-24
	Date	6/5/77	7/29/77	7/29/77	7/29/77	8/2/77	8/2/77	8/3/77	8/3/77
	pH	7.5	6.8	6.5	6.5	6.4	8.5	6.4	6.5
	Temp. °C	8	4	10	9	4.5	10	1	3
					mg/ℓ				
B		0.5	0.5	1	0.5	0.5	3	0.5	0.5
Na		6.5	0.8	0.6	1.4	3	125	3	1.2
Mg		6	<0.3	<0.4	<0.3	2	20	1	<0.3
SiO_2		42	24	13	21	27	54	29	23
S						-			
Cl		6	0.2	0.3	0.8	1.5	25	1.3	0.5
K		3.5	0.3	0.3	0.6	<0.5	16	0.5	0.8
Ca		19	0.5	0.4	2	4	51	4	1.4
					µg/ℓ				
Mn		1.6	0.7	3	2	144	<7	0.5	2
Fe		90	38	180	100	5800	210	14	20
Ba		7	2.3	2.7	1.3	<3	10	<0.5	<1
Mo		<0.1	<0.1	<0.05	<0.04	0.13	5.5	≤0.1	<0.04
Rb		5	0.9	0.5	1.8	1.3	8	2	1.3
Cs		0.09	≤0.008	0.009	0.014	<0.04	0.06	0.06	0.01
Co		0.04	0.02	0.08	0.06	0.11	0.05	<0.01	0.03
Sb		0.01	0.01	<0.009	<0.02	0.04	0.05	0.02	<0.01
Cr		<0.4	0.23	0.45	0.23	0.7	<0.3	<0.1	0.2
Zn		1	0.8	2.5	0.8	3	4.6	<1	1
Ag		<0.07	≤0.02	≤0.6	<0.01	<0.06	<0.05	<0.04	<0.1
Ce		0.18	0.12	0.36	0.15	-	-	-	-
Sm		0.009	0.009	0.02	0.01	0.02	0.01	0.002	0.008
Eu		<0.001	<0.002	<0.004	<0.004	<0.004	<0.002	<0.001	<0.004
U		0.23	0.012	<0.02	<0.02	<0.01	0.04	0.02	<0.01
Ir		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
As		<0.5	<0.01	<0.1	<0.1	<0.2	<0.2	<0.2	-
Br		6	1	1	2	6	34	3	3
W		<0.1	<0.01	<0.02	<0.02	<0.05	<0.4	<0.03	<0.03
Sc		0.025	0.021	0.06	0.03	0.05	<0.01	<0.003	0.01
Hf		0.02	0.008	0.021	0.01	<0.02	<0.005	<0.001	0.007
Th		0.009	0.026	0.03	0.03	<0.01	<0.01	<0.001	0.02

Table 4c

MT. HOOD WATER SAMPLES

									Old Maid Flat Well		
	Sample	MH-25	MH-28	MH-29	MH-30	MH-31	MH-32	MH-36	MH-33B	MH-35	MH-40
	Date	8/3/77	8/24/77	8/25/77	2/30/77	9/7/77	9/7/77	2/22/78	12/19/77	2/21/78	2/22/78
	pH	6.5	7	7.4	~4.7	6.5	6.5	7.8	10	10	10
	Temp. °C	9.5	9	6	2	10	4	4	9	6	11
						mg/ℓ					
B		0.5	0.5	0.3	0.1	1	1	0.5	10	7	7
Na		5	1.3	3.8	2.7	2	0.6	4	130	136	132
Mg		3	<0.5	<2	2.5	<1	<0.5	2	<1	<1	<1
SiO_2		47	16	61	14	28	24	10	40	34	31
S								15	23	23	25
Cl		1	<1	<1	<0.1	1	1.7	2	135	124	123
K		<0.3	<0.2	2	1	0.9	<0.2	0.1	<1	<0.2	<0.2
Ca		11	2.7	8.6	17	3	1	43	72	11	11
						µg/ℓ					
Mn		35	8	2.5	119	2	<0.1	10	<40	<8	<7
Fe		155	64	30	1200	103	25	120	200	21	<10
Ba		<3	3.5	2	<10	<1	<1	2.3	7	<4	<2
Mo		<0.05	0.15	0.17	0.4	0.3	0.2	4	<0.7	35	37
Rb		2	0.7	4.2	<0.6	1.1	0.5	1.5	1.0	1.3	1.3
Cs		<0.02	0.02	0.03	<0.03	0.02	<0.01	0.4	0.06	0.07	0.15
Co		0.14	0.10	0.035	3.3	0.06	0.02		0.08	<0.03	
Sb		0.11	<0.01	0.01	0.06	0.06	0.03	1	0.07	0.05	<0.01
Cr		0.2	0.87	0.04	1.2	0.23	0.20	<0.2	0.5	<0.5	<0.4
Zn		1	3.5	5	2400	13	0.8	7	4	2	<0.4
Ag		<0.05	-	-	0.79	0.06	0.10	<0.2	<0.2	≤0.1	<0.07
Ce		0.095	0.048	<0.04	2.4	0.2	<0.04				
Sm		0.013	0.005	0.0036	0.37	0.016	0.0026	<0.03	0.03	<0.04	<0.04
Eu		-	<0.002	≤0.0014	0.08	0.006	<0.004	<0.003	-	<0.003	<0.004
U		<0.01	<0.005	0.027	0.063	0.01	<0.004	0.05	0.15	0.12	0.14
Ir		<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0002	≤0.0008	<0.0004	<0.0010
As								4	<2	<15	<10
Br		5	1.5	4.8	<1	2.5	1	9	115	300	280
W		≤0.1	<0.1	<0.1	0.8	0.15	<0.06	<0.5	<0.4	12	13
Sc		0.013	0.011	0.013	0.11	0.026	0.007	0.053	0.06	0.013	0.011
Hf		<0.003	<0.005	<0.008				<0.05		<0.02	<0.015
Th		<0.002	<0.004	<0.005	0.03	0.013	<0.001	<0.007	<0.03	<0.015	<0.009
Ta					0.02						
Yb					0.15						

their element abundances are lower than those of the Swim Warm Springs. Exceptions are the iron-manganese-rich spring, MH 2, emanating from glacial debris in the White River Valley, the Ca-Mg-rich water of the spring from basalt in the Robin Hood Quarry (MH 10), and Fe-Mn-rich water from the outflow of a small pond in the strongly altered fumarolic area of the summit crater. In both the Fe-Mn waters of the summit crater and White River Valley spring there were identifiable contents of iridium, though in lower abundance than in the winter sample from "East side of pool" at Swim. (Fe and Mn were both below detection limits in the sample from Swim). Water from a cold well in the Government Camp area (MH 3) is similar in character, except for its high Zn content, to cold "andesite" waters. However, a cold well near Brightwood (MH 22), most likely producing from the Rhododendron Formation, has water low in Fe and Mn and relatively high in Na and Mg, in contrast to a nearby cold spring (MH 21).

c. Old Maid Flat Geothermal Test Hole

Water samples were obtained from the artesian-flowing geothermal test hole in Old Maid Flat in December 1977 and February 1978. It is expected that the water was flowing from a depth of 450m; total depth at that time was 550m. Since that time the hole has been deepened to 1200m. The initial sample, taken only a few days followng cessation of drilling, contained unusually high contents of SiO_2, Mn, Fe, Ba, and other constituents, indicating that the sample was contaminated by drilling fluid. A sample taken 16 days later (MH 33b) contained considerably lower amounts of these constituents but somewhat greater amounts of SiO_2, Cl, Ca, Fe, and Ba than samples obtained two months later (MH 35 and MH 40). It is possible that water from the Old Maid Flat well was still slightly contaminated by drilling fluid.

d. Comparison of Water Chemistries

To facilitate comparison between the chemistries of the various water sources, major- and trace-element contents were plotted generally in order of increasing abundance in Figures 10, 11, 12, and 13. The patterns on these figures afford qualitative assessment of significant differences or similarities between water types. Mean values and standard deviations of element contents of cold waters emanating from springs in andesite and of waters from Swim Warm Springs are plotted on Figures 10 and 11. In Figure 10, which compares major elements, there is a "high" in sulfur and sodium in the warm spring water, in contrast to the cold "andesite" water where SiO_2 is relatively prominent. In the comparison of mean values of trace-element contents in both water types (Figure 11), uranium is prominent with respect to its neighbors, Sm and Cs at Swim Warm Springs. Barium stands out among the trace elements in the cold-spring waters.

Plots of major-element contents in waters from the geothermal test well in Old Maid Flat (MH 40) and the cold spring in Robin Hood Quarry (MH 10) comprise Figure 12. Similar diagrams of trace-element contents in these two sources are shown in Figure 13. The major-element pattern of the Old Maid Flat well water has a Na-S "high," similar to but considerably more accentuated than, that of the Swim Warm Spring waters (Figure 10). The trace-element pattern of Old Maid Flat well water has a sharp "high" of Mo with respect to its neighbors on the plot, Cs and Rb; Br is also accentuated. The major element pattern of cold water emanating from basalt in Robin Hood Quarry accentuates S and Ca, in contrast to the cold "andesite" waters where SiO_2 predominates. The trace element pattern of the Robin Hood Quarry water has prominences of Mo and Ba; Ba is also relatively prominent in the cold "andesite" water. Barium and calcium contents are relatively high in a sample of basalt from Robin Hood Quarry (MHR-2, Table 2), and a sample of felsic dike rock from the quarry (MHR-1) also has a relatively high Ba content.

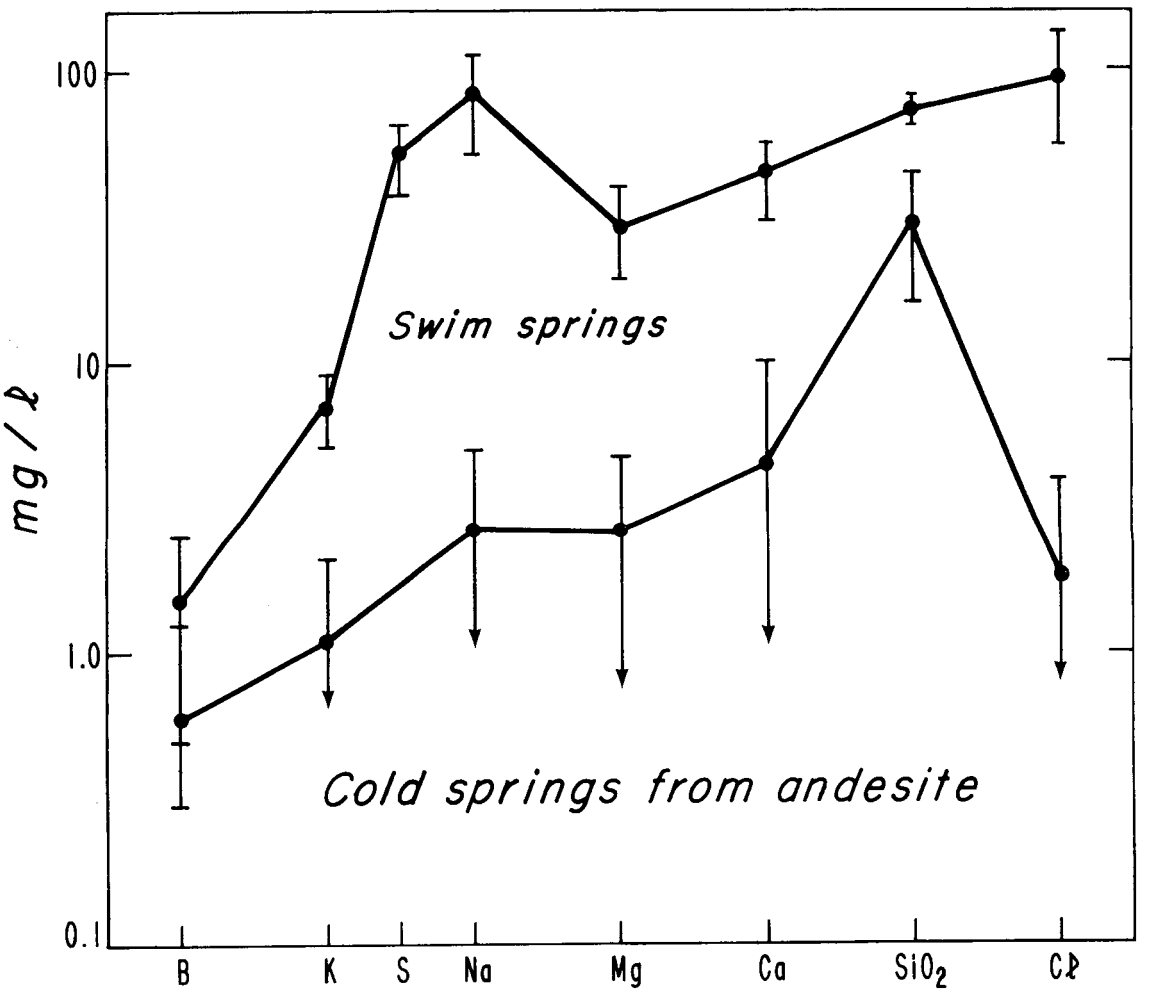


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Figure 10. Major element contents of Swim Warm Springs and cold water from andesite.

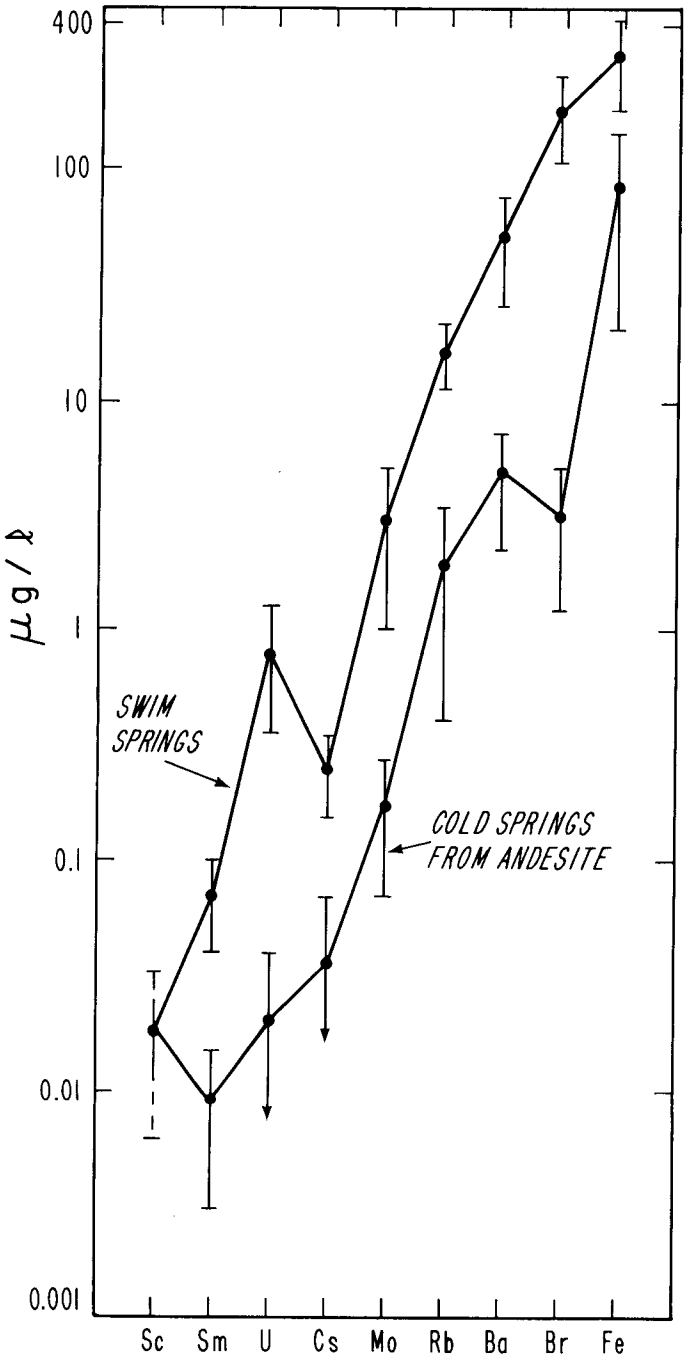

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Figure 11. Trace-element contents of Swim Warm Springs and cold water from andesite.

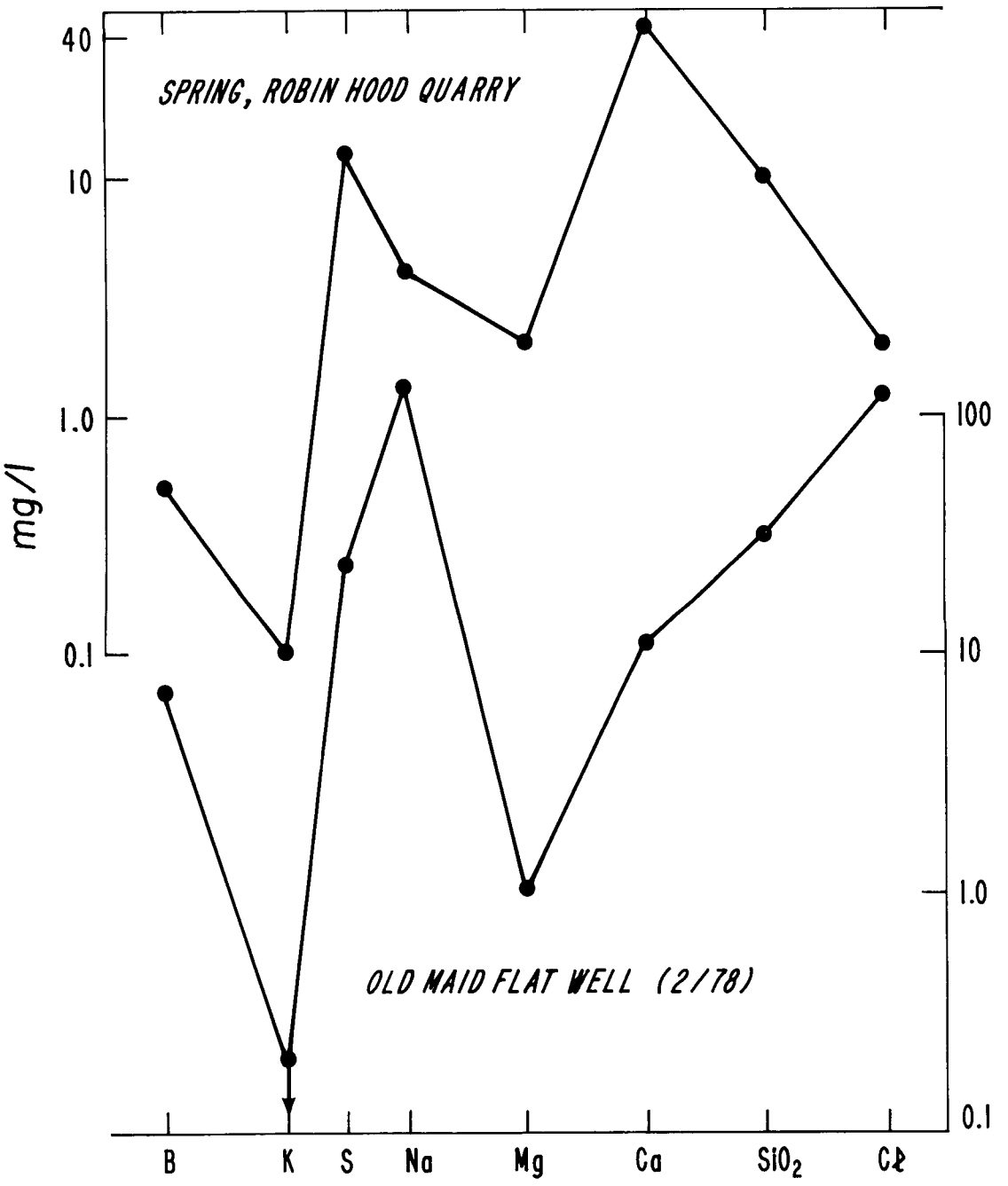

Figure 12. Major-element contents of the spring in Robin Hood Quarry and of water from the geothermal test well in Old Maid Flat.

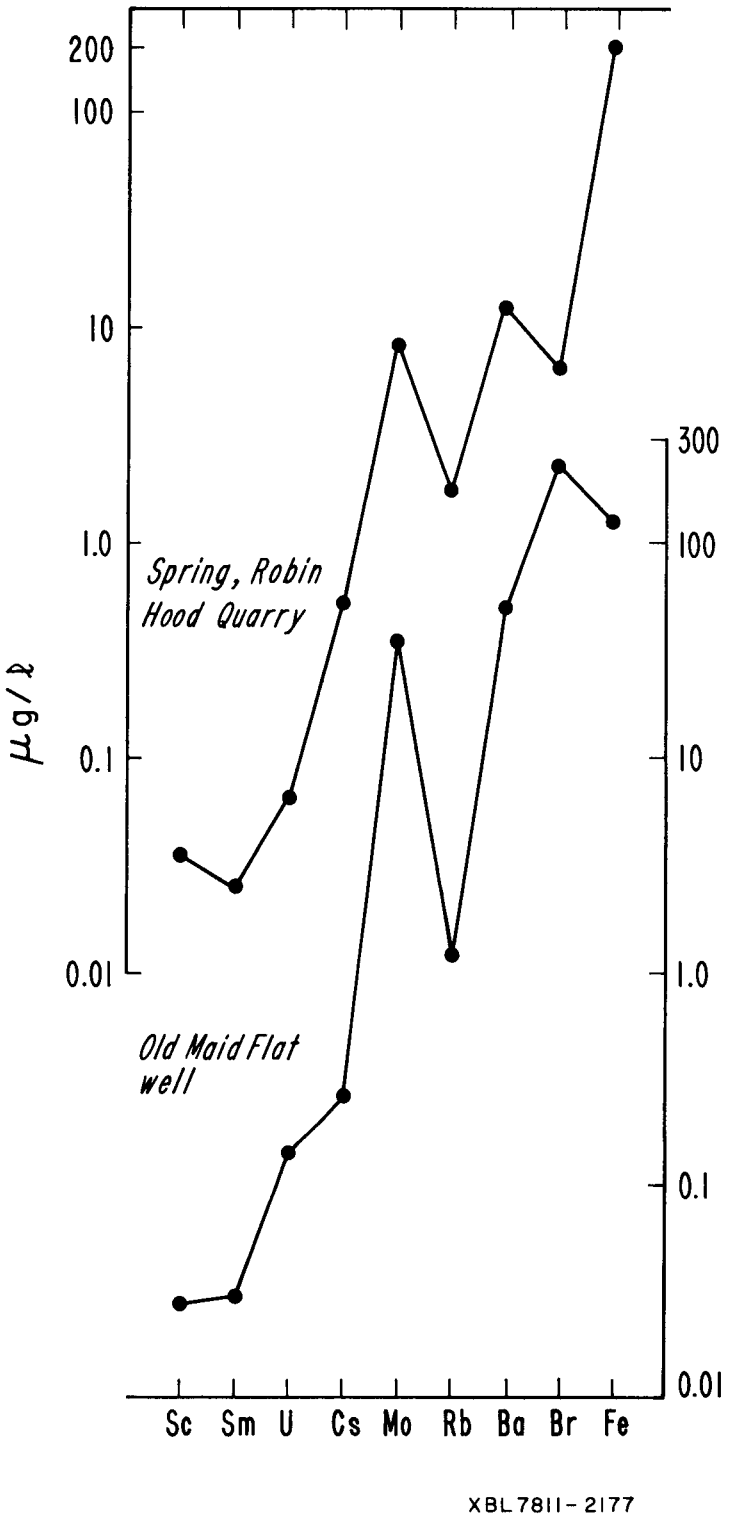

Figure 13. Trace-element content of the spring in Robin Hood Quarry and of water from the geothermal test well in Old Maid Flat.

e. Estimates of Subsurface Temperature

Major-element analyses were used to calculate the water temperature at depth within the Swim Warm Springs system. The calculations were based on chemical geothermometers afforded by the SiO_2 content of water and the ratio of Na to K, corrected for Ca (Fournier and Truesdell, 1973). The temperature of water at depth was also estimated by the ratio of oxygen isotopes in sulfate in the water (McKenzie and Truesdell, 1976), measured by N. Nehring and A. H. Truesdell at the U.S. Geological Survey, Menlo Park, California.

The temperature of hot water, unmixed with nearer-surface cold water, and the proportion of mixed cold water in Swim Warm Springs, were estimated by applying the mixing model of Fournier and Truesdell (1974). In this model simultaneous equations are employed, incorporating as factors the temperature of warm spring water, the SiO_2 content of the warm spring water, the temperature of the near-surface cold water, and the silica content of cold spring water.

The estimates of subsurface water temperature at Swim Warm Springs are summarized in Table 5. The temperatures estimated by the Na-K-Ca geothermometer and by the mixing model may be less reliable than those estimated by the silica and oxygen-isotope geothermometers, because surface flow at Swim is low. The Na-K-Ca and mixing-model temperatures should not be discounted, however, because the mixing model indicates the large proportion of near-surface cold water intuitively expected at Swim. Therefore, the agreement between the silica and oxygen-isotope temperatures indicate that the temperature at depth is, at least, within the range of 100-125°C, the temperature may be 150° to over 200°C.

The samples from the Old Maid Flat hole may contain some vestiges of drilling fluid. However, if we assume equilibrium conditions then the

Table 5

Summary of Estimated Subsurface Temperature
at Swim Warm Springs

Geothermometers	
SiO_2	100-125°C
Na-K-Ca (β = 1/3)	152-154°C
$\delta 18_O - SO_4$	108-110°C
Silica Mixing Model[a]	
Temperature of unmixed hot water	192-240°C[b]
Fraction of cold water	0.92

a) Fournier and Truesdell, 1974.
b) Questionable because it is a low-flowing system.

silica and alkali-element ratio geothermometers give consistent temperatures of 80-90°C. The temperature measured at 450m was 33°C; a measurement of bottom-hole temperature, following completion of the hole, was 81°C.

f. Oxygen and Hydrogen Isotope Ratios

A plot of isotope ratios of hydrogen and oxygen in cold and warm spring waters comprises Figure 14. The ratios are expressed in delta values, given in mils (°/oo), and defined as:

$$\delta \text{ in } {}^{o}/_{oo} = \frac{R_{(sample)} \quad R_{(standard)}}{R(standard)} \times 1000 \qquad \text{(Hoefs, 1973),}$$

where R represents the isotope ratios of deuterium to hydrogen and $18_O/16_O$; the standard is "mean ocean water" (Craig, 1961). The points for warm and cold springs fall close to the line for meteoric waters, indicating that the warm waters are much diluted by near-surface runoff. The warm water points would be shifted to the right of the meteoric water line if a substantial component of the spring water had been in contact with rock at depth. However, the grouping of the warm water points at more negative values indicates that the source of the warm spring water is generally higher on the mountain than the sources of most of the cold springs sampled. Exceptions are the cold springs at Mt. Hood Meadows (MH 4) and a spring in Robin Hood Quarry (MH 10), which fall in the same range as the warm waters. The grouping of the points indicates that the cold waters have shorter pathways between their sources and the springs, while a component of the warm water may circulate deeply enough in the mountain to come in proximity to a hot central conduit system.

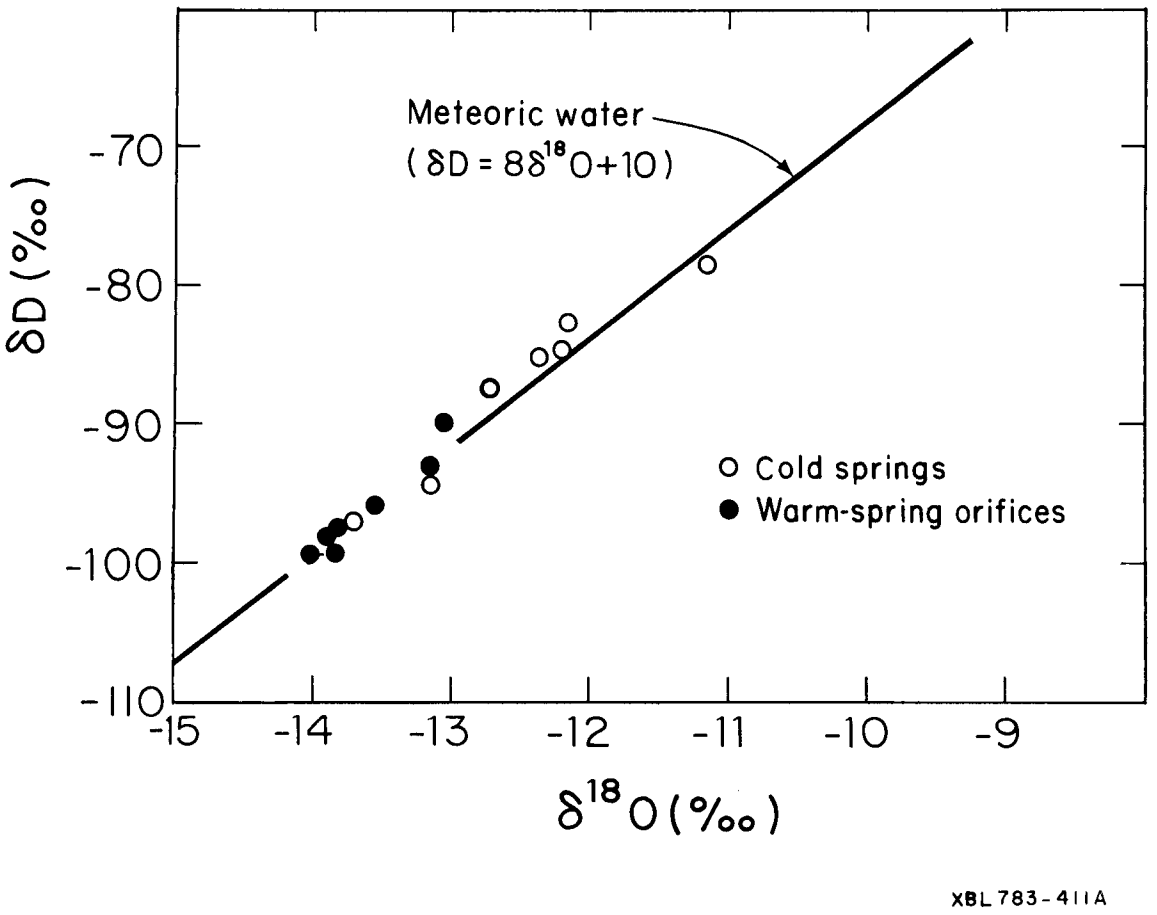

Figure 14. Isotope ratios of hydrogen and oxygen in cold and warm-spring water of Mt. Hood.

B. Rock Analyses

A limited number of samples of the igneous rock types in the Mt. Hood region were collected and analyzed. A more detailed investigation of the petrology, mineralogy, and geochemistry of Mt. Hood's extrusive rocks is presently being conducted by Craig White of the University of Oregon.

Results of major and trace-element analyses of 13 rock samples, together with brief sample descriptions, are listed in Table 6. Seven of the samples are andesite, two (MHR 3 and 11) are of appreciably altered rock. The major-element contents of the samples of relatively unaltered andesite are fairly uniform, with silica contents in the range 58-63%, Al_2O_3 17.4-17.7%, CaO 5.4-6.4%, Na_2O 3.7-4.3%, and K_2O 1.0-1.5%. There do not appear to be significant differences between chemistries of samples of Pliocene andesite from the west and east flanks of Mt. Hood (MHR 10 and 13), and the andesite of the more recent flows on the south flank of the mountain (MHR 5 and 6). This is supported by the small standard-deviations of mean values of rare-earth-element (REE) ratios (REE contents in sample/REE contents in standard chrondrite) of the unaltered andesite (Figure 15). The relatively higher Fe and Mg contents of the andesite from Cloud Cap (MHR 12) are in keeping with the presence of olivine in that rock, in comparison with other andesite samples where hornblende is the principal mafic mineral. The altered brecciated andesite sample (MHR 3) from the south flank of Mt. Hood is somewhat lower in MgO, but higher in K_2O than the fresher samples, while the strongly altered andesite (MHR 11) from the west flank of the mountain has considerably greater MgO and much less K_2O than a sample of nearby, relatively unaltered andesite (MHR 10). Both fresh and altered andesite samples from the MHR 10 and 11 localities have identifiable iridium contents, in contrast to other rock samples where the abundance of that element was well below detectability limits. It is surprising to find Ir in andesitic rocks; it is more normally associated with ultramafic rocks: peridotite, pyroxenite, and serpentinite.

Table 6a

MT. HOOD ROCK SAMPLES

Major Elements
(% by weight)

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13
Na_2O[(a)]	4.0	2.2	3.2	3.8	4.1	4.3	5.2	3.8	2.7	4.1	2.6	4.0	3.7
MgO[(a)]	0.3	4.0	1.6	1.2	3.1	2.9	3.7	3.3	2.4	1.7	6.5	3.1	2.8
Al_2O_3[(a)]	13.6	13.1	16.4	15.3	17.7	17.5	17.7	17.8	16.7	17.4	17.3	17.4	17.7
SiO_2[(a)]	71.7	50.3	59.3	64.9	60.4	61.5	58.1	58.0	62.3	62.8	54.8	58.3	59.8
K_2O[(a)]	3.7	1.2	2.4	3.0	1.5	1.3	1.2	0.9	1.3	1.3	0.3	1.0	1.3
CaO[(a)]	1.4	7.1	4.3	0.7	5.8	5.7	5.5	7.1	4.3	5.4	1.6	6.3	5.6
TiO_2	1.4	7.1	0.8	0.7	0.8	0.7	0.8	0.7	0.6	0.5	1.0	0.9	0.8
MnO	0.04	0.23	0.12	0.05	0.10	0.09	0.07	0.10	0.04	0.04	0.03	0.13	0.07
FeO	1.8	13.2	4.6	3.3	5.7	5.7	3.9	5.4	3.7	4.2	5.1	6.3	5.2
Cr_2O_3	0.00	0.04	0.02	0.01	0.03	0.03	0.02	0.02					
TOTAL	96.7	94.0	92.7	93.0	99.2	99.7	96.2	97.1	94.0	97.4	89.2	97.4	97.0

(a) Analyses by x-ray fluorescence.

Table 6b

MT. HOOD ROCK SAMPLES

Trace Elements
(ppm)

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13
Rb	120	190	40	65	20	20	30	20	40	18	<4	8	32
Cs	2	5	1	<1	<1	<1	<1	<1	2	5	0.5	<0.3	0.4
Ba	600	640	300	460	350	300	250	200	240	300	120	350	300
Hf	5.4	5.0	7.1	6.2	4.2	4.1	3.6	3.7	3.3	4.0	3.7	4.5	4.1
Cr	2	40	7	4	40	55	10	70	50	30	65	46	41
Co	3	37	7.6	5.8	19	19	16	21	13	12.8	21	21	19
Ni	<10	<30	<20	<10	30	30	<10	40	40	23	33	34	25
Sc	2.3	37.7	10.5	9.6	13.9	13.3	19.4	17.2	12.8	9.0	18	15	15
Th	15	4.5	6.6	6.2	3.7	2.4	2.4	2.4	2.3	3.0	2.2	2.1	3.6
Ta	1.3	0.84	1.1	1.0	0.57	0.54	0.54	0.51	0.54	0.65	0.51	0.62	0.59
La	25	23	25	24	19	15	10	18	13	16	13	17.5	16.2
Ce	56	52	58	53	45	33	29	44	27	36	29	40	35
Nd	15	27	26	26	15	17	15	20	14	16	16	20	18
Sm	2.6	6.3	4.8	5.2	3.6	3.2	2.8	3.9	3.0	3.1	4.0	4.3	3.4
Eu	0.66	2.2	1.5	1.3	1.4	1.3	0.83	1.3	1.1	1.1	1.0	1.4	1.1
Tb	0.41	1.0	0.71	0.76	0.49	0.46	0.52	0.47	0.45	0.45	0.60	0.55	0.47
Dy	2.5	7.9	4.9	4.9	3.2	2.9	3.7	3.3	3.3	2.5	4.4	3.8	3.0
Yb	1.7	3.7	2.7	2.6	1.6	1.5	2.1	1.8	1.6	0.95	2.1	1.9	1.4
Lu	0.22	0.54	0.35	0.32	0.19	0.18	0.24	0.27	0.21	0.14	0.27	0.25	0.19
U*	4.5	1.3	1.4	1.9	1.2	0.9	1.8	0.6	0.7	0.95**	0.76	0.61	1.05
Ir	≤0.02										≤0.003	<0.0010	<0.0010

* By γ spectrometry
** By neutron activation

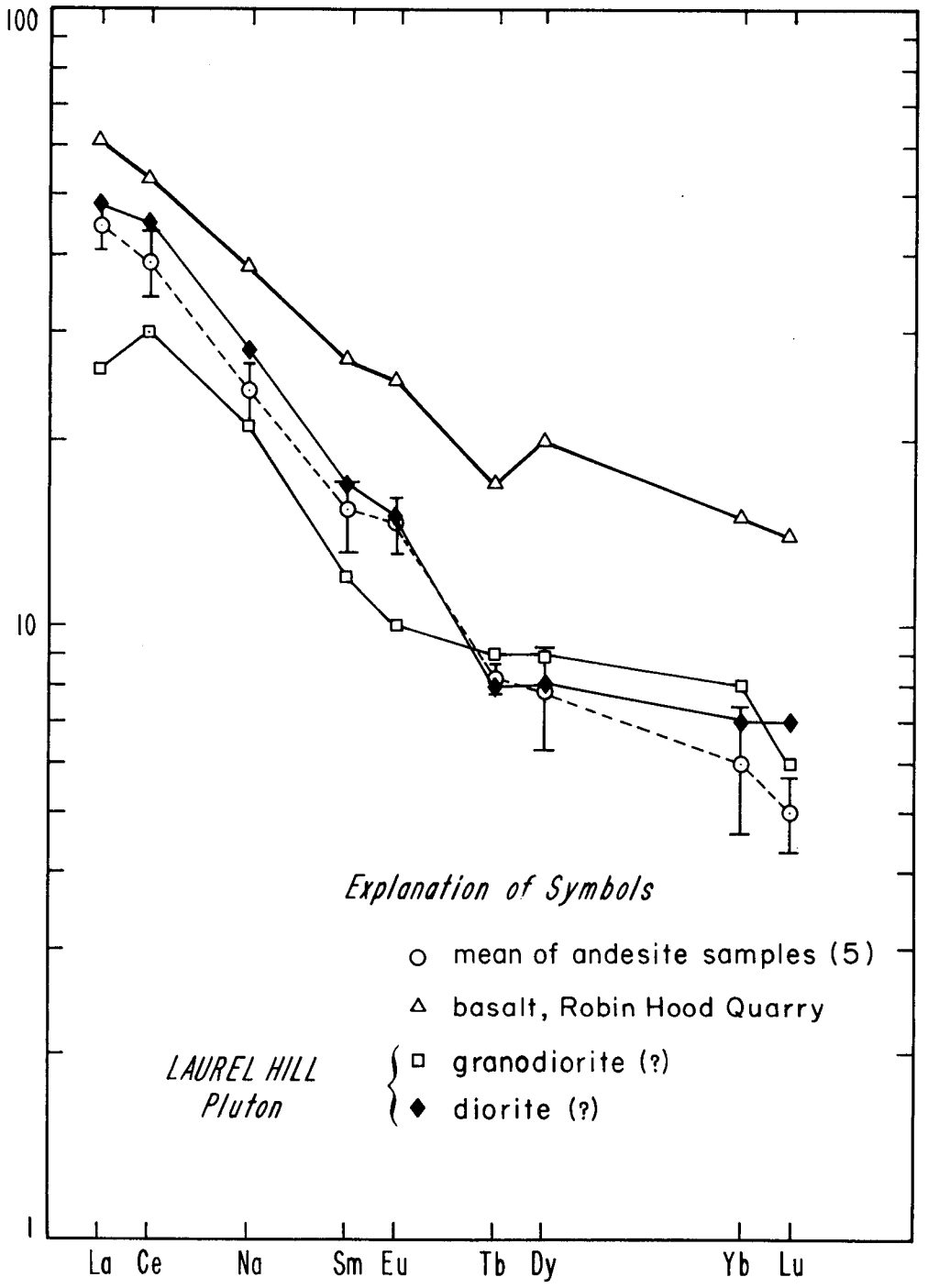

Figure 15. Rare-earth element ratios (sample/chrondrite) of rock samples from Mt. Hood.

The relatively high barium contents of the samples of felsic dike rock and basalt (MHR 1 and 2, respectively) from the Robin Hood Quarry, are reflected in the water sample from that locality (MH 10, Table 4a). The basalt has higher rare-earth-element ratios than those of the andesite or of the intrusive rocks. Comparison of major- and trace-element contents of the Robin Hood Quarry basalt with contents of Columbia River Basalt flows (Asaro and others, 1978) indicates strong similarities. An example is shown in Table 7, where sample MHR 2 is compared with basalt of the Roza flow of central Washington.

Major- and trace-element contents of the two samples of relatively unaltered intrusive rocks, diorite-granodiorite, from the Laurel Hill pluton (MHR 7 and 8), are similar to contents of the unaltered andesite samples. This is illustrated by the similarity between REE patterns of the andesite and intrusive rocks (Figure 15). A sample of altered intrusive rock from locality MHR 9 in the Laurel Hill pluton has markedly lower Na_2O, MgO and CaO, but higher SiO_2 than the unaltered samples. The similarity between the chemistries of the intrusive rocks and the andesites suggests that the intrusives may represent the roots of the Pliocene extrusive centers on the western flank of Mt. Hood. However, our sampling of andesites to date has not been extensive enough to support or deny the conclusions of Wise (1969) regarding the origin and character of the andesites of Mt. Hood.

C. Gas Analyses

Results of analyses of gases collected from two sites on Mt. Hood, Steel Cliffs and Crater Rock in the Summit Crater area, are listed in Table 8. These may be compared with analyses by Ayres and Creswell (1951) of gas samples collected in 1935 and 1951 from fumaroles near the Steel Cliffs. The bar graphs, Figure 16, permit this comparison and show that carbon dioxide predominates (88-97%) in the group of gases other than water vapor, with H_2S comprising 1 to 11% of this group. The Ayres and Creswell sample

Table 7

Major- and Trace-Element Contents of the
Robin Hood Quarry and Roza Flow basalts

	Robin Hood Quarry	Roza flow
	(%)	
SiO_2	50.3	50.3
Al_2O_3	13.1	13.6
FeO	12.9	14.3
MgO	4.0	4.4
CaO	7.1	8.2[5]
Na_2O	2.2	2.7
K_2O	1.2	1.2
TiO_2	2.5	2.6
	(ppm)	
Sc	37.7	39.0
Eu	2.2	2.67
Co	36.6	41.0
Ba	641	498
Cr	40.3	40.5

Table 8

Fumarolic Gas Analyses*

	Steel Cliffs	Crater Rock
Temperature	88-91°C	90°C
moles CO_2	0.1830	0.3056
moles H_2S	3.8368×10^{-3}	2.9228×10^{-3}
moles NH_3	1.8862×10^{-3}	1.72×10^{-3}
moles H_2O	1.1215	0
Gases other than H_2O (mole %)		
CO_2	96.85	98.43
H_2S	2.03	0.94
He	1.8×10^{-4}	4.3×10^{-3}
H_2	0.11	0.32
Ar	4.6×10^{-3}	2.0×10^{-3}
O_2	0	2.2×10^{-3}
N_2	0.87	0.25
CH_4**	1.0×10^{-3}	1.5×10^{-3}
NH_3	1.00	0.55

* Collected July 1977; analyzed by N. Nehring and A.H. Truesdell, U.S. Geological Survey, Menlo Park, California.

** Besides methane, chromatograms indicate the presence of ethene, ethane, propene, propane, 2-methyl-propane, 1-butene, n-butane, and n-pentane.

Gases other than water vapor

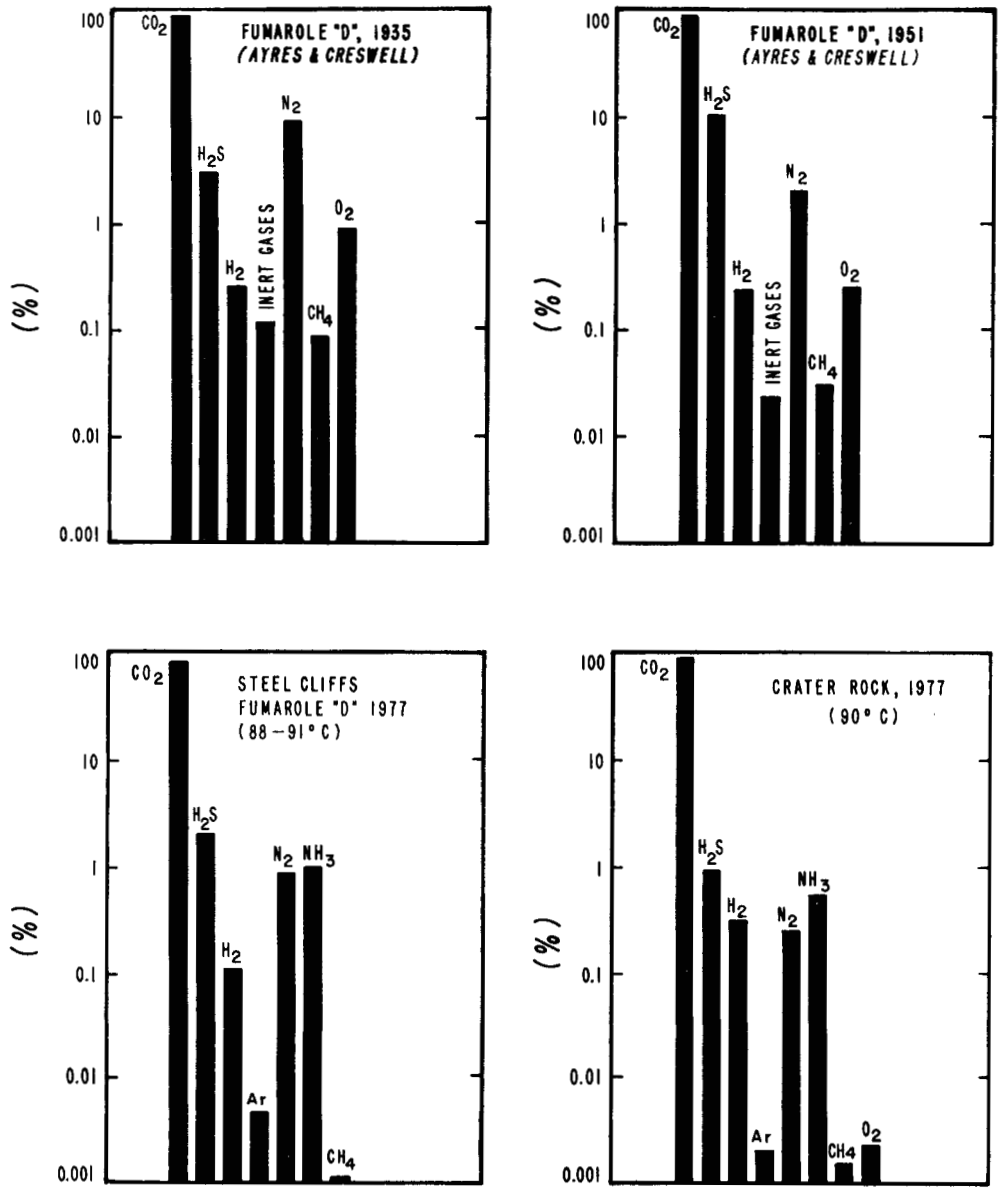

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Figure 16. Bar graphs, showing abundances of constituents (other than water vapor) of fumarolic gases, Mt. Hood.

of 1951 differs from the 1935 sample in its relative contents of CO_2, H_2S, and other constituents. The difference between the 1951 sample and our 1977 sample is of the same order. The 1977 Steel Cliffs and Crater Rock samples have similar bar-graph patterns, with their H_2S contents substantially higher than H_2, N_2, and NH_3, which are in turn at least two orders of magnitude higher than argon.

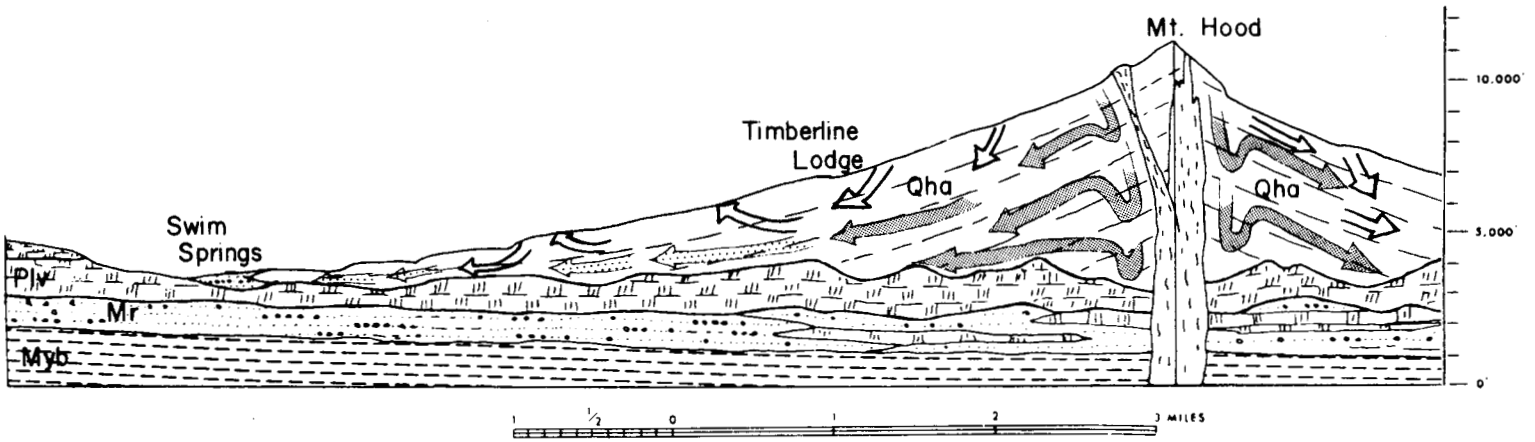
A second set of gas samples was collected from fumaroles in the Summit Crater area in October 1978. It is expected that sufficient water vapor was collected at that time to permit analyses of stable isotope contents, providing comparison with isotope ratios in spring-water samples.

IV. ORIGIN OF WARM WATER AT SWIM SPRINGS

It is appropriate here to speculate briefly on the source of the warm water and the pathway it takes to reach Swim Springs. The most likely explanation for the occurrence of warm water at Swim is that the water has been heated higher on the mountain, has migrated downslope, mixing with cold water, and comes to the surface at Swim. Snow- and glacier-melt water near the summit may come in close proximity to the hot central neck of the mountain, manifested by the steam zone of the summit-crater fumaroles. Some of this heated water probably percolates downslope in the andesitic mud-and ash-flows, mixing with cold water along its path (Figure 17).

The oxygen-hydrogen isotope data (Figure 12) provide evidence for the high-elevation origin of the Swim water. Meteoric water deposited at higher elevations has a larger component of lighter isotopes than does water at lower elevations. This indicates that a significant proportion of the warm water originated at higher elevations than the cold spring water.

Field measurements and analyses of cold springs also suggest that there is a small thermal component in some of the cold-spring water on the south flank of Mt. Hood. Surface and spring waters in the Mt. Hood region



XBL 792-8469

Figure 17. North-south geologic cross section of Mt. Hood (after Wise, 1968) showing, schematically, the hypothesized circulation paths of hot water (dark arrows) heated near the volcano's central neck, mixed warm water (lighter arrows), and cold water (un-shaded arrows). The warm water emanating at Swim Springs is strongly mixed, and cold water in springs on the south flank of the mountain may contain a small component of the deeper-flowing hot water. Myb = Yakima Basalt; Mr = Rhododendron Formation; Plv = Lower Pliocene basalt and andesite; Qha = Mt. Hood andesite flows.

generally contain a few ppm of total dissolved solids, 1 to 3 ppm chloride, and have specific conductances of 30 to 70 μmohs/cm. In contrast, as is illusrated in Figure 9, several of the cold springs on the south flank, below the 6000 ft elevation, have chloride contents and/or specific conductances well in excess of these values. For comparison, undiluted geothermal waters may contain several hundred to several thousand ppm chloride and have specific conductances in the range from several hundred to several thousand μmohs/cm; at Swim, the values are ∿900 ppm total dissolved solids, ∿150 ppm chloride, and 1300 μmohs/cm specific conductance.

Another possible explanation for the presence of warm water at Swim Springs is deep circulation along a fault zone. An east-west oriented fault zone in the vicinity of Swim has been suggested from analyses of earthquake epicentral data (R. Couch, personal communication, 1977). However, to date, other geological and geophysical investigations have not confirmed the fault zone. If a fault zone were present and it contained permeable zones, these could serve as conduits for deep circulation of meteoric water. It is more likely that if a fault zone is present, it would serve as an impermeable barrier to warm water moving down-slope, causing some impoundment and the emanation at Swim Springs. That the highest temperature orifice at Swim is lowest in elevation (Figure 5) could be attributed to nearly vertical circulation associated with a fault zone. More plausible, however, is the explanation that the water emanating at the lower orifice is warm water moving down-slope from a deeper horizon in the andesite, and therefore less mixed with cold water than the water in the higher orifices. Neither the fault-zone nor the down-slope moving warm water mechanisms for Swim Springs are mutually exclusive; both could be operating.

V. CONCLUSIONS

Though this is not a final report, sufficient data have been obtained to provide some preliminary conclusions on the geochemical setting of Mt. Hood. Firmer conclusions on the usefulness of the geochemistry in evaluating the geothermal resource potential await results of analyses presently underway.

1. The warm water at Swim Springs on the south flank of Mt. Hood has a large component (~90%) of nearer-surface cold water. The flux of cold-water runoff nearly masks the surface indications of deeper-circulating hot water. The upper-slope orifices at Swim are the most diluted, those downslope are successively less diluted. The oxygen-hydrogen isotope data indicate that cold-spring waters have short pathways between their sources and the springs, while a component of the warm-spring water has its origin considerably higher on the mountain.

2. Chemical geothermometers and mixing-model calculations indicate that temperatures at depth in the Swim Springs system are within the range 104-170°C. The silica mixing model gives a range of 192-240°C for unmixed hot water.

3. The chloride contents and specific conductances of the water sources indicate that most of the cold spring waters are derived almost directly from snow melt. Relatively high chloride contents and specific conductances in some springs on the south flank of Mt. Hood indicate that these waters may circulate deeper or may mix with geothermal waters.

4. Water in the geothermal test hole in Old Maid Flat, in a sample most likely from the Rhododendron Formation, has a different chemical character from the water at Swim. Geothermometry is consistent with a temperature gradient of 60°C/km as measured in the Old Maid Flat well.

5. The Platinum-group element, iridium, is present in identifiable abundances at one orifice at Swim Warm Springs, a cold spring, and in the small lake in the summit crater area. Iridium also occurs in altered andesite at one location on the western flank of Mt. Hood. The association of Ir with an andesitic volcano is surprising; it is generally considered to be associated with basic to ultrabasic igneous rocks.

6. The similarity between major- and trace-element contents of Pliocene andesite on the west flank of the mountain and intermediate intrusive rocks of the Laurel Hill pluton in that area supports Wise's (1969) contention that the pluton represents the root zone of a center of extrusion of the andesite.

7. The basalt exposed in the Robin Hood Quarry in the Hood River Valley has major- and trace-element contents very similar to those of the Roza flow of central Washington. This supports the idea that the basalt on the east side of the valley is Columbia River Basalt, on the upward-thrown side of a north-south trending normal fault.

VI. CONTINUING ACTIVITIES

Activities underway include analyses of gas samples collected in October 1978 in the summit fumarolic area. In the sampling of 1977 we were not able to collect sufficient water vapor to permit determination of isotope ratios. The volume of water vapor collected in 1978 is sufficient for these analyses. This will afford comparison with the isotope ratios of cold- and warm-spring water reported here.

Water analyses still to be completed at the time of publication include a sample collected in October 1978 from the geothermal test hole drilled near Timberline Lodge and a set of samples collected at that time from the three orifices sampled periodically at Swim Springs. Deepening of the geothermal test hole in Old Maid Flat in the summer of 1978 may permit us to obtain a fluid sample from a deeper aquifer (most likely within the Columbia River Basalt) than the Rhododendron Formation sampled in 1977.

Samples of altered and unaltered andesite from the fumarolic area in the summit crater were collected in October 1978. These are being analyzed for major and trace elements and will indicate if iridium and silver are present in the strongly altered ground, coinciding with the presence of these elements in the runoff water from the small lake.

It is recommended that one or more geothermal test holes be drilled in the Swim Warm Springs area. These holes should be deep enough to obtain temperature measurements and fluid samples from below the zone of near-surface and shallow cold-water runoff, to permit major-, trace-element, and isotope analyses of relatively unmixed hot water. The holes should be located on the up hill gradient from the Swim system to test whether the water emanating from Swim is leakage from volcanic units higher on Mt. Hood, or whether it is from deeper circulation within a fault zone.

LIST OF FIGURES

Figure 1. Regional geologic setting of Mt. Hood. (XBL 784-665)

Figure 2. Location map, Mt. Hood area. (XBL 784-644)

Figure 3. Local geologic setting of Mt. Hood (after Wise, 1968), showing locations of water and rock samples. (XBL 788-2661)

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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