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CHEMICAL AND ISOTOPIC DATA FOR WATER FROM THERMAL SPRINGS AND WELLS OF OREGON

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CHEMICAL AND ISOTOPIC DATA FOR WATER FROM THERMAL SPRINGS AND WELLS OF OREGON

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ABSTRACT

The thermal springs of Oregon range in composition from dilute $NaHCO_3$ waters to moderately saline CO_2-charged $NaCl$-$NaHCO_3$ waters. Most of the thermal springs are located in southeastern or south-central Oregon, with a few in northeastern Oregon and near the contact of the Western Cascades with the High Cascades. Thermal springs in the central and northern parts of the Cascades generally issue moderately saline NaCl waters. Farther south in the Cascades, the thermal waters are high in CO_2 as well as chloride. Most thermal springs in northeastern Oregon issue dilute $NaHCO_3$ waters of high pH (>8.5). These waters are similar to the thermal waters which issue from the Idaho batholith, farther east. Most of the remaining thermal waters are Na mixed-anion waters. Based on the chemical geothermometers, Mickey Springs, Hot Borax Lake, Alvord Hot Springs, Neal Hot Springs, Vale Hot Springs, Crump Well, Hunters (Lakeview) Hot Springs, and perhaps some of the springs in the Cascades are associated with the highest temperature systms (>150°C).

INTRODUCTION

Data presented in this paper are stored in the U.S. Geological Survey Geotherm file. Geotherm is a computerized file created and maintained as part of the Geological Survey's Geothermal Research program (Teshin and others, 1979). Geotherm contains information on the physical characteristics, geology, geochemistry, and hydrology of national and some international geothermal resources. The data include published information, data from other computer files, personal communications, and compilations of various government and private organizations. Retrievals are available to the public in a variety of formats: tape, punched cards, listings, or tables. Requests should be sent to: Geotherm Project, Mail Stop 84, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025.

Geotherm is currently composed of three subfiles: geothermal fields/areas, chemistry and physical properties of thermal wells and springs (sample file), and geothermal drill holes. In addition to these subfiles, there is a file containing the references listed in each record. The data retrieved from the sample file were formatted and special programs were written to calculate temperatures using geothermometers and to create the tables. The records in Geotherm contain more data than are listed in the tables. An example of a complete record is illustrated in figure 1.

The physiographic provinces of Fenneman (1946), shown on figure 2, have differing geologic settings which, in large part, determine the chemical character of the thermal fluids. The Basin and Range province is characterized by a thick sequence of nonmarine volcanic and sedimentary rocks of Cenozoic age, broken by faults which bound the major topographic features (Walker and Peterson, 1969). The volcanics range from basalt to rhyolite and the sedimentary rocks contain considerable volcanic debris. The Owyhee Uplands of southeastern Oregon make up a relatively unbroken plateau consisting of basaltic, andesitic, and rhyolitic sheets and their associated pyroclastics of middle to late Cenozoic age (Corcoran and Walker, 1969). The High Lava Plains of southcentral Oregon also consist of basalt, andesite, and rhyolite flows and their associated sedimentary rocks (Walker, 1969). The Blue Mountains are generally made up of intrusive rock, Quaternary basalts, and older sediments and volcanics, some of which are highly metamorphosed. Intrusive rocks of two ages are present, an older Permian to Triassic suite

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GEOTHERM SAMPLE FILE                                                                GEOTHERM FILE ID:  0000711
  NAME OF SAMPLE SOURCE... HOT LAKE
  WARING NUMBER........... 11
LOCATION                                   TOWNSHIP-RANGE                    COORDINATES
  COUNTRY............  UNITED STATES     04S 039E  05 NW OF SE               LAT/LONG...  45-14.63 N 117-57.51 W
  STATE..............  OREGON
  COUNTY.............  UNION
  MAP REFERENCE......  CRAIG MTN. 1:24000, GRANGEVILLE 1:250000
SAMPLE DESCRIPTION AND CONDITIONS
  DATE/COLLECTOR.......  1972/00/00 BARNES GROUP
  TEMPERATURE (C)......    80.0
   DISCHARGE...........    1500.  L/MIN
  WATER TREATMENT........... PRESSURE-FILTERED THROUGH A .45 MICROMETRE MEMBRANE, PORTION ACIDIFIED, DILUTED.
  DEPOSITS OR ALTERATION.... TRAVERTINE
  PERTINENT LITHOLOGY....... BASALT AND MYLONITE
WATER ANALYSIS
  DATE/ANALYST.............  1972/00/00 BARNES GROUP
  PH.......................    9.21
  SPECIFIC CONDUCTANCE.....    688.
  ANALYSIS IN MG/L                                                              ISOTOPES (0/00)
    AG.... L 0.02       CO3.....    12.      LI...     0.03   SB...  L 0.2       DEL D OF WATER.......     -127.7
    AL....              CR......             MG...  L  0.1    SC...              DEL O(18) OF WATER...     -16.56
    AS....   0.01       CS...... L 0.1       MN...  L  0.02   SE...              DEL O(18) OF SO4.....     4.63
    AU.... L 0.1        CU......    0.01     MO...            SIO2.    48.
    B.....   2.9        F.......    1.7      NA...     130.
    BA.... L 0.1        FE+3....             NA+K.            SO4..    56.
    BE.... L 0.1        FE(TOT). L 0.02      NB...            SR...  L 0.05
    BR....   0.4
    CA....   4.9        HCO3....    75.
    CA+MG.              HG......    0.0032   PB...  L  0.06
    CD.... L 0.01       H2S.....             PO4..     0.09
    CL....   140.       I.......    0.08     RB...  L  0.02
    CO.... L 0.05       K.......    2.7
GAS ANALYSIS
  ANALYSIS IN VOLUME %                                                          ISOTOPES (00/0)
    CH4..    9.
    C2H6.                                    N2...     90.
    CO2..  L 1.
OTHER ANALYTICAL DATA... O2+AR=2
REFERENCE AND IDENTIFICATION
  COMPILED BY............  SANFORD, LINDA
  COMPILER AFFILIATION...  U.S. GEOLOGICAL SURVEY
  COMPILER CROSS INDEX...  02
  REFERENCE..............  MARINER AND OTHERS, 1974; MARINER AND OTHERS, 1975; NEHRING AND OTHERS, 1979
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Figure 1. Example of a complete Geotherm record

OREGON

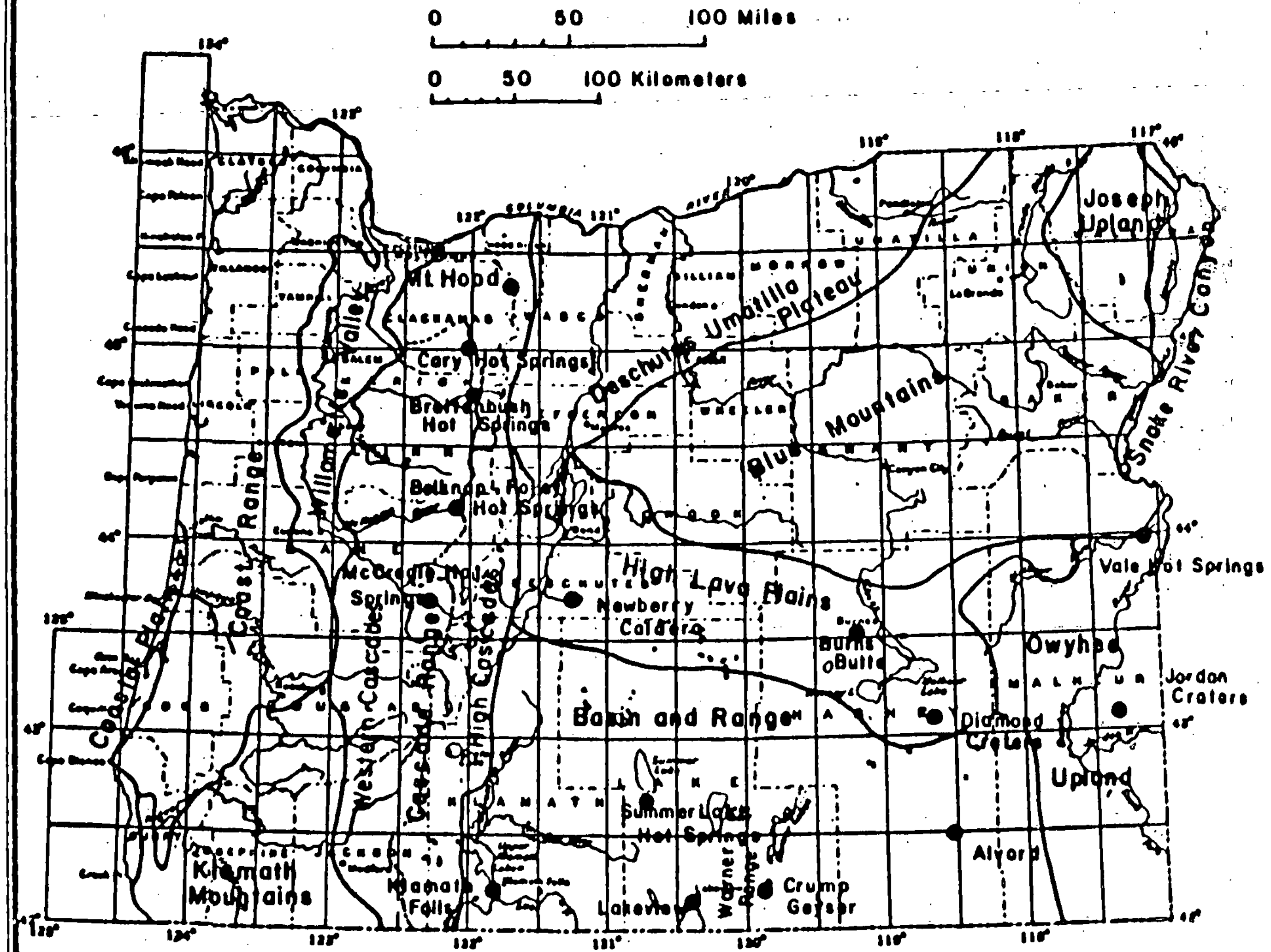

Figure 2. Physiographic Divisions, Known Geothermal Resource Areas, and other features of possible geothermal importance.

which ranges from peridotite to granite, and a Lower Cretaceous suite which ranges from gabbro to granodiorite (Thayer and Wagner, 1969). Several of the younger intrusives are outliers of the Idaho batholith. The Cascade province consists of two subdivisions, the High Cascades and the Western Cascades. The High Cascade Subprovince is a relatively narrow plateau of basalt and andesite flows of Pleistocene and Pliocene Age. The Western Cascade Subprovince is made up of slightly deformed and altered volcanic and pyroclastic rocks that range from late Eocene to late Miocene in age. A few small diorite intrusions also occur in the altered zones of the Western Cascades. The southern end of the Cascades is underlain by a complex of graywacke, siltstone, and interbedded volcanics of Triassic to Cretaceous age, some of which have been regionally metamorphosed. Intrusives associated with these rocks range from granite to peridotite (Griggs, 1969). This type of basement rock extends from the Klamath Mountains in southwestern Oregon to the Blue Mountains in northeastern Oregon. The northern part of the Cascades is underlain by marine and estuarine deposits of Eocene age which are exposed in the Coast Ranges to the west.

Thirteen KGRA's (Known Geothermal Resource Areas) have been designated in Oregon: Mt. Hood, Cary Hot Springs, Breitenbush Hot Springs, Belknap-Foley Hot Springs, and McCredie Hot Springs in the Cascades; Klamath Falls, Lakeview, Crump Geyser, Alvord, and Summer Lake Hot Springs in the Basin and Range province, Newberry Caldera and Burns Butte in the High Lava Plains; and Vale Hot Springs in the Owyhee Uplands. Groh (1966) pointed out several other areas of potential geothermal importance: Jordan Craters in the Owyhee Uplands; Diamond Craters in the Harney Basin; the area southeast of Newberry Caldera in the High Lava Plains; and the Warner Range in the southern part of the Basin and Range province.

Brook and others (1979) list eight areas which they believe have mean reservoir temperatures of more than 150°C: Newberry Caldera 230° (230°C), Crump's Hot Spring (167°C), Mickey Hot Springs (207°C), Alvord Hot Springs (181°C), Hot (Borax) Lake (181°C), Trout Creek Area (154°C), Neal Hot Springs (188°C), and Vale Hot Springs (157°C). These areas are estimated to have an aggregate thermal energy of 90 x 10^{18} joules, most of which is in the Vale, Alvord, and Newberry areas. About 55 x 10^{18} joules are estimated to be present in 20 systems of lower temperature (90° to 150°C), with approximately 70 percent of this amount in the Klamath Falls and Lakeview areas. The temperatures used in the estimates are mean temperatures for the respective systems and do not reflect the maximum and minimum temperatures of the reservoirs. Since volumes of the individual systems are more important in determining the amount of stored heat than the temperatures, and since the volume estimates may undergo considerable change as drillhole and geophysical data become available, changes in the estimated quantities of thermal heat available in Oregon are anticipated.

Chemical data exist for many of Oregon's thermal waters, but they are often scattered in the literature or in unpublished files. A compilation of the raw chemical data for Oregon, as it was entered into Geotherm, has recently been published by the Oregon Department of Geology and Mineral Industries as Open-File Report 0-79-3. The data stored in Geotherm cannot be considered to be of uniform quality since they were collected for a myriad of purposes and by different techniques. Anyone considering a sampling program should consult the available literature on general water sampling, such as Brown and others (1970), and the special techniques described for handling geothermal waters such as those given by Presser and Barnes (1974).

The approximately 170 thermal springs and wells identified in Oregon are not distributed uniformly over the state (Bowen, Peterson and Riccio, 1979; Waring, 1965). The largest number of springs issue in the Basin and Range province of southeastern Oregon, with progressively fewer springs in the High Lava Plains, Owyhee Uplands, Blue Mountains, and Cascade Range. The Coastal Plain, Coast Range, Klamath Mountains, and Willamette Valley of western Oregon are devoid of thermal springs. Curiously, most hot springs do not occur in the areas of most recent volcanic activity. Crater Lake, formed some 7,000 years ago by a violent volcanic eruption, has no hot springs associated with it, and the smaller Newberry Caldera has only two areas of weak thermal springs. The springs at Newberry may be drowned fumaroles; they issue in or at the edges of the lakes and appear to be dominantly gas vents. Diamond Craters in the eastern High Lava Plains and Jordan Craters in the Owyhee Uplands are also of Holocene age, but neither has thermal springs nearby. With the exception of Mt. Hood, which has a fumarole on it and a weak thermal spring at its base, the prominent volcanoes of the High Cascades, which have all been formed in the last three million years, do not have thermal springs directly associated with them. Most of the thermal springs in the Cascades issue to the west of the crest, near the contact of the High Cascades and the older Western Cascades.

DATA

Chemical data for the springs and wells (table 1) are arranged by county and numbered to correspond to the thermal springs and wells on a map prepared by Bowen and others (1978). This compilation represents all of the chemical and isotopic data in Geotherm as of October, 1979. Entries for springs that have been analyzed several times are arranged chronologically. Sources of data, topographic map coverage, and year of collection are listed in table 2. Two of the chemical analyses have gross imbalances of ionic charge and hence are incomplete or otherwise inaccurate. Joaquin Miller Hot Springs in Grant County has 25.3 millequivalents cations to 5.5 milliequivalents anions. A sample recently collected by us indicates that the reported alkalinity is low by more than a factor of 10. The sodium concentration of the sample from Camp Collins in Multnomah County seems to be excessively small. If the sodium concentration were greater by a factor of 10, the charge balance would be much better, 4.88 milliequivalents cations to 4.80 milliequivalents anions rather than the 0.95 to 4.80 as reported.

Waters from several geographic areas can be distinguished on the basis of their chemical composition. Thermal waters in the Western Cascades from Austin to Kitson and McCredie Hot Springs are high in chloride, but low in sulfate and bicarbonate. These sodium chloride waters may originate from the Eocene sediments which are thought to underlie this part of the Cascades. Ratios of B/Cl, Br/Cl, and HCO_3/Cl are similar to those reported for connate waters (White, 1960). Connate marine waters have been noted in springs and wells in the Coast Range, the Western Cascades, and at depths of as little as 30 meters in the Willamette Valley (Piper, 1942). Farther south in the Cascades, the water of Umpqua Hot Springs is similarly high in chloride, but is also high in CO_2. Many CO_2-charged mineral springs issue in Douglas County (Wagner, 1959). CO_2-charged thermal waters also issue from Weberg Hot Springs in southwestern Grant County; this area also has many cold CO_2-charged springs. The water issuing from Weberg Hot Springs differs from that of Umpqua Hot Springs in that it contains very little chloride. The rest of Grant County, and the southern part of Umatilla, Union, and western Baker counties, all in the northeastern part of Oregon, have thermal springs which issue dilute, high-pH thermal water similar to waters from thermal springs in granitic rocks of the Idaho batholith. Bagby Hot Springs in the Cascades is another spring that yields the dilute, high-pH waters associated with granitic rock. These waters are high enough in pH to require corrections to the silica concentrations, as discussed in the section on

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS
[Map code refers to Bowen, Peterson, and Riccio 1978; Concentrations in mg/l; (ND) not detected]

Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
BAKER COUNTY															
01	RADIUM HOT SPRINGS	44-55.82 117-56.36 07S/039E -28 NE	55/05	290	57.2	9.7	80.	63.	2.0	1.6		101	31.	17.	1.0
01	RADIUM HOT SPRINGS	44-55.82 117-56.36 07S/039E -28 NE	72/00	290	58.	9.56	78.	58.	1.1	1.5	0.1	141	34.	17.	1.3
02	SAM-O SPRING	44-46.76 117-48.65 09S/040E -16 SE	77/02	891	27.0	8.1	67.6	171.	12.2	16.2	6.	519	3.7	15.9	1.2
05	KROPP HOT SPRING	45-00.8 117-53.1 06S/039E -25 NW		445	43.0	7.3	58.	93.	1.5	1.1	0.1	52	31.6	80.8	1.19
06	FISHER HOT SPRING	44-58.48 118-02.61 07S/038E -10 NW	72/06	197	37.0	9.8	38.9	40.		1.4	<0.1	83	12.	1.8	0.4
CLACKAMAS COUNTY															
01	ACID-SULFATE SPRING ON MT. HOOD	45-22.3 121-41.8 02S/009E -29	76/06	227		3.8	19.	5.	0.2	13.	2.8		77.	1.	
02	SWIM WARM SPRINGS	45-17.7 121-44.3 03S/8.5E -24 SW	76/12	1300	26.0	7.3	72.3	136.	11.7	60.	48.	218	205.	161.	0.23
03	AUSTIN HOT SPRINGS (CAREY)	45-01.30 122-00.50 06S/007E -30 NW	72/00	1720	86.0	7.63	81.	300.	7.1	35.	0.1	58	140.	430.	1.4
04	BAGBY HOT SPRINGS	44-56.15 122-10.35 07S/005E -26 NW	70/03	290	57.2	9.7	81.5	54.	0.8	3.7	0.1	68	33.7	14.6	0.68
04	BAGBY HOT SPRINGS	44-56.15 122-10.35 07S/005E -26 NW	77/09		58.	9.37	74.	53.	0.74	3.3	<0.05	69	42.	14.	0.66
05	GEOTHERMAL GRADIENT TEST NEAR AUSTIN HOT	45-01.65 121-57.80 06S/007E -21 SW	76/08	282	35.6	7.6	36.	48.	2.8	12.	2.6	162	3.6	2.	0.71
DESCHUTES COUNTY															
01	EAST LAKE HOT SPRINGS	43-43.1 121-12.2 21S/013E -29 SW	73/00	396	62.0	6.49	36.	32.	3.8	38.	16.	184	58.	0.4	0.2
01	EAST LAKE HOT SPRINGS	43-43.1 121-12.2 21S/013E -29 SW	75/08	767	49.	6.42	199.	53.		70.	34.	547	25.	1.7	0.16
02	PAULINA HOT SPRINGS	43-43.7 121-45.0 21S/012E -26 NE	77/07			6.82	205.	140.	17.	56.	60.	856	<1.	6.0	0.57
02	WARM WELL AT LITTLE CRATER CAMPGROUND	43-42.9 121-14.5 21S/012E -36 NW	75/08	900	35.5	6.46	161.	83.	10.	54.	48.	679	<1.	5.1	0.6
DOUGLAS COUNTY															
01	UMPQUA HOT SPRINGS	43-17.70 121-21.90 26S/004E -20 NE	77/09	11300	46.5	6.37	90.	2400.	63.	340.	41.	1380	193.	3500.	1.5
01	UMPQUA HOT SPRINGS	43-17.70 121-21.90 26S/004E -20 NE	78/06	10920	46.	6.2	96.	2150.	62.	428.	42.4	1120	139.2	3340.	1.2
GRANT COUNTY															
01	RITTER HOT SPRINGS	44-53.60 119-08.50 08S/030E -08 NW	73/00	319	41.0	9.68	70.	72.	0.82	1.6	<0.05	145	9.	29.	4.0
04	BLUE MOUNTAIN HOT SPRINGS	44-21.30 118-34.40 14S/034E -13 S/2	72/00	610	58.0	7.96	47.	140.	3.3	2.2	0.2	329	11.	15.	10.6
05	JOAQUIN MILLER RESORT	44-16.81 118-57.36 15S/031E -11 SE	78/07	2194	40.	6.8		500.	11.2	45.2	12.1	103	1.6	121.	7.1

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Concentrations in mg/l; (ND) not detected; (m) monomeric aluminum]

Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
	BAKER COUNTY												
01	RADIUM HOT SPRINGS								0.2	ND	ND	ND	
01	RADIUM HOT SPRINGS	0.42	0.01	<0.02	<0.1	<0.05	0.01	0.007			<0.02	<0.02	0.0005
02	SAM-O SPRING	1.6	0.06							0.43	<0.1	0.05	
05	KROPP HOT SPRING	3.3	<0.1							0.04	<0.03	<0.03	
06	FISHER HOT SPRING	2.8	1.0							0.07	<0.03	<0.03	
	CLACKAMAS COUNTY												
01	ACID-SULFATE SPRING ON MT. HOOD		<0.01										
02	SWIM WARM SPRINGS	0.32	0.13						<0.02	<0.02	<0.05	<0.05	
03	AUSTIN HOT SPRINGS (CAREY)	2.6	0.4	0.03	<0.1	0.33	2.	0.03			<0.02	<0.02	0.0002
04	BAGBY HOT SPRINGS	0.6								0.2			
04	BAGBY HOT SPRINGS	0.07	0.02										
05	GEOTHERMAL GRADIENT TEST NEAR AUSTIN HOT	0.42	0.01						0.38	<0.05	18.		
	DESCHUTES COUNTY												
01	EAST LAKE HOT SPRINGS	0.93	0.01	<0.02	<0.1	0.14					<0.02	0.10	0.0003
01	EAST LAKE HOT SPRINGS	1.1	0.04	0.03	<0.1					0.008m	0.66	0.90	
02	PAULINA HOT SPRINGS	0.87	0.22	0.04	<0.1								
02	WARM WELL AT LITTLE CRATER CAMPGROUND	2.5	0.12	0.02	<0.1					0.002m	4.	0.25	<0.0001
	DOUGLAS COUNTY												
01	UMPQUA HOT SPRINGS	41.	2.4	0.16	0.2					<0.002m	0.44		<0.0001
01	UMPQUA HOT SPRINGS	41.2	2.4							2.2	6.2		
	GRANT COUNTY												
01	RITTER HOT SPRINGS	2.6	0.01	<0.02	<0.1	<0.05					<0.02	<0.02	0.0005
04	BLUE MOUNTAIN HOT SPRINGS	1.6	0.07	<0.02	<0.1	<0.05	0.04	0.01			<0.02	<0.02	0.0004
05	JOAQUIN MILLER RESORT	12.7	0.25						0.02	0.08	0.1	1.8	

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

[Map code refers to Bowen, Peterson, and Riccio 1978;
Concentrations in mg/l; (ND) not detected]

Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
GRANT COUNTY															
07	WEBERG HOT SPRING	44-00.1 119-38.8 18S/026E -18	72/00	2570	46.0	6.53	82.	610.	36.	38.	7.8	1712	13.	50.	3.9
HARNEY COUNTY															
01	UNNAMED SPRING	43-39.76 118-44.30 22S/32.5E-14 SW	31/09		22.					16.		86	4.	1.9	
02	O. J. THOMAS	43-37.65 118-51.75 22S/032E -34 NE	68/09	716	72.0	9.5	89.	157.	1.8	1.0	0.2	236	89.	38.	2.8
04	MILLPOND SPRING	43-32.43 119-04.86 23S/030E -35 NE	31/08		26.					14.		109	11.	8.	
05	HARNEY VALLEY DEV CO. OIL TEST WELL	43-30.25 118-54.30 24S/032E -08 SE	68/09	602	46.0	9.6	72.	135.	1.6	0.8	0.2	265	27.	11.	12.
08	ISLAND RANCH WELL	43-25.40 118-55.95 25S/032E -07 NW	69/08	1450	41.0	9.3	54.	386.	4.4	0.5	0.2	967	8.	9.	19.
09	CRANE HOT SPRINGS	43-26.45 118-38.30 24S/033E -34 SW	31/08		49.					2.		218	80.	82.	
09	CRANE HOT SPRINGS	43-26.45 118-38.30 24S/033E -34 SW	68/09	814	80.0	8.3	80.	170.	3.6	3.8	0.2	211	81.	78.	9.3
09	CRANE HOT SPRINGS	43-26.45 118-38.30 24S/033E -34 SW	72/00	810	78.0	8.1	83.	170.	3.9	3.7	0.1	208	85.	79.	9.0
10	WARM SPRING NEAR VENATOR	43-23.7 118-18.4 25S/036E -16 SW	77/06	650	41.0	9.1	370.	100.	1.0	2.7	0.1	134	51.	70.	1.1
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	43-10.6 119-03.6 27S/29.5E-36 SE	31/08		59.		92.	622.	12.	13.	3.0	601	140.	562.	
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	43-10.6 119-03.6 27S/29.5E-36	72/00	2970	68.0	7.26	92.	630.	13.	12.	1.8	568	143.	590.	3.3
22	MICKEY SPRINGS	42-40.6 118-20.7 33S/035E -13	70/07	2200	85.	8.5	167.	478.	20.	1.	1.2		205.	230.	19.6
22	MICKEY SPRINGS	42-40.6 118-20.7 33S/035E -13	72/00	2490	73.0	8.05	200.	550.	35.	0.9	0.1	796	230.	240.	16.
22	MICKEY SPRINGS	42-40.6 118-20.7 33S/035E -13	76/09	2200	86.	8.31	214.	550.	31.	1.0	<1.	804	210.	240.	16.
22	MICKEY SPRINGS	42-40.6 118-20.7 33S/035E -13	76/09	2220	86.	8.31	214.	550.	30.	1.0	0.1	814	220.	240.	17.
22	MICKEY SPRINGS	42-40.54 118-20.67 33S/035E -13	76/09	2290			200.	560.	32.	0.6	<0.1	836	220.	245.	17.
23	ALVORD HOT SPRINGS	42-32.6 118-32.1 34S/034E -33 SE	55/11	4490	82.2	7.3	135.	1040.	66.	13.	1.0	1250	211.	760.	7.2
23	ALVORD HOT SPRINGS	42-32.6 118-32.1 34S/034E -33 NW	72/00	4590	76.0	6.73	120.	960.	69.	13.	2.2	1198	220.	780.	10.2
23	ALVORD HOT SPRINGS	42-32.6 118-32.1 34S/034E -33	76/09	4100	78.5	6.90	129.	990.	64.	12.	2.1	1225	180.	770.	9.6
23	ALVORD HOT SPRINGS	42-32.6 118-32.1 34S/034E -33	76/09	4070	78.5	6.89	128.	1000.	63.	12.	2.2	1230	180.	770.	11.
24	HOT BORAX LAKE	42-19.60 118-36.17 37S/033E -15 SW	53/09	2227	29.4	7.7	184.	488.	23.	17.		424	343.	286.	8.
24	HOT BORAX LAKE	42-19.60 118-36.17 37S/033E -15 SW	61/06	2410	31.1	7.8	193.	516.	27.	16.	0.5	450	367.	305.	9.7

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS
[Map code refers to Bowen, Peterson, and Riccio, 1978; Concentrations in mg/l; (ND) not detected; (m) monomeric aluminum]

Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
GRANT COUNTY													
07	WEBERG HOT SPRING	15.	0.7	0.09	<0.1	2.1	0.1	0.1			0.24	0.06	0.0003
HARNEY COUNTY													
01	UNNAMED SPRING								1.0				
02	O. J. THOMAS	3.99							ND		0.03		
04	MILLPOND SPRING								1.1				
05	HARNEY VALLEY DEV CO. OIL TEST WELL	4.11							0.2		0.20		
08	ISLAND RANCH WELL								0.1				
09	CRANE HOT SPRINGS								1.4				
09	CRANE HOT SPRINGS	6.2							ND		0.02		
09	CRANE HOT SPRINGS	7.9	0.09	0.03	<0.1	0.06	0.1	0.02		0.022m	<0.02	<0.02	0.0005
10	WARM SPRING NEAR VENATOR	2.2									0.03	N	
15	UNNAMED HOT SPRING NEAR HARNEY LAKE								0.5		0.03		
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	11.3	0.45	0.08	<0.1	0.11	29.	0.2		0.005m	0.05	0.04	0.0001
22	MICKEY SPRINGS	9.2	<0.2						0.02	<0.01	0.05	0.02	
22	MICKEY SPRINGS	10.5	1.1	0.20	0.1	0.15	1.	0.09		0.058m	<0.02	<0.02	0.0001
22	MICKEY SPRINGS	11.	0.90	0.18	0.1								
22	MICKEY SPRINGS	11.	0.90	0.14	<0.1					0.068m	<0.02		
22	MICKEY SPRINGS	11.	0.85	0.15	<0.1								
23	ALVORD HOT SPRINGS	28.							1.1		0.02	N	
23	ALVORD HOT SPRINGS	30.	2.1	0.33	0.2	0.92	2.	0.09		0.003m	0.12	0.02	0.0001
23	ALVORD HOT SPRINGS	35.	1.9		0.1								
23	ALVORD HOT SPRINGS	36.	1.9	0.24	0.1								
24	HOT BORAX LAKE	17.9	<1.5						2.5				
24	HOT BORAX LAKE	18.											

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

[Map code refers to Bowen, Peterson, and Riccio 1978;
Concentrations in mg/l; (ND)not detected]

Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
	HARNEY COUNTY														
24	HOT BORAX LAKE	42-19.60 118-36.17 37S/033E -15 SW	72/00	2410	36.0	7.28	190.	500.	31.	16.	0.3	422	353.	300.	9.0
27	UNNAMED HOT SPRING NEAR TROUT CREEK	42-11.3 118-23.0 39S/037E -16	70/08	1060		8.3	79.	230.	25.	18.4	0.9		177.	226.	12.0
27	UNNAMED HOT SPRING NEAR TROUT CREEK	42-11.3 118-23.0 39S/037E -16	72/00	1168	52.0	6.77	105.	270.	10.8	18.	0.8	441	204.	24.	12.8
39	GOODMAN SPRING (HOTCHKISS)	43-31.73 119-04.83 23S/030E -35 SE	68/09	210	22.0	7.5	46.	35.	3.2	8.2	1.4	92	15.	7.	0.6
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.17 118-36.08 37S/033E -11 SW	53/09	2050	73.9	7.6	119.	430.	27.	15.		382	319.	255.	7.0
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-19.82 118-36.16 37S/033E -14 NW	53/09	2160	79.4	8.1	173.	456.	30.	14.	0.3	416	339.	270.	7.0
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.08 118-36.11 37S/033E -11	57/05	2190	87.0	7.5	160.	426.	29.	9.6		425	325.	265.	6.5
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.17 118-36.08 37S/033E -11 SW	73/06	2020	96.0	7.30	160.	450.	28.	14.	0.3	382	434.	250.	7.2
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.17 118-36.08 37S/033E -11 SW	76/09	1990	91.	7.94	189.	460.	29.	15.	0.3	434	320.	270.	7.5
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.08 118-36.11 37S/033E -11	76/09	1840	97.	7.36	169.	435.	24.	13.	0.2	389	300.	250.	7.6
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-19.82 118-36.16 37S/033E -14 NW	76/09	1910	90.5	7.04	154.	435.	26.	15.	0.3	420	300.	250.	7.0
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-19.82 118-36.16 37S/033E -14 NW	76/09	2040	86.	8.67	157.	450.	26.	14.	0.3	423	300.	250.	7.7
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-20.17 118-36.08 37S/033E -11 SW	76/09	1840	97.	7.26	163.	425.	24.	12.	0.2	372	300.	250.	7.4
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	42-19.82 118-36.16 37S/033E -14 NW	76/09	1890	84.	7.48	164.	440.	25.	12.	0.2	386	310.	250.	7.5
44	HOTCHKISS WELL	43-31.42 119-03.83 24S/030E -01 NE	31/08		27.		51.	30.	2.4	9.6	1.7	95	13.	5.2	
44	HOTCHKISS WELL	43-31.42 119-03.83 24S/030E -01 NE	68/09	194	27.	8.1	46.	31.	2.9	8.8	1.4	93	12.	5.	0.5
45	HINES LUMBER CO. WELL	43-32.34 119-04.80 23S/030E -35 NE	68/07	222	25.0	7.8	55.	33.	4.	11.	2.	105	14.	7.	0.5
46	CITY OF HINES WELL	43-33.57 119-05.31 23S/030E -23 SW	68/07	289	17.0	7.8	60.	35.	6.9	15.	5.7	128	15.	13.	0.5
	JACKSON COUNTY														
01	JACKSON HOT SPRING	42-13.30 122-44.65 38S/001E -48 SW	52/04	460	35.0	9.3	65.	95.	1.2	2.8	1.4	81	26.	80.	2.0
	KLAMATH COUNTY														
	ALFRED JACOBSEN	42-07.65 121-44.40 39S/009E -34 NE	74/05	290	30.0	7.6	65.	49.	12.	9.7	2.4	160	13.	7.9	0.1
	BILL HILL	42-03.55 121-36.60 40S/010E -26 NW	74/06	245	20.0	7.7	26.	19.	6.4	9.1	13.	140	5.6	4.2	
	CLAUDE SHUCK	42-11.35 121-39.80 39S/010E -08 SE	74/05	220	24.	8.2	57.	25.	6.2	9.7	4.1	112	15.	2.8	0.2

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

[Map code refers to Bowen, Peterson, and Riccio, 1978; Concentrations in mg/l; (ND) not detected; (m) monomeric aluminum]

Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
	HARNEY COUNTY												
24	HOT BORAX LAKE	16.6	0.65	0.23	0.1	0.42	2.	0.2			<0.02	0.03	0.0004
27	UNNAMED HOT SPRING NEAR TROUT CREEK	1.6	<0.5						0.05	<0.01	0.03		
27	UNNAMED HOT SPRING NEAR TROUT CREEK	0.89	0.68	0.10	0.1	0.30				0.002m	0.09	<0.02	0.0003
39	GOODMAN SPRING (HOTCHKISS)	0.23							2.1		0.02		
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	12.	<1.5						1.2				
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	14.	<1.5						1.3				
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	15.	ND			ND	1.8	0.2	ND	ND	ND	0.10	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	15.	0.51	0.18	0.1	0.60				0.020m	<0.02	0.04	0.0008
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	15.	0.50	0.23	0.2								
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	14.	0.50	0.17	0.1					0.028m	<0.02	0.05	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	15.	0.5	0.18	0.2								
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	14.	0.55	0.18	0.1								
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	14.	0.45	0.17	0.1						<0.02		
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	15.	0.45	0.18	0.1								
44	HOTCHKISS WELL								1.2		0.01		
44	HOTCHKISS WELL	0.06							1.1				
45	HINES LUMBER CO. WELL	0.38							1.5		0.02		
46	CITY OF HINES WELL	0.53							3.8		0.05		
	JACKSON COUNTY												
01	JACKSON HOT SPRING	2.9							0.2		0.07		
	KLAMATH COUNTY												
	ALFRED JACOBSEN	0.05									0.12	0.050	
	BILL HILL	0.02									0.04	0.030	
	CLAUDE SHUCK	0.02									0.05	0.010	

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS
[Map code refers to Bowen, Peterson, and Riccio 1978;
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Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
	KLAMATH COUNTY														
	CLYDE DEHILINGER	42-06.75 121-39.65 40S/010E -05 SE	74/06	240	24.0	7.9	72.	40.	6.5	8.1	3.1	150	2.3	4.9	
	FALCON HEIGHTS SCHOOL	42-07.80 121-45.10 39S/009E -34 SW	74/05	350	37.0	7.8	80.	57.	7.1	7.7	4.5	170	26.	8.9	0.22
	GEORGE CARTER	42-00.55 121-36.90 41S/010E -14 NW	74/06	660	22.	8.2	41.	99.	7.9	29.	2.3	100	95.	98.	
	GEORGE STACY CO.	42-08.40 121-39.80 39S/010E -32 NE	74/06	170	25.0	8.3	34.	20.	4.0	13.	2.0	94	11.	2.0	
	JACK O'CONNER	42-02.00 121-42.95 41S/009E -01 NE	74/05	640	38.0	8.3	65.	130.	3.0	7.5	0.6	116	140.	50.	
	LEN DOBRY	42-08.90 121-38.65 39S/010E -28 SE	74/05	195	21.0	7.6	65.	32.	4.5	5.7	1.1	100	14.	3.4	
	LESTER BROOKSHIRE	42-08.70 121-39.70 39S/010E -29	74/05	175	25.0	8.1	35.	21.	3.4	13.	2.0	97	10.	2.8	0.1
	MELVIN MCCOLLUM	42-11.50 121-41.05 39S/010E -07 NE	74/05	300	25.0	7.5	52.	20.	4.0	24.	13.	120	53.	3.1	0.2
	MONTE DEHILINGER	42-07.60 121-40.40 39S/010E -32 SW	74/06	260	26.0	7.6	54.	22.	6.7	17.	11.	160	7.1	3.6	
	O'CONNER LIVESTOCK CO.	42-01.00 121-41.00 41S/010E -07 SE	74/06	1300	30.0	7.8	80.	210.	7.0	58.	6.4	250	210.	160.	
	OREGON WATER CORP.(4)	42-12.10 121-41.40 39S/010E -06 SW	70/08		26.	8.6	63.	36.		8.5	5.8		6.5	3.0	0.32
	POPE'S MEAT CO.	42-01.95 121-37.50 41S/010E -03 NE	74/06	190	22.0	8.5	25.	30.	3.2	8.6	1.4	104	6.0	4.4	
	RAY BIXLER	42-11.55 121-37.95 39S/010E -10 NW	74/05	190	22.0	7.8	49.	16.	3.3	12.	8.4	110	7.9	1.9	0.2
	ROBERT LANGLEY	42-10.75 121-37.90 39S/010E -15 SE	74/05	200	23.	7.4	50.	22.	5.5	10.	6.3	112	14.	2.6	
	TOWN OF MERRILL	42-01.50 121-36.00 41S/010E -02 SE	55/02	316	21.0	8.3	38.	44.	3.8	11.	4.3	114	21.	27.	0.1
	U.S. AIR FORCE(1)	42-08.05 121-45.25 39S/009E -34 NW	72/10	240	31.0	7.0	53.	47.	9.0	3.8	1.2	128	8.	6.0	0.3
	U.S. AIR FORCE(2)	42-08.10 121-45.35 39S/009E -34 NW	72/10	255	30.		51.	48.	8.5	5.6	2.3	145	9.	6.3	0.2
	WEYERHAUSER WELL NO. 4	42-10.70 121-48.10 39S/009E -18 SW	72/08	200	22.	8.3	16.	32.	3.3	10.	1.9	124	4.	4.	0.11
01	EAGLE POINT SPRING	42-25.85 121-57.75 36S/007E -23 SE	72/08	305	35.	8.3	38.	62.	5.7	0.6	<0.1	136	62.	16.	0.75
02	J. E. FRIESEN	42-13.75 121-46.15 38S/009E -28 SW	55/02	1230	73.0	8.7	87.	221.	4.4	25.		48	431.	56.	1.6
02	LOIS MERRUYS	42-13.65 121-01.45 38S/009E -33 NW	54/12	1100	71.0	8.5	83.	207.	3.8	22.		91	393.	50.	1.4
02	MEDO-BELL DAIRY	42-13.8 121-46.4 38S/009E -28 SW	55/01	1160	81.0	8.8	81.	213.	4.2	23.		68	405.	54.	1.2
02	MILLS SCHOOL	42-13.45 121-45.90 38S/009E -33 NE		1200	89.0	8.3	78.	370.	3.0	27.	<0.2	46	482.	54.	1.2
02	MOYINA WATER CO.	42-12.60 121-42.45 39S/009E -01 NW	66/08	222	50.	7.4	64.	38.	5.0	7.9	2.3		5.6	1.8	0.22

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

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Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
	KLAMATH COUNTY												
	CLYDE DEHILINGER	0.04									0.02	ND	
	FALCON HEIGHTS SCHOOL	0.1									0.19	0.030	
	GEORGE CARTER	0.15									0.02	0.020	
	GEORGE STACY CO.	0.01									0.04	0.010	
	JACK O'CONNER												
	LEN DOBRY												
	LESTER BROOKSHIRE	0.006									0.02	0.02	
	MELVIN MCCOLLUM	0.02									1.4	0.07	
	MONTE DEHILINGER	0.02									0.02	ND	
	O'CONNER LIVESTOCK CO.	0.69									0.04	0.15	
	OREGON WATER CORP.(4)										0.33	<0.005	
	POPE'S MEAT CO.	0.02									0.02	ND	
	RAY BIXLER	0.02									0.15	1.4	
	ROBERT LANGLEY												
	TOWN OF MERRILL	0.01							ND		0.12		
	U.S. AIR FORCE(1)										0.04	<0.01	
	U.S. AIR FORCE(2)										0.03	<0.01	
	WEYERHAUSER WELL NO. 4	0.09											
01	EAGLE POINT SPRING	0.140											
02	J. E. FRIESEN	0.91							ND		ND		
02	LOIS MERRUYS	0.74							0.2		ND		
02	MEDO-BELL DAIRY	0.96							ND		0.04		
02	MILLS SCHOOL	0.96									0.03	0.03	
02	MOYINA WATER CO.										0.42	<0.05	

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Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
KLAMATH COUNTY															
02	O.I.T. NO. 5	42-13.85 121-46.40 38S/009E -28 SW	67/00	1000	89.0	8.6	73.	331.	3.5	25.1	1.04	55	384.	48.	1.12
02	O.I.T. NO. 6	42-14.90 121-46.85 38S/009E -20 NE	72/08		88.0	8.2	31.	195.	3.9	24.2	<0.1	44	400.	58.	1.45
02	O.I.T. NO. 6	42-14.90 121-46.85 38S/009E -20 NE	75/03		79.		90.								
02	OREGON WATER CORP.(1)	42-13.30 121-47.45 38S/009E -32 NW	30/03	200	21.		46.	29.		10.	4.	117		8.	
02	OREGON WATER CORP.(2)	42-13.30 121-47.45 38S/009E -32 NW	71/09		21.0	8.3	24.	26.		11.2	6.8		1.2	5.3	0.01
02	OREGON WATER CORP.(3)	42-13.30 121-47.45 38S/009E -32 NW	71/09	205	20.0	8.4	25.	26.		11.2	5.8		0.6	5.3	0.02
03	HOWARD HOLLIDAY	42-10.55 121-49.70 39S/008E -13 SW	74/05	220	25.0	7.9	27.	27.	2.9	12.	3.1	122	5.4	5.1	0.1
04	MAZAMA SCHOOL	42-11.85 121-43.90 39S/009E -11 NW		895	61.0	8.3	92.	246.	6.0	5.4	1.0	120	256.	35.	1.0
06	ABE BOEHM	42-04.05 121-45.40 40S/009E -28 NE	74/05	2700	25.0	7.1	100.	480.	18.	180.	47.	1462	300.	170.	0.2
06	ABE BOEHM	42-04.05 121-45.40 40S/009E -28 NE	75/08		25.								308.	205.	
06	DAN O'CONNER	42-04.85 121-43.85 40S/009E -23 NW	74/05	260	24.0	7.6	42.	32.	8.1	12.	6.6	130	14.	9.1	
06	JACK LISKEY	42-02.95 121-44.40 40S/009E -34 NE	74/05	1030	93.0	8.9	90.	200.	4.0	15.	<0.1	52	360.	59.	1.5
06	JACK LISKEY	42-02.25 121-43.60 41S/009E -02 NW	74/05	2400	22.0	7.6	100.	580.	12.	35.	16.	1550	13.	140.	
06	JACK LISKEY	42-02.25 121-43.60 41S/009E -02 NW	75/08		25.								5.	152.	
06	O. H. OSBORN	42-03.30 121-44.70 40S/009E -27 SW	74/05	920	90.0	9.5	90.	190.	4.1	15.		55	270.	56.	1.5
07	OLENE GAP HOT SPRINGS	42-10.45 121-36.90 39S/010E -14 SW	67/00	1000	73.9	7.3	79.	294.	4.5	34.9	1.09	40	346.	58.	1.12
07	OLENE GAP HOT SPRINGS	42-10.45 121-36.90 39S/010E -14 SW	72/00	1140	74.0	7.68	98.	190.	7.2	40.	0.2	55	400.	59.	1.2
07	OLENE GAP HOT SPRINGS	42-10.45 121-36.90 39S/010E -14 SW	75/07		87.								385.	59.	
08	ROENICKE HOT SPRING	42-10.40 121-37.05 39S/010E -14 SW	72/10	1300	65.0	8.2	48.	217.	5.0	35.	0.1	50	430.	65.	1.5
16	MELVIN FEIGI	42-08.20 121-30.10 40S/011E -03 NE	70/10	273	31.0	8.8	110.	66.	1.0	1.2		153	5.8	5.	0.4
22	RAY SMITH WELL	42-27.25 121-25.40 36S/011E -16 NW	70/10	148	25.	8.4	50.	30.	1.9	3.8	0.1	86	5.2	2.5	0.2
23	KLAMATH ICE CO.	42-13.40 121-01.40 38S/009E -33 NW	36/04		51.7	9.0	70.						383.	53.	
24	J. K. O'NEIL	42-08.30 121-38.10 39S/010E -34 NW	72/03	222		7.6	45.2	22.	5.4	6.4	5.2	101	9.5	2.5	0.2
24	J. K. O'NEIL	42-08.30 121-38.10 39S/010E -34 NW	74/05	190	23.0	7.4	50.	26.	5.1	6.1	5.5	112	15.	2.8	

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS
[Map code refers to Bowen, Peterson, and Riccio, 1978;
Concentrations in mg/l; (ND) not detected; (m) monomeric aluminum]

Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
KLAMATH COUNTY													
02	O.I.T. NO. 5								<0.01	0.03	0.03	<0.02	
02	O.I.T. NO. 6	1.0											
02	O.I.T. NO. 6		0.12										
02	OREGON WATER CORP.(1)										<0.05		
02	OREGON WATER CORP.(2)										0.03	<0.01	
02	OREGON WATER CORP.(3)										0.05	<0.01	
03	HOWARD HOLLIDAY	0.04	0.02								0.03	ND	
04	MAZAMA SCHOOL										0.07		
06	ABE BOEHM	1.4	0.16								0.1	2.4	
06	ABE BOEHM												
06	DAN O'CONNER												
06	JACK LISKEY	0.65	0.08										
06	JACK LISKEY										0.07		
06	JACK LISKEY												
06	O. H. OSBORN	0.77									0.26	ND	
07	OLENE GAP HOT SPRINGS								0.91	0.03	0.03	0.06	
07	OLENE GAP HOT SPRINGS	1.0	0.15	0.02	<0.1	0.58	0.08	0.01			<0.02	<0.02	
07	OLENE GAP HOT SPRINGS												
08	ROENICKE HOT SPRING	1.9											
16	MELVIN FEIGI	ND							2.9		0.02		
22	RAY SMITH WELL								0.3		0.03		
23	KLAMATH ICE CO.										ND		
24	J. K. O'NEIL								0.03	<0.01	0.02	0.02	
24	J. K. O'NEIL												

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS
[Map code refers to Bowen, Peterson, and Riccio 1978;
Concentrations in mg/l; (ND) not detected]

Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
LAKE COUNTY															
05	ANA RIVER SPRING	42-59.8 120-45.3 30S/017E -06	48/12		18.9	8.4	37.	39.	3.2	5.2	3.1	108	6.7	13.	0.2
14	SUMMER LAKE HOT SPRING (WOODWARD)	42-43.53 120-38.75 33S/017E -12 NE	48/10	1760	46.7	8.5	96.	399.	6.8	1.4	0.6	374	111.	285.	2.2
14	SUMMER LAKE HOT SPRING (WOODWARD)	42-43.53 120-38.75 33S/017E -12 NE	72/00	1790	43.0	8.43	94.	390.	4.6	2.1	0.1	426	120.	280.	2.2
23	HUNTERS HOT SPRINGS (LAKEVIEW)	42-13.32 120-22.09 39S/020E -04 NW	56/10	1110	98.0	8.3	146.	209.	9.5	12.		74	265.	116.	
23	HUNTERS HOT SPRINGS (LAKEVIEW)	42-13.32 120-22.09 39S/020E -04 NW	57/10	1140	86.0	8.4	140.	208.	10.	8.0	2.4	74	258.	120.	4.5
23	HUNTERS HOT SPRINGS (LAKEVIEW)	42-13.32 120-22.09 39S/020E -04 NW	72/00	1120	96.0	7.77	140.	210.	8.5	13.	<0.1	81	260.	120.	4.4
24	LEITHEAD HOT SPRINGS (JOYLAND PLU	42-09.71 120-20.60 39S/020E -27 NE	48/06	813	69.4	7.7	66.	152.	2.2	15.	0.4	84	152.	99.	3.1
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	42-09.35 120-20.67 39S/020E -27 SE	48/05	1320	85.0	7.3	140.	268.	8.8	8.5	1.4	208	223.	146.	6.9
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	42-09.35 120-20.67 39S/020E -27 SE	72/00	1370	88.0	7.76	130.	280.	9.0	8.8	0.1	236	240.	170.	5.4
28	ANTELOPE HOT SPRINGS	42-29.97 119-41.48 35S/026E -32 NW	48/08	876	40.0	8.3	168.	191.	13.	10.	2.5	376	57.	64.	3.60
32	FISHER HOT SPRINGS	42-17.84 119-46.55 38S/025E -10 NW	72/00	513	68.0	7.93	77.	92.	7.9	8.4	1.0	107	59.	56.	3.5
33	CRUMP SPRING	42-13.60 119-52.78 38S/024E -34 SW	48/09	935	40.0	8.7	125.	175.	8.7	18.	2.	130	115.	150.	1.9
33	CRUMP SPRING	42-13.60 119-52.78 38S/024E -34 SW	72/00	1490	78.0	7.26	180.	280.	11.	16.	0.2	155	200.	240.	4.9
33	CRUMP WELL (1)	42-13.59 119-52.87 38S/024E -34 SW	59/07	1580	99.0	8.7	169.	298.	12.	10.	0.5	143	209.	263.	5.2
33	CRUMP WELL (2)	42-13.59 119-52.87 38S/024E -34 SW	60/09	1460	88.0	8.1		281.	10.					248.	
LANE COUNTY															
01	BELKNAP HOT SPRINGS	44-11.65 122-02.90 16S/006E -11 NE	03/00		86.7		80.9	364.	69.	455.	13.		168.	1343.	
01	BELKNAP HOT SPRINGS	44-11.65 122-02.90 16S/006E -11 NE	72/00	4300	71.0	7.62	96.	690.	15.	210.	0.2	19	170.	1300.	1.2
02	FOLEY SPRINGS	44-09.20 122-05.85 16S/006E -28 NW	76/03	4800	80.6	8.	60.4	475.	11.2	494.	0.8	16	550.	1304.	0.81
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	44-04.95 122-14.00 17S/005E -20	73/00	2890	44.0	7.76	50.	392.	6.3	225.	0.1	21	260.	788.	0.8
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	44-04.95 122-14.00 17S/005E -20 NW	76/03	2660	42.0	8.2	47.	320.	6.8	196.	0.2	18	185.	693.	0.87
04	WALL CREEK WARM SPRINGS	43-48.45 122-18.55 20S/004E -26 NW	76/03	2340	41.0	7.2	62.7	315.	10.8	130.	1.		108.	602.	4.1
05	MCCREDIE SPRINGS	43-42.35 122-17.20 21S/004E -36 NW	74/00	6730	73.	7.29	79.	1000.	22.	460.	0.9	21	240.	2200.	2.7
05	MCCREDIE SPRINGS	43-42.35 122-17.20 21S/004E -36 NW	76/03	6770	71.0	7.4	65.4	910.	28.	500.	0.9	20		2232.	2.68

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

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Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
LAKE COUNTY													
05	ANA RIVER SPRING	0.5							0.1		0.15		
14	SUMMER LAKE HOT SPRING (WOODWARD)	1.0							0.1		0.03		
14	SUMMER LAKE HOT SPRING (WOODWARD)	6.9	0.15	<0.02	<0.1	0.07	1.				<0.02	<0.02	
23	HUNTERS HOT SPRINGS (LAKEVIEW)	7.2	0.2			0.5			7.2				
23	HUNTERS HOT SPRINGS (LAKEVIEW)	7.1							0.3	ND	0.01	ND	
23	HUNTERS HOT SPRINGS (LAKEVIEW)	6.9	0.15	0.04	<0.1	0.32	0.4	0.08		0.034m	<0.02	<0.02	0.0004
24	LEITHEAD HOT SPRINGS (JOYLAND PLU	7.0							0.2		0.05		
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	9.9							0.3		0.02		
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	11.2	0.15	0.04	<0.1	0.17	1.	0.1		0.014m	<0.02	<0.02	0.0017
28	ANTELOPE HOT SPRINGS	1.5							0.2		0.02		
32	FISHER HOT SPRINGS	2.2	0.04	0.02	<0.1	0.05	0.4	0.03		0.011m	<0.02	<0.02	<0.0001
33	CRUMP SPRING	7.3							1.5		0.04		
33	CRUMP SPRING	13.6	0.4	0.07	0.1	0.12	0.4	0.1		0.017m	<0.02	0.03	0.0004
33	CRUMP WELL (1)	18.	0.39			0.31	0.9	0.1	1.0	0.65	0.15	N	
33	CRUMP WELL (2)	13.	0.33										
LANE COUNTY													
01	BELKNAP HOT SPRINGS											†	
01	BELKNAP HOT SPRINGS	6.4	0.95	0.05	<0.1	1.4	33.	0.2			0.02	0.02	<0.0001
02	FOLEY SPRINGS	10.2	0.96							<0.01	<0.05		
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	5.1	0.52	0.03	<0.1	2.0					<0.02	<0.02	0.0005
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	6.2	0.64							<0.05	0.1	<0.05	
04	WALL CREEK WARM SPRINGS	6.6	0.57							<0.05		<0.05	
05	MCCREDIE SPRINGS	18.	1.4	0.11	0.1					0.010m	0.02	0.10	
05	MCCREDIE SPRINGS	17.8	1.98								0.1	0.05	

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Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
LANE COUNTY															
06	KITSON SPRINGS	43-41.35 122-22.50 22S/004E -06	58/03	10500	44.4	7.4	47.	1450.	28.	726.	5.7	27	197.	3420.	2.8
06	KITSON SPRINGS	43-41.35 122-22.50 22S/004E -06 NE	78/05	10100	43.	7.31	45.	1500.	26.	710.	1.6	24	210.	3450.	2.4
08	BIGELOW HOT SPRINGS	44-14.35 122-03.50 15S/006E -26 NW	76/03	3800	61.0	7.8	68.9	540.	16.6	188.	1.		102.	1148.	1.37
MALHEUR COUNTY															
03	NEAL HOT SPRINGS	44-01.45 117-27.60 18S/043E -09 NW	72/00	1010	87.0	7.32	180.	190.	16.	8.8	0.2	200	120.	120.	9.4
04	BEULAH HOT SPRINGS	43-56.65 118-08.15 19S/037E -02 SE	72/00	1090	60.0	7.56	170.	200.	6.0	24.	0.2	163	290.	55.	4.7
05	VALE HOT SPRINGS	43-58.96 117-13.98 18S/045E -20 SE	74/00	1530	73.0	7.47	130.	310.	16.	19.	0.8	143	100.	360.	6.1
05	VALE HOT SPRINGS	43-58.96 117-14.98 18S/045E -20 SE	74/08		90.								112.	350.	
06	UNNAMED HOT SPRINGS NEAR LITTLE VALLEY	43-53.48 117-30.00 19S/043E -30 NW	73/00	740	70.0	8.71	115.	160.	3.2	3.2	<0.05	129	110.	74.	6.8
08	MITCHELL BUTTE HOT SPRINGS	43-45.78 117-09.34 21S/045E -12 NE	72/00	559	62.0	8.69	94.	110.	1.6	4.6	<0.1	78	130.	28.	10.4
18	UNNAMED HOT SPRING AT THREE FORKS	42-32.0 117-10.9 35S/045E -03	35/07		35.0		44.	62.		12.	1.6	119	31.	19.	4.9
18	UNNAMED HOT SPRING AT THREE FORKS	42-32.0 117-10.9 35S/045E -03	73/00	338	34.0	8.11	40.	61.	1.2	10.5	0.7	110	34.	18.	4.2
19	UNNAMED HOT SPRING NEAR MCDERMITT	42-04.7 117-45.6 40S/042E -25	57/05	604	53.5	9.2	90.	135.	1.8	1.2		263	46.	15.	7.0
19	UNNAMED HOT SPRING NEAR MCDERMITT	42-04.7 117-45.6 40S/042E -25	72/00	598	52.0	8.79	72.	130.	1.0	0.6	<0.1	263	52.	14.	6.6
23	LUCE HOT SPRINGS	43-28.15 118-12.08 24S/037E -20	72/00	1330	63.0	7.43	110.	240.	9.7	34.	0.5	162	290.	140.	4.8
24	JONESBORO WARM SPRING	43-47.5 117-57.5 20S/039E -29 SE			44.5	9.6	70.	72.	0.7	1.0	<0.1	148	35.	11.	0.8
25	JUNTURA WARM SPRING #1	43-45.5 118-04.0 21S/038E -09 SW			25.0	9.4	55.	24.	8.2	48.	21.	204	15.	120.	1.0
26	JUNTURA WARM SPRING #2	43-45.5 118-05.5 21S/038E -17 NW			35.0	9.7	79.	78.	0.8	1.0	<0.1	133	43.	140.	1.3
27	ARTESIAN WELL	43-41.8 117-05.7 21S/046E -33 SE	77/03	670	46.0	9.5	43.7	124.	0.8	1.8	<0.1	94	164.	12.2	2.7
28	ALKALI FLAT GRADIENT WELL	44-06.60 117-13.60 17S/045E -08 NE	75/05	2400	24.0	8.3	32.0	482.	6.7	16.4	0.5	140	135.2	598.	2.2
29	NORTH HARPER BLM WELL	43-55.76 117-12.72 19S/045E -09 SE	76/06	714	36.0	8.0	39.7	134.	2.2	3.0	0.5	192	121.	4.3	1.51
30	UNNAMED WARM SPRING NEAR BULLY CREEK	44-01.95 117-26.95 18S/043E -04 SE	77/06	115	37.0	7.8	99.	1.	0.4	36.6	14.7	45	1.0	0.5	0.7
MARION COUNTY															
01	BREITENBUSH HOT SPRINGS	44-46.86 121-58.54 09S/007E -20 NE	72/00	4030	92.0	7.31	83.	720.	31.	100.	1.3	144	140.	1300.	3.4

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Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
LANE COUNTY													
06	KITSON SPRINGS	25.	1.8				6.6	0.9	2.7	0.27	0.01	ND	
06	KITSON SPRINGS	22.	2.0	0.10	0.1					0.002m	<0.04	0.15	<0.0001
08	BIGELOW HOT SPRINGS	6.5	1.1							<0.05	0.1	<0.005	
MALHEUR COUNTY													
03	NEAL HOT SPRINGS	4.1	0.3	0.09	0.1	0.16	0.5	0.06		0.008m	<0.02	0.06	0.0001
04	BEULAH HOT SPRINGS	4.7	0.24	<0.02	<0.1	0.17	0.1	0.03		0.006m	<0.02	0.03	0.0001
05	VALE HOT SPRINGS	9.4	0.28	0.09	<0.1					0.017m	<0.02	0.04	
05	VALE HOT SPRINGS												
06	UNNAMED HOT SPRINGS NEAR LITTLE VALLEY	4.7	0.11	0.02	<0.1	<0.05					<0.02	<0.02	0.0007
08	MITCHELL BUTTE HOT SPRINGS	0.49	0.03	<0.02	<0.1	<0.05	0.2	0.01		0.015m	<0.02	<0.02	0.0001
18	UNNAMED HOT SPRING AT THREE FORKS								2.9		0.02		
18	UNNAMED HOT SPRING AT THREE FORKS	0.11	0.04	<0.02	<0.1	0.06					<0.02	<0.02	
19	UNNAMED HOT SPRING NEAR MCDERMITT	0.70	ND						ND				
19	UNNAMED HOT SPRING NEAR MCDERMITT	1.1	0.06	<0.02	<0.1	<0.05	0.4	0.008		0.013m	<0.02	<0.02	0.0001
23	LUCE HOT SPRINGS	6.6	0.27	0.04	<0.1	0.42	0.5	0.03			<0.02	0.04	0.0001
24	JONESBORO WARM SPRING	<0.1	<0.1										
25	JUNTURA WARM SPRING #1	<1.0	<0.1										
26	JUNTURA WARM SPRING #2	<1.0	<0.1										
27	ARTESIAN WELL	0.31	0.04						0.02	0.1	<0.1	<0.05	
28	ALKALI FLAT GRADIENT WELL	14.	0.4						0.03	0.01	0.1	0.05	
29	NORTH HARPER BLM WELL	0.26	0.21						0.14	<0.05	<0.05	<0.05	
30	UNNAMED WARM SPRING NEAR BULLY CREEK	0.15	0.04						0.06	0.28	0.4	0.05	
MARION COUNTY													
01	BREITENBUSH HOT SPRINGS	4.1	1.8	0.18	0.1	0.73	5.	0.1			0.02	0.22	0.0002

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Major Elements

Map Code	Name	Location	Date Yr/Mo	Sp Cond (umho)	Temp (C)	pH	Silica (SiO2)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Alkalinity (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)
MARION COUNTY															
01	BREITENBUSH HOT SPRINGS - WELL	44-46.86 121-58.54 09S/007E -20 NE	78/02		110.0	8.5	182.	690.	34.	90.	1.3	89	96.	1170.	4.0
MULTNOMAH COUNTY															
01	CORBETT WARM SPRING	45-32.5 122-17.5 01N/004E -27 SE		570	18.0	8.2	44.2	85.	8.9	21.7	0.8	127	5.9	77.4	2.4
02	YMCA CAMP COLLINS	45-30.2 122-18.3 01S/004E -10 NW	56/09	517	23.3	8.6	60.	10.	9.6	5.2	0.2	124	1.2	92.	3.2
UMATILLA COUNTY															
01	BINGHAM SPRINGS	45-44.47 118-13.96 03N/037E -18 NE	54/04	765	34.4	8.6	68.	133.	7.6	14.	3.5	82	0.2	192.	4.0
03	LEHMAN SPRINGS	45-09.06 118-39.55 05S/033E -12 NE	72/00	252	61.0	9.18	44.	53.	0.7	0.9	0.1	127	23.6	5.4	2.1
UNION COUNTY															
01	COVE WARM SPRING	45-17.67 117-48.38 03S/040E -22 NW	57/06	150	29.4	9.8	29.	30.	0.5	1.6		70	9.8	5.0	0.3
01	WELL	45-19.89 118-05.43 03S/038E -05 SW	55/01		27.	7.9	84.	27.	5.	5.	0.3		3.3	3.2	0.5
01	WELL	45-19.89 118-05.43 03S/038E -05 SW	55/01		25.	7.9	72.	30.	5.	4.8	1.3	63	4.8	2.1	0.5
01	WELL	45-20.07 118-05.83 03S/038E -06 NE	57/05	146	27.		71.	19.	5.	10.	0.2	84	6.5	1.	0.5
02	HOT LAKE	45-14.63 117-57.51 04S/039E -05 SE	72/00	688	80.0	9.21	48.	130.	2.7	4.9	<0.1	99	56.	140.	1.7
05	WAGNER WELL	45-27.43 117-59.84 01S/038E -24 SE	50/08	148	29.	8.0		28.	4.0	3.6	0.8	72	8.3	3.1	2.0
07	MEDICAL HOT SPRINGS	45-01.08 117-37.48 06S/041E -25 NE			60.0		97.	191.	3.4	62.	1.2	22	432.	77.	
07	MEDICAL HOT SPRINGS	45-01.08 117-37.48 06S/041E -25 NE	73/00	1173	60.0	8.23	80.	190.	7.0	72.	0.2	28	400.	77.	1.2
WALLOWA COUNTY															
01	COOK CREEK WARM SPRING	45-53.49 116-52.41 05N/048E -30 NW	74/11	610	36.0	7.95	46.1	61.	2.5	36.	1.1	44	163.8	203.	0.09
WASCO COUNTY															
01	KAHNEETAH HOT SPRINGS	44-51.72 121-12.05 08S/013E -20 NE	73/00	1370	52.0	8.32	104.	325.	3.4	3.2	<0.05	511	34.	155.	21.
02	MILTON MARTIN WELL	45-31.70 121-12.95 01N/013E -32 NE	58/07	279	22.2	8.5	84.	41.	7.2	15.	2.9	167	2.4	6.0	0.9
03	J. SANDOZ WELL	45-33.8 121-16.6 01N/012E -38	58/07	378	27.8	7.9	95.	62.	11.	16.	4.6		1.5	7.5	1.6

Table 1: CHEMICAL COMPOSITION OF THERMAL SPRING AND WELL WATERS

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Concentrations in mg/l; (ND) not detected; (m) monomeric aluminum]

Minor and Trace Elements

Map Code	Name	Boron (B)	Lithium (Li)	Rubidium (Rb)	Cesium (Cs)	Strontium (Sr)	Bromide (Br)	Iodide (I)	Nitrate (NO3)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Mercury (Hg)
MARION COUNTY													
01	BREITENBUSH HOT SPRINGS - WELL	5.43	1.9										
MULTNOMAH COUNTY													
01	CORBETT WARM SPRING	1.2	0.03						0.01	0.16	0.20	0.10	
02	YMCA CAMP COLLINS	0.38							0.5		0.06		
UMATILLA COUNTY													
01	BINGHAM SPRINGS	10.							0.2		0.20		
03	LEHMAN SPRINGS	0.12	0.03	<0.02	<0.1	<0.05	0.006	0.001			<0.02	<0.02	0.0003
UNION COUNTY													
01	COVE WARM SPRING	0.08							ND				
01	WELL												
01	WELL												
01	WELL												
02	HOT LAKE	2.9	0.03	<0.02	<0.1	<0.05	0.4	0.08			<0.02	<0.02	0.0032
05	WAGNER WELL	0.1							0.2				
07	MEDICAL HOT SPRINGS												
07	MEDICAL HOT SPRINGS	2.2	0.05	0.02	<0.1	0.80	0.2				<0.02	<0.02	0.0004
WALLOWA COUNTY													
01	COOK CREEK WARM SPRING		<0.01						0.13	0.16	0.15	<0.05	
WASCO COUNTY													
01	KAHNEETAH HOT SPRINGS	2.6	0.52	0.02	<0.1	<0.05					<0.02	<0.02	0.0003
02	MILTON MARTIN WELL								ND	1.0	0.03	ND	
03	J. SANDOZ WELL									ND	0.04	ND	

Table 2: REFERENCES FOR ANALYSES

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Map reference refers to U. S. Geoogical Survey topographic maps]

Map Code	Name	Sample Date	Map Reference	Analysis Reference
BAKER COUNTY				
01	RADIUM HOT SPRINGS	55/05	HAINES 1:24000	SCOTT AND BARKER, 1962
01	RADIUM HOT SPRINGS	72/00	HAINES 1:24000, BAKER 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
02	SAM-O SPRING	77/02	BAKER 1:24000, BAKER 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
05	KROPP HOT SPRING		NORTH POWDER 1:24000, GRANGEVILLE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
06	FISHER HOT SPRING	72/06	ROCK CREEK 1:24000, CANYON CITY 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
CLACKAMAS COUNTY				
01	ACID-SULFATE SPRING ON MT. HOOD	76/06	MT. HOOD SOUTH 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
01	MT. HOOD FUMAROLES	35/00	MT. HOOD SOUTH 1:24000	PHILLIPS, 1936
01	MT. HOOD FUMAROLES	35/00	MT. HOOD SOUTH 1:24000	PHILLIPS, 1936
01	MT. HOOD FUMAROLES	35/00	MT. HOOD SOUTH 1:24000	PHILLIPS, 1936
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
01	MT. HOOD FUMAROLES	51/00	MT. HOOD SOUTH 1:24000	AYERS AND CRESWELL, 1951
02	SWIM WARM SPRINGS	76/12	MT. HOOD SOUTH 1:24000, THE DALLES 1:250000	OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY, UNPUBLISHED DATA
03	AUSTIN HOT SPRINGS (CAREY)	72/00	FISH CREEK MTN. 1:62500, VANCOUVER 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
04	BAGBY HOT SPRINGS	70/03	BATTLE AX 1:62500, SALEM 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
04	BAGBY HOT SPRINGS	77/09	BATTLE AX 1:62500	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
05	GEOTHERMAL GRADIENT TEST NEAR AUSTIN HOT	76/08	HIGH ROCK 1:62500, THE DALLES 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
DESCHUTES COUNTY				
01	EAST LAKE HOT SPRINGS	73/00	NEWBERRY CRATER 1:125000, CRESCENT 1:250000	MARINER AND OTHERS, 1975
01	EAST LAKE HOT SPRINGS	75/08	NEWBERRY CRATER 1:125000, CRESCENT 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
01	EAST LAKE HOT SPRINGS	77/07	NEWBERRY CRATER 1:125000, CRESCENT 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
02	PAULINA HOT SPRINGS		NEWBERRY CRATER 1:125000, CRESCENT 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
02	PAULINA HOT SPRINGS	77/07	NEWBERRY CRATER 1:125000, CRESCENT 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
02	WARM WELL AT LITTLE CRATER CAMPGROUND	75/08	NEWBERRY CRATER 1:125000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
DOUGLAS COUNTY				
01	UMPQUA HOT SPRINGS	77/09	TOKETEE FALLS 1:62500	MARINER AND OTHERS, 1978
01	UMPQUA HOT SPRINGS	78/06	TOKETEE FALLS 1:62500	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA

Table 2: REFERENCES FOR ANALYSES
[Map code refers to Bowen, Peterson, and Riccio, 1978;
Map reference refers to U. S. Geoogical Survey topographic maps]

Map Code	Name	Sample Date	Map Reference	Analysis Reference
GRANT COUNTY				
01	RITTER HOT SPRINGS	73/00	RITTER 1:62500, CANYON CITY 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
04	BLUE MOUNTAIN HOT SPRINGS	72/00	PRAIRIE CITY 1:62500, CANYON CITY 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
05	JOAQUIN MILLER RESORT	78/07	CANYON MTN. 1:24000, JOHN DAY 1:62500	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
07	WEBERG HOT SPRING	72/00	CANYON CITY 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
HARNEY COUNTY				
01	UNNAMED SPRING	31/09	BUCHANAN 1:24000	PIPER AND OTHERS, 1939
02	O. J. THOMAS	68/09	HARNEY 1:62500	LEONARD, 1970
04	MILLPOND SPRING	31/08	BURNS 1:24000	PIPER AND OTHERS, 1939
05	HARNEY VALLEY DEV CO. OIL TEST WELL	68/09	HARNEY 1:62500	LEONARD, 1970
08	ISLAND RANCH WELL	69/08	LAWEN 1:62500	LEONARD, 1970
09	CRANE HOT SPRINGS	31/08	CRANE 1:62500, BURNS 1:250000	PIPER AND OTHERS, 1939
09	CRANE HOT SPRINGS	68/09	CRANE 1:62500	LEONARD, 1970
09	CRANE HOT SPRINGS	72/00	CRANE 1:62500, BURNS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
10	WARM SPRING NEAR VENATOR	77/06	BURNS 1:250000	GONTHIER AND OTHERS, 1977
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	31/08	BURNS 1:250000	PIPER AND OTHERS, 1939
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	72/00	CRANE 1:62500, BURNS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
22	MICKEY SPRINGS	70/07	ADEL 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
22	MICKEY SPRINGS	72/00	ADEL 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
22	MICKEY SPRINGS	76/09	ADEL 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
22	MICKEY SPRINGS	76/09	ADEL 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
22	MICKEY SPRINGS	76/09	ADEL 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
23	ALVORD HOT SPRINGS	55/11	ADEL 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
23	ALVORD HOT SPRINGS	72/00	ADEL 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
23	ALVORD HOT SPRINGS	76/09	ADEL 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
23	ALVORD HOT SPRINGS	76/09	ADEL 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
24	HOT BORAX LAKE	53/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
24	HOT BORAX LAKE	61/06	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA

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Map Code	Name	Sample Date	Map Reference	Analysis Reference
HARNEY COUNTY				
24	HOT BORAX LAKE	72/00	BORAX LAKE 1:24000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
27	UNNAMED HOT SPRING NEAR TROUT CREEK	70/08	ADEL 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
27	UNNAMED HOT SPRING NEAR TROUT CREEK	72/00	ADEL 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
39	GOODMAN SPRING (HOTCHKISS)	68/09	BURNS 1:24000	LEONARD, 1970
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	53/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	53/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	57/05	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	73/06	BORAX LAKE 1:24000, ADEL 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	76/09	BORAX LAKE 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
44	HOTCHKISS WELL	31/08	BURNS 1:24000	PIPER AND OTHERS, 1939
44	HOTCHKISS WELL	68/09	BURNS 1:24000	LEONARD, 1970
45	HINES LUMBER CO. WELL	68/07	BURNS 1:24000, BURNS 1:62500	LEONARD, 1970
46	CITY OF HINES WELL	68/07	BURNS 1:24000, BURNS 1:62500	LEONARD, 1970
JACKSON COUNTY				
01	JACKSON HOT SPRING	52/04	ASHLAND 1:62500	ROBISON, 1972
KLAMATH COUNTY				
	ALFRED JACOBSEN	74/05	MERRILL 1:62500	SAMMEL, 1976
	ANNIE SPRING		CRATER LAKE NATIONAL PARK AND VICINITY 1:62500	SAMMEL, 1976
	BILL HILL	74/06	MERRILL 1:62500	SAMMEL, 1976
	CLAUDE SHUCK	74/05	MERRILL 1:62500	SAMMEL, 1976
	CLYDE DEHILINGER	74/06	MERRILL 1:62500	SAMMEL, 1976
	FALCON HEIGHTS SCHOOL	74/05	KLAMATH FALLS 1:62500	SAMMEL, 1976
	GEORGE CARTER	74/06	MERRILL 1:62500	SAMMEL, 1976
	GEORGE STACY CO.	74/06	MERRILL 1:62500	SAMMEL, 1976
	JACK O'CONNER	74/05	MERRILL 1:62500	SAMMEL, 1976
	LEN DOBRY	74/05	MERRILL 1:62500	SAMMEL, 1976

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Map reference refers to U. S. Geoogical Survey topographic maps]

Map Code	Name	Sample Date	Map Reference	Analysis Reference
KLAMATH COUNTY				
	LESTER BROOKSHIRE	74/05	MERRILL 1:62500	SAMMEL, 1976
	MELVIN MCCOLLUM	74/05	MERRILL 1:62500	SAMMEL, 1976
	MONTE DEHILINGER	74/06	MERRILL 1:62500	SAMMEL, 1976
	O'CONNER LIVESTOCK CO.	74/06	MERRILL 1:62500	SAMMEL, 1976
	OREGON WATER CORP.(4)	70/08	MERRILL 1:62500	SAMMEL, 1976
	POPE'S MEAT CO.	74/06	MERRILL 1:62500	SAMMEL, 1976
	RAY BIXLER	74/05	MERRILL 1:62500	SAMMEL, 1976
	ROBERT LANGLEY	74/05	MERRILL 1:62500	SAMMEL, 1976
	S. AND C. KILGORE		GERBER RESERVOIR 1:62500	SAMMEL, 1976
	TOWN OF MERRILL	55/02	MERRILL 1:62500	NEWCOMB AND HART, 1958
	U.S. AIR FORCE(1)	72/10	KLAMATH FALLS 1:62500	SAMMEL, 1976
	U.S. AIR FORCE(2)	72/10	KLAMATH FALLS 1:62500	SAMMEL, 1976
	WEYERHAUSER WELL NO. 4	72/08	KLAMATH FALLS 1:62500	SAMMEL, 1976
01	EAGLE POINT SPRING	72/08	MODOC POINT 1:62500	SAMMEL, 1976
02	J. E. FRIESEN	55/02	KLAMATH FALLS 1:62500	NEWCOMB AND HART, 1958
02	LOIS MERRUYS	54/12	KLAMATH FALLS 1:62500	NEWCOMB AND HART, 1958
02	MEDO-BELL DAIRY	55/01	KLAMATH FALLS 1:62500	NEWCOMB AND HART, 1958
02	MEDO-BELL DAIRY	75/07	KLAMATH FALLS 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
02	MILLS SCHOOL		KLAMATH FALLS 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
02	MOYINA WATER CO.	66/08	MERRILL 1:62500	SAMMEL, 1976
02	O.I.T. NO. 5	67/00	KLAMATH FALLS 1:62500	PETERSON AND GROH, 1967
02	O.I.T. NO. 6	72/08	KLAMATH FALLS 1:62500	SAMMEL, 1976
02	O.I.T. NO. 6	75/03	KLAMATH FALLS 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
02	OREGON WATER CORP.(1)	30/03	KLAMATH FALLS 1:62500	SAMMEL, 1976
02	OREGON WATER CORP.(2)	71/09	KLAMATH FALLS 1:62500	SAMMEL, 1976
02	OREGON WATER CORP.(3)	71/09	KLAMATH FALLS 1:62500	SAMMEL, 1976
03	HOWARD HOLLIDAY	74/05	KLAMATH FALLS 1:62500	SAMMEL, 1976
04	MAZAMA SCHOOL		MERRILL 1:62500	SAMMEL, 1976
06	ABE BOEHM	74/05	KLAMATH FALLS 1:62500	SAMMEL, 1976
06	ABE BOEHM	75/08	KLAMATH FALLS 1:62500	NEHRING AND OTHERS, 1979
06	DAN O'CONNER	74/05	MERRILL 1:62500	SAMMEL, 1976
06	JACK LISKEY	74/05	MERRILL 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
06	JACK LISKEY	74/05	MERRILL 1:62500	SAMMEL, 1976
06	JACK LISKEY	75/08	MERRILL 1:62500	NEHRING AND OTHERS, 1979
06	O. H. OSBORN	74/05	MERRILL 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
07	OLENE GAP HOT SPRINGS	67/00	MERRILL 1:62500	PETERSON AND GROH, 1967
07	OLENE GAP HOT SPRINGS	72/00	MERRILL 1:62500, KLAMATH FALLS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
07	OLENE GAP HOT SPRINGS	75/07	MERRILL 1:62500	SAMMEL, 1976 NEHRING AND OTHERS, 1979
08	ROENICKE HOT SPRING	72/10	MERRILL 1:62500	SAMMEL, 1976
16	MELVIN FEIGI	70/10	MERRILL 1:62500	LEONARD AND HARRIS, 1974
22	RAY SMITH WELL	70/10	BEATTY 1:62500	LEONARD AND HARRIS, 1974
23	KLAMATH ICE CO.	36/04	KLAMATH FALLS 1:62500	NEWCOMB AND HART, 1958
24	J. K. O'NEIL	72/03	MERRILL 1:62500	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA

Table 2: REFERENCES FOR ANALYSES

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Map reference refers to U. S. Geoogical Survey topographic maps]

Map Code	Name	Sample Date	Map Reference	Analysis Reference
KLAMATH COUNTY				
24	J. K. O'NEIL	74/05	MERRILL 1:62500	SAMMEL, 1976
LAKE COUNTY				
05	ANA RIVER SPRING	48/12	KLAMATH FALLS 1:250000	TRAUGER, 1950
14	SUMMER LAKE HOT SPRING (WOODWARD)	48/10	SLIDE MTN. 1:24000	TRAUGER, 1950
14	SUMMER LAKE HOT SPRING (WOODWARD)	72/00	SLIDE MTN. 1:24000, KLAMATH FALLS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
23	HUNTERS HOT SPRINGS (LAKEVIEW)	56/10	LAKEVIEW NE 1:24000, KLAMATH FALLS 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
23	HUNTERS HOT SPRINGS (LAKEVIEW)	57/10	LAKEVIEW NE 1:24000, KLAMATH FALLS 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
23	HUNTERS HOT SPRINGS (LAKEVIEW)	72/00	LAKEVIEW NE 1:24000, KLAMATH FALLS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
24	LEITHEAD HOT SPRINGS (JOYLAND PLUNGE, LEO	48/06	LAKEVIEW NE 1:24000	TRAUGER, 1950
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	48/05	LAKEVIEW NE 1:24000	TRAUGER, 1950
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	72/00	LAKEVIEW NE 1:24000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
28	ANTELOPE HOT SPRINGS	48/08	WARNER PEAK 1:24000	TRAUGER, 1950
32	FISHER HOT SPRINGS	72/00	CRUMP LAKE 1:24000, ADEL 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
33	CRUMP SPRING	48/09	ADEL 1:24000	TRAUGER, 1950
33	CRUMP SPRING	72/00	ADEL 1:24000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
33	CRUMP WELL (1)	59/07	ADEL 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
33	CRUMP WELL (2)	60/09	ADEL 1:24000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
LANE COUNTY				
01	BELKNAP HOT SPRINGS	03/00	MCKENZIE BRIDGE 1:62500	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
01	BELKNAP HOT SPRINGS	72/00	MCKENZIE BRIDGE 1:62500, SALEM 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
02	FOLEY SPRINGS	76/03	MCKENZIE BRIDGE 1:62500, SALEM 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	73/00	MCKENZIE BRIDGE 1:62500, SALEM 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	76/03	MCKENZIE BRIDGE 1:62500, SALEM 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
04	WALL CREEK WARM SPRINGS	76/03	SARDINE BUTTE 1:62500, ROSEBERG 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
05	MCCREDIE SPRINGS	74/00	OAKRIDGE 1:62500, ROSEBERG 1:250000	MARINER AND OTHERS, 1975
05	MCCREDIE SPRINGS	76/03	OAKRIDGE 1:62500, ROSEBERG 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA

Table 2: REFERENCES FOR ANALYSES

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Map Code	Name	Sample Date	Map Reference	Analysis Reference
LANE COUNTY				
06	KITSON SPRINGS	58/03	OAKRIDGE 1:62500	MADISON, 1966
06	KITSON SPRINGS	78/05	OAKRIDGE 1:62500	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
08	BIGELOW HOT SPRINGS	76/03	MCKENZIE BRIDGE 1:62500, SALEM 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
MALHEUR COUNTY				
03	NEAL HOT SPRINGS	72/00	JAMIESON 1:62500, BAKER 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
04	BEULAH HOT SPRINGS	72/00	BEULAH 1:62500, BURNS 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
05	VALE HOT SPRINGS	74/00	VALE EAST 1:24000, BOISE 1:250000	MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
05	VALE HOT SPRINGS	74/08	VALE EAST 1:24000	NEHRING AND OTHERS, 1979
06	UNNAMED HOT SPRINGS NEAR LITTLE VALLEY	73/00	HARPER 1:62500, BOISE 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
08	MITCHELL BUTTE HOT SPRINGS	72/00	MITCHELL BUTTE 1:24000, BOISE 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
18	UNNAMED HOT SPRING AT THREE FORKS	35/07	JORDAN VALLEY 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
18	UNNAMED HOT SPRING AT THREE FORKS	73/00	JORDAN VALLEY 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
19	UNNAMED HOT SPRING NEAR MCDERMITT	57/05	JORDAN VALLEY 1:250000	U.S. GEOLOGICAL SURVEY, UNPUBLISHED DATA
19	UNNAMED HOT SPRING NEAR MCDERMITT	72/00	JORDAN VALLEY 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
23	LUCE HOT SPRINGS	72/00	MCEWEN BUTTE 1:24000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
24	JONESBORO WARM SPRING		WESTFALL BUTTE 1:62500, BOISE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
25	JUNTURA WARM SPRING #1		BEULAH 1:62500, BURNS 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
26	JUNTURA WARM SPRING #2		BEULAH 1:62500, BURNS 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
27	ARTESIAN WELL	77/03	ADRIAN 1:24000, BOISE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
28	ALKALI FLAT GRADIENT WELL	75/05	MOORES HOLLOW 1:62500, BOISE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
29	NORTH HARPER BLM WELL	76/06	JAMIESON 1:62500, BAKER 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
30	UNNAMED WARM SPRING NEAR BULLY CREEK	77/06	JAMIESON 1:62500, BOISE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
MARION COUNTY				
01	BREITENBUSH HOT SPRINGS	72/00	BREITENBUSH HOT SPRINGS 1:62500	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 NEHRING AND OTHERS, 1979
01	BREITENBUSH HOT SPRINGS - WELL	78/02	BREITENBUSH HOT SPRINGS 1:62500	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA NEHRING AND OTHERS, 1979

Table 2: REFERENCES FOR ANALYSES

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Map reference refers to U. S. Geoogical Survey topographic maps]

Map Code	Name	Sample Date	Map Reference	Analysis Reference
MULTNOMAH COUNTY				
01	CORBETT WARM SPRING		WASHOUGAL 1:24000, VANCOUVER 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
02	YMCA CAMP COLLINS	56/09	WASHOUGAL 1:24000, VANCOUVER 1:250000	NEWCOMB, 1972
UMATILLA COUNTY				
01	BINGHAM SPRINGS	54/04	BINGHAM SPRINGS 1:24000, PENDLETON 1:250000	HOGENSON, 1964
03	LEHMAN SPRINGS	72/00	LEHMAN SPRINGS 1:24000, PENDLETON 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
UNION COUNTY				
01	COVE WARM SPRING	57/06	COVE 1:24000, GRANGEVILLE 1:250000	HAMPTON AND BROWN, 1964
01	WELL	55/01	LA GRANDE SE 1:24000	HAMPTON AND BROWN, 1964
01	WELL	55/01	LA GRANDE SE 1:24000	HAMPTON AND BROWN, 1964
01	WELL	57/05	LA GRANDE SE 1:24000	HAMPTON AND BROWN, 1964
02	HOT LAKE	72/00	CRAIG MTN. 1:24000, GRANGEVILLE 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975 VEHRING AND OTHERS, 1979
05	WAGNER WELL	50/08	IMBLER 1:24000	HAMPTON AND BROWN, 1964
07	MEDICAL HOT SPRINGS		FLAGSTAFF BUTTE 1:24000, GRANGEVILLE 1:250000	LINDGREN, 1901
07	MEDICAL HOT SPRINGS	73/00	FLAGSTAFF BUTTE 1:24000, GRANGEVILLE 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
WALLOWA COUNTY				
01	COOK CREEK WARM SPRING	74/11	WAPSHILLA CREEK 1:24000, GRANGEVILLE 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA
WASCO COUNTY				
01	KAHNEETAH HOT SPRINGS	73/00	EAGLE BUTTE 1:24000, BEND 1:250000	MARINER AND OTHERS, 1974 MARINER AND OTHERS, 1975
02	MILTON MARTIN WELL	58/07	THE DALLES 1:62500, THE DALLES 1:250000	NEWCOMB, 1972
03	J. SANDOZ WELL	58/07	WHITE SALMON 1:62500,THE DALLES 1:250000	OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES, UNPUBLISHED DATA

geothermometry. The only other waters which "stand out" as chemically different are from the base of Mt. Hood and Newberry Caldera. These waters have unusually large concentrations of magnesium for thermal fluids, probably due to water-rock reaction at low tempertures. The rest of the samples are from southeastern and southcentral Oregon where volcanic flows are interbedded with tuffaceous sediments. The waters from these springs contain more nearly equal proportions of sulfate, chloride, and bicarbonate.

Table 3 contains gas and isotopic data for the relatively small number of springs for which data exist. The data from Mt. Hood and East Lake are misleading. The Mt. Hood analyses are from fumaroles which discharged principally water vapor. Air contamination appears to be a problem in all of these samples. However, it is probable that carbon dioxide is the principal gas rising from depth. The water vapor is probably from the vaporization of liquid water in fractures and pore spaces. The East Lake-Paulina Lake gas samples are also contaminated by air and altered by gas-water reaction. The thermal "springs" at East and Paulina lakes issue in or at the shoreline of the respective lakes. The proportions of the various gases in these samples appear to be controlled by the discharge rates. Vents with the largest gas discharges have the highest proportions of carbon dioxide. The slower the discharge rate, the cooler the water in contact with the gas, and the more CO_2 will dissolve. The methane and carbon dioxide do not appear to have a common origin since the carbon dioxide appears to be of deep origin (δC13 = -6 permil) while the methane appears to be of biologic origin (δC13 about -50 permil). It is probable that the methane originates from the anaerobic decay of plant material trapped in the lava and ash flows. Finally, some air contamination may be unavoidable in these samples since nitrogen and oxygen may be exsolving from the cold lake water as the hot CO_2-charged gas from depth contacts it.

In terms of the deuterium and oxygen(18) isotopic compositions (table 3) of the thermal waters, four samples appear to have undergone considerable evaporation: East Lake, Hot Borax Lake, and samples from the Abe Boehm and Jack Liskey wells near Klamath Falls. These samples are all greatly enriched (>10 permil) relative to nearby fresh and thermal waters, and have appreciable oxygen shifts relative to meteoric water.

The O^{18} compositions of dissolved sulfate range from +15 to -10 permil. Marine sulfates are typically about +15 permil, while high-temperature hydrothermal systems are usually about -10 permil.

Table 3: GAS AND ISOTOPIC COMPOSITION OF THERMAL SPRING AND WELL DISCHARGES
[Map code refers to Bowen, Peterson, and Riccio, 1978;
Isotopic compositions in the standard notation and are relative to SMOW;
Gas concentrations in volume percent; (*) Ar + O2]

Map Code	Name	Date	Temp (C)	Argon (% Ar)	Methane (% CH4)	Carbon Dioxide (% CO2)	Nitrogen (% N2)	Oxygen (% O2)	Del D of H2O (o/oo)	Del O(18) of H2O (o/oo)	Del O(18) of SO4 (o/oo)
BAKER COUNTY											
01	RADIUM HOT SPRINGS	72/00	58.						-138.3	-17.85	
CLACKAMAS COUNTY											
01	MT. HOOD FUMAROLES	35/00	89.4		0.0011	1.13	0.116	0.011			
01	MT. HOOD FUMAROLES	35/00	71.1			0.68	78.5	19.5			
01	MT. HOOD FUMAROLES	35/00	89.4			1.27	0.057	0.001			
01	MT. HOOD FUMAROLES	51/00			0.0005	1.49	0.035	0.004			
01	MT. HOOD FUMAROLES	51/00	89.4		0.0010	2.23	0.041	0.004			
01	MT. HOOD FUMAROLES	51/00			0.0014	2.12	0.044	0.003			
01	MT. HOOD FUMAROLES	51/00	91.1		0.0011	1.81		0.006			
01	MT. HOOD FUMAROLES	51/00	86.1			17.4	9.8	2.48			
01	MT. HOOD FUMAROLES	51/00	89.4		0.0006	1.43	0.032	0.003			
02	SWIM WARM SPRINGS	76/12	26.0							-14.01	1.52
03	AUSTIN HOT SPRINGS (CAREY)	72/00	86.0						-94.5	-12.22	-2.41
DESCHUTES COUNTY											
01	EAST LAKE HOT SPRINGS	73/00	62.0		9.	56.	30.	6*	-76.2	-9.42	
01	EAST LAKE HOT SPRINGS	75/08	49.		2.9	91.	5.1	0.9			
01	EAST LAKE HOT SPRINGS	77/07			1.95	95.55		2.72*			
02	PAULINA HOT SPRINGS				5.41	71.37					
02	PAULINA HOT SPRINGS	77/07		0.09	0.55	93.45	4.74	0.03			
DOUGLAS COUNTY											
01	UMPQUA HOT SPRINGS	77/09	46.5	<0.02	<0.005	99.38	0.49	0.04			
GRANT COUNTY											
01	RITTER HOT SPRINGS	73/00	41.0						-119.	-14.83	
04	BLUE MOUNTAIN HOT SPRINGS	72/00	58.0						-126.6	-16.13	
07	WEBERG HOT SPRING	72/00	46.0		2.	95.	1.	1*	-122.1	-15.14	
HARNEY COUNTY											
09	CRANE HOT SPRINGS	72/00	78.0						-133.5	-16.17	
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	72/00	68.0		1.	9.	91.	1*	-128.5		
22	MICKEY SPRINGS	72/00	73.0		1.	23.	60.	18*	-124.3	-13.42	-7.91
23	ALVORD HOT SPRINGS	72/00	76.0						-123.6	-13.23	-6.05
24	HOT BORAX LAKE	72/00	36.0						-115.8	-11.57	-7.95
27	UNNAMED HOT SPRING NEAR TROUT CREEK	72/00	52.0						-127.4	-16.17	-9.22
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	73/06	96.0						-125.4	-14.36	-8.58
KLAMATH COUNTY											
	ANNIE SPRING		25.0							-14.40	
	FALCON HEIGHTS SCHOOL	74/05	37.0						-120.5	-15.69	
	MELVIN MCCOLLUM	74/05	25.0						-115.2	-14.71	
	S. AND C. KILGORE		20.0							-16.00	
	WEYERHAUSER WELL NO. 4	72/08	22.						-109.1	-14.60	
01	EAGLE POINT SPRING	72/08	35.						-109.7	-15.22	
02	MEDO-BELL DAIRY	75/07	81.						-119.6	-14.95	-5.45
02	MILLS SCHOOL		89.0						-121.8	-14.93	-4.94
02	O.I.T. NO. 6	75/03	79.						-118.7	-14.99	-5.45

Table 3: GAS AND ISOTOPIC COMPOSITION OF THERMAL SPRING AND WELL DISCHARGES

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Isotopic compositions in the standard notation and are relative to SMOW;
Gas concentrations in volume percent; (*) Ar + O2]

Map Code	Name	Date	Temp (C)	Argon (% Ar)	Methane (% CH4)	Carbon Dioxide (% CO2)	Nitrogen (% N2)	Oxygen (% O2)	Del D of H2O (o/oo)	Del O(18) of H2O (o/oo)	Del O(18) of SO4 (o/oo)
KLAMATH COUNTY											
06	ABE BOEHM	74/05	25.0						-73.2	-7.38	
06	ABE BOEHM	75/08	25.							-6.78	15.42
06	JACK LISKEY	74/05	93.0						-116.6	-14.75	-2.13
06	JACK LISKEY	74/05	22.0						-87.2	-8.83	
06	JACK LISKEY	75/08	25.							-8.57	8.69
06	O. H. OSBORN	74/05	90.0						-117.0	-14.95	-1.85
07	OLENE GAP HOT SPRINGS	72/00	74.0						-113.3	-13.00	
07	OLENE GAP HOT SPRINGS	75/07	87.						-115.3	-13.73	-4.82
16	MELVIN FEIGI	70/10	31.0							-16.80	
LAKE COUNTY											
14	SUMMER LAKE HOT SPRING (WOODWARD)	72/00	43.0						-115.0	-13.32	-4.00
23	HUNTERS HOT SPRINGS (LAKEVIEW)	72/00	96.0						-119.0	-14.32	-3.69
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	72/00	88.0		42.	2.	54.	2*	-119.4	-13.72	
32	FISHER HOT SPRINGS	72/00	68.0						-117.0		
33	CRUMP SPRING	72/00	78.0		6.	14.	75.	5*	-115.5	-13.28	-4.71
LANE COUNTY											
01	BELKNAP HOT SPRINGS	72/00	71.0						-95.8	-11.74	0.35
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	73/00	44.0						-92.5	-11.97	
05	MCCREDIE SPRINGS	74/00	73.		<1.	<1.	98.	1*	-94.0		
MALHEUR COUNTY											
03	NEAL HOT SPRINGS	72/00	87.0		6.		62.	12*	-138.7	-16.52	-8.37
04	BEULAH HOT SPRINGS	72/00	60.0						-131.7	-13.22	
05	VALE HOT SPRINGS	74/00	73.0						-135.0	-15.18	-6.56
05	VALE HOT SPRINGS	74/08	90.							-15.30	-3.91
06	UNNAMED HOT SPRINGS NEAR LITTLE VALLEY	73/00	70.0						-139.7	-16.52	-8.63
08	MITCHELL BUTTE HOT SPRINGS	72/00	62.0						-137.3	-16.58	
18	UNNAMED HOT SPRING AT THREE FORKS	73/00	34.0						-127.4	-16.09	
19	UNNAMED HOT SPRING NEAR MCDERMITT	72/00	52.0						-134.6	-16.75	
23	LUCE HOT SPRINGS	72/00	63.0						-134.0	-15.15	
MARION COUNTY											
01	BREITENBUSH HOT SPRINGS	72/00	92.0						-97.5	-11.66	-2.67
01	BREITENBUSH HOT SPRINGS - WELL	78/02	110.0							-12.59	-3.28
UMATILLA COUNTY											
03	LEHMAN SPRINGS	72/00	61.0		<0.1	<0.1	94.	4*	-121.3	-16.52	
UNION COUNTY											
02	HOT LAKE	72/00	80.0		9.	<1.	90.	2*	-127.7	-16.56	4.63
07	MEDICAL HOT SPRINGS	73/00	60.0						-130.2	-16.99	
WASCO COUNTY											
01	KAHNEETAH HOT SPRINGS	73/00	52.0						-118.9	-14.75	

GEOTHERMOMETRY

The chemical composition of the thermal waters can be used, under certain conditions, to provide estimates of the last temperature of equilibrium of the water and the country rock. The variables which are most often used include silica concentration, and relative proportions among sodium, potassium, calcium, and magnesium. Sufficient isotopic data on sulfate and water are available on some of the samples to calculate temperatures of equilibrium from the sulfate-water isotope geothermometer. The silica, Na-K-Ca, and sulfate-water geothermometers, which are used to estimate most of the temperatures, are valid only for hot-water systems and only when certain assumptions are met. These assumptions, discussed in detail by Fournier and others (1974), are listed below:

1. Temperature-dependent reactions at depth control the concentration of the constituents used in the geothermometer.

2. The reservoir contains an adequate supply of the reactants.

3. Water-rock equilibrium is established in the reservoir.

4. The constituents used in the geothermometer do not re-equilibrate with the confining rock as the water flows to the surface.

5. Mixing of thermal and nonthermal groundwater does not occur.

The concentration of silica in a thermal water depends prinipally on the temperature-dependent solubility of quartz, chalcedony, alpha-cristobalite, or amorphous silica (Fournier, 1973; Fournier and Rowe, 1966). The dissolved silica is generally present as H_4SiO_4, which is the silica species in equilibrium with the respective silica mineral:

$$\begin{array}{ccccc} \text{silicic acid} & & \text{silica mineral} & & \text{water} \\ H_4SiO_4 & = & SiO_2 & + & 2H_2O \end{array} \qquad (1)$$

This is the reaction on which all of the silica geothermometers are based. We may make the following practical generalizations:

1. The solubility of quartz limits silica concentrations in all high-temperature reservoirs (>180°C) and quartz may be the

limiting mineral in granitic aquifers down to temperatures at least as low as 90°C (R. O. Fournier, oral communication).

2. Chalcedony limits silica concentrations in lower-temperature reservoirs and may be the limiting mineral in basaltic rock up to 180°C (Arnorsson, 1975).

The silica geothermometers give apparently good results in thermal systems which are associated with springs of neutral to slightly acid pH. However, several thermal systems listed in the tables discharge dilute alkaline waters with anamolously large silica concentrations. These dilute thermal waters contain little or no dissolved carbon dioxide and typically occur in granitic terrains. Since the silica geothermometers are based on equilibrium with H_4SiO_4, the concentration of this dissolved species must be calculated to obtain an accurate estimate of the temperature in the thermal reservoir. At any temperature and pH, the total dissolved silica concentration is distributed among H_4SiO_4, $H_3SiO_4^-$, and $H_2SiO_4^{-2}$:

$$H_4SiO_4 = H_3SiO_4^- + H^+ \qquad (2)$$

and

$$H_3SiO_4^- = H_2SiO_4^{-2} + H^+ \qquad (3)$$

Equation (3) is important only at very alkaline pH's (>10) and is not important for the thermal waters encountered in Oregon. Equation (2), however, is important in waters with pH's above 8. For example, at a temperature of 80°C and pH of 9, approximately 44 percent of the dissolved silica is in the dissociated form ($H_3SiO_4^-$); while, at a pH of 7, less than 1 percent of the dissolved silica is in the dissociated form. For example, if total dissolved silica is 100 mg/L, and chalcedony is the limiting silica mineral then temperature estimates should be reduced from 111°C (pH 7) to 78°C (pH 9). To correct for the dissociation of silica, we have used a correction which requires that the pH of the thermal spring is approximately the same as that in the thermal reservoir. This assumption requires that the equilibrium constants for the weak acids remain approximately constant despite temperature changes. The concentration of silicic acid (H_4SiO_4) is calculated at the spring temperature and pH. This concentration, recast as SiO_2, is used in the appropriate geothermometer. This correction works best in systems which have aquifer-temperatures near the measured spring temperature. Corrected values for the waters with high pH's are shown in parentheses in table 4. Changes in the dissociation constants of the weak acids as functions of temperature will result in temperature estimates which are slightly too low for systems in which the true aquifer temperature is appreciably above the spring temperature.

Mixing of thermal (high silica) and nonthermal (low silica) waters can sharply reduce the temperatures estimated from the silica geothermometers. However, it is possible to calculate the temperature of the thermal aquifer if sufficient chemical and isotopic data are available for both the thermal and cold waters, if chemical equilibrium has not taken place at or below the mixing temperature, and if there has been no conductive heat loss (Fournier and Truesdell, 1974). The problem with any unexplored system is in proving that the water issuing at the surface is mixed. The simplest proof would be a linear trend between measured spring temperatures and chloride concentration. Normal groundwater usually has low chloride concentrations, while thermal waters from high-temperature systems contain at least several hundred milligrams per liter chloride. A linear trend between the isotopic compositions of the water (deuterium and oxygen(18)) and dissolved chloride is also definitive proof of mixing. Thermal and shallow groundwaters do not usually originate from the same precipitation area and so they have different deuterium concentrations. Since deuterium concentrations do not usually change as a result of water-rock reactions, source waters are isotopically "tagged" and change composition only by mixing or evaporation (boiling). The oxygen isotopic compositions of thermal and fresh waters usually differ by several parts per mil. As water-rock reaction proceeds, the water becomes progressively enriched in the heavier oxygen atoms. Very few areas have a sufficient number of springs of differing chemical and isotopic composition to prove mixing by the rigorous criteria discussed above. Mixing models were not used in preparing table 4, since mixing has not been demonstrated at most sites.

The Na-K-Ca geothermometer (Fournier and Truesdell, 1973) is based on an empirical relationship between the proportions of sodium to potassium, square root of calcium to sodium, and measured reservoir temperatures. Temperatures estimated from the Na-K-Ca geothermometer can be sharply increased by loss of calcium after the thermal fluid leaves the reservoir. Sensitivity of the geothermometer to loss of calcium can be tested in a specific water by doubling the measured calcium concentration and recalculating the estimated reservoir temperature. A change of only a few degrees indicates that the loss of calcium does not appreciably alter the estimated reservoir temperature. High magnesium concentrations or large magnesium

Table 4: GEOTHERMOMETER CALCULATIONS(C)

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Numbers in parentheses are calculated from silicic acid (H4SiO4) concentration calculated at the spring temperature;
waters with magnesium-correction ratios > 50 are indicated by the term "cold"]

Map Code	Name	Measured	Na-K	Na-K-Ca 1/3	Na-K-Ca 4/3	Na-K-Ca Mg-corrected	SiO2 conductive	SiO2 adiabatic	SiO2 chalcedony	SiO2 opal	Sulfate-water
BAKER COUNTY											
01	RADIUM HOT SPRINGS	57.2	106	130	97		125(65)	122	97(33)	6	
01	RADIUM HOT SPRINGS	58.0	81	108	77		124(69)	121	96(37)	5	
02	SAM-O SPRING	27.0	152	165	120	52	116	115	88	-1	
05	KROPP HOT SPRING	43.0	74	110	100		109	109	79	-8	
06	FISHER HOT SPRING	37.0					90(44)	93	60(11)	-24	
CLACKAMAS COUNTY											
01	ACID-SULFATE SPRING ON MT. HOOD		114	90	-16		62	67	29	-48	
02	SWIM WARM SPRINGS	26.0	165	159	83	cold	123	118	91	2	109
03	AUSTIN HOT SPRINGS (CAREY)	86.0	91	118	87	90	126	123	98	7	181
04	BAGBY HOT SPRINGS	57.2	70	93	49		126(65)	123	98(33)	7	
04	BAGBY HOT SPRINGS	58.0	68	91	49		121(78)	119	93(47)	3	
05	GEOTHERMAL GRADIENT TEST NEAR AUSTIN HOT	35.6	140	137	61		87	90	56	-27	
DESCHUTES COUNTY											
01	EAST LAKE HOT SPRINGS	62.0	188	155	44		87	90	56	-27	
01	EAST LAKE HOT SPRINGS	49.0					180	168	158	56	
02	PAULINA HOT SPRINGS		190	178	98	cold	182	170	161	58	
02	WARM WELL AT LITTLE CRATER CAMPGROUND	35.5	189	169	75	cold	166	156	142	43	
DOUGLAS COUNTY											
01	UMPQUA HOT SPRINGS	46.5	96	135	141	100	131	128	104	12	
01	UMPQUA HOT SPRINGS	46.0	101	136	132	108	135	131	108	15	
GRANT COUNTY											
01	RITTER HOT SPRINGS	41.0	60	92	71		118(68)	117	90(31)		
04	BLUE MOUNTAIN HOT SPRINGS	58.0	91	126	118		99	100	69	-16	
05	JOAQUIN MILLER RESORT	40.0	89	121	104	61					
07	WEBERG HOT SPRING	46.0	140	169	162	92	126	124	99	7	
HARNEY COUNTY											
02	O. J. THOMAS	72.0	60	104	116	102	131(71)	127	103(39)	11	
05	HARNEY VALLEY DEV CO. OIL TEST WELL	46.0	61	105	115	96	123	118	91	1	
08	ISLAND RANCH WELL	41.0	60	120	196	115	105(76)	106	76(45)	-11	
09	CRANE HOT SPRINGS	80.0	86	120	109		125	122	97	6	
09	CRANE HOT SPRINGS	78.0	90	124	113		127	124	99	8	
10	WARM SPRING NEAR VENATOR	41.0	55	88	67		225(192)	205	213(173)	101	
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	59.0	82	126	144	82	133	129	105	13	
15	UNNAMED HOT SPRING NEAR HARNEY LAKE	68.0	85	130	150	105	133	129	105	13	
22	MICKEY SPRINGS	85.0	120	179	272	111	168	158	145	45	
				[illegible]	110	204	180	168	159	56	273

Table 4: GEOTHERMOMETER CALCULATIONS(C)

[Map code refers to Bowen, Peterson, and Riccio, 1978;
Numbers in parentheses are calculated from silicic acid (H4SiO4) concentration calculated at the spring temperature;
Waters with magnesium-correction ratios > 50 are indicated by the term "cold"]

Map Code	Name	Measured	Na-K	Na-K-Ca 1/3	Na-K-Ca 4/3	Na-K-Ca Mg-corrected	SiO2 conductive	SiO2 adiabatic	SiO2 chalcedony	SiO2 opal	Sulfate-water
HARNEY COUNTY											
22	MICKEY SPRINGS	86.0	138	198	312		185	172	164	61	
22	MICKEY SPRINGS	86.0	136	196	309	195	185	172	164	61	
22	MICKEY SPRINGS		138	205	349		180	168	159	56	
23	ALVORD HOT SPRINGS	82.2	145	193	252	182	155	147	130	33	
23	ALVORD HOT SPRINGS	76.0	153	198	254	164	148	141	122	26	231
23	ALVORD HOT SPRINGS	78.5	146	194	253	160	152	145	127	30	
23	ALVORD HOT SPRINGS	78.5	144	192	252	157	151	145	126	30	
24	HOT BORAX LAKE	29.4	127	161	163		174	164	152	51	
24	HOT BORAX LAKE	31.1	133	168	174	157	178	166	156	54	
24	HOT BORAX LAKE	36.0	143	176	181		176	165	155	53	336
27	UNNAMED HOT SPRING NEAR TROUT CREEK		181	191	152	174	124	122	96	6	
27	UNNAMED HOT SPRING NEAR TROUT CREEK	52.0	118	143	118	141	140	135	114	19	235
39	GOODMAN SPRING (HOTCHKISS)	22.0	169	156	69		98	99	68	-17	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	73.9	144	175	173		147	141	122	26	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	79.4	147	179	182		170	160	148	47	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	87.0	149	183	193		165	156	142	42	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	96.0	144	176	178		165	156	142	42	231
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	91.0	145	176	178		176	165	154	53	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	97.0	136	169	172		169	159	146	46	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	90.5	141	172	171		163	154	139	40	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	86.0	139	172	174		164	155	141	41	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	97.0	138	171	174		166	157	143	44	
43	UNNAMED HOT SPRING NEAR HOT BORAX LAKE	84.0	138	172	177		167	157	144	44	
44	HOTCHKISS WELL	27.0	160	146	56		103	103	73	-13	
44	HOTCHKISS WELL	27.0	171	155	64		98	99	68	-17	
45	HINES LUMBER CO. WELL	25.0	190	167	70		106	106	77	-10	
46	CITY OF HINES WELL	17.0	230	192	81	46	111	110	81	-7	
JACKSON COUNTY											
01	JACKSON HOT SPRING	35.0	64	95	72	42	114(89)	113	86(58)	-3	
KLAMATH COUNTY											
	ALFRED JACOBSEN	30.0	250	221	131	78	114	113	86	-3	
	BILL HILL	20.0	284	217	83	cold	74	78	42	-38	
	CLAUDE SHUCK	24.0	252	203	84	46	108	108	79	-9	
	CLYDE DEHILINGER	24.0	213	189	95	53	120	118	91	1	
	FALCON HEIGHTS SCHOOL	37.0	192	181	104	33	125	122	97	6	

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Waters with magnesium-correction ratios > 50 are indicated by the term "cold"]

Map Code	Name	Measured	Na-K	Na-K-Ca 1/3	Na-K-Ca 4/3	Na-K-Ca Mg-corrected	SiO2 conductive	SiO2 adiabatic	SiO2 chalcedony	SiO2 opal	Sulfate-water
	KLAMATH COUNTY										
	GEORGE CARTER	22.0	160	156	83	126	93	95	62	-22	
	GEORGE STACY CO.	25.0	231	183	61		85	88	54	-29	
	JACK O'CONNER	38.0	90	116	83		114	113	86	-3	
	LEN DOBRY	21.0	201	180	88	95	114	113	86	-3	
	LESTER BROOKSHIRE	25.0	213	173	57		86	89	55	-28	
	MELVIN MCCOLLUM	25.0	231	178	50		104	104	74	-12	
	MONTE DEHILINGER	26.0	273	207	73	22	105	106	76	-11	
	O'CONNER LIVESTOCK CO.	30.0	108	123	72	102	125	122	97	6	
	OREGON WATER CORP.(4)	26.0					113	112	84	-4	
	POPE'S MEAT CO.	22.0	180	161	67		72(69)	77	40(38)	-39	
	RAY BIXLER	22.0	234	182	55		101	102	71	-15	
	ROBERT LANGLEY	23.0	252	200	78	25	102	103	72	-14	
	TOWN OF MERRILL	21.0	165	155	71	41	89	92	59	-25	
	U.S. AIR FORCE(1)	31.0	227	209	129	100	105	105	75	-12	
	U.S. AIR FORCE(2)	30.0	220	201	117	65	103	103	73	-13	
	WEYERHAUSER WELL NO. 4	22.0	178	159	65		55	62	23	-53	
01	EAGLE POINT SPRING	35.0	169	190	170		89	92	59	-25	
02	J. E. FRIESEN	73.0	83	109	75		130(111)	126	102(82)	10	
02	LOIS MERRUYS	71.0	80	106	73		127(115)	124	99(86)	8	
02	MEDO-BELL DAIRY	81.0	83	109	75		125(102)	123	98(72)	7	
02	MEDO-BELL DAIRY	81.0									185
02	MILLS SCHOOL	89.0	47	83	67		124	121	96	5	
02	MOYINA WATER CO.	50.0	196	177	86	64	114	113	85	-4	
02	O.I.T. NO. 5	89.0	57	91	72		120(104)	118	92(74)	2	
02	O.I.T. NO. 6	88.0	83	108	71		81	84	49	-32	
02	O.I.T. NO. 6	79.0					131	128	104	12	185
02	OREGON WATER CORP.(1)	21.0					98	99	68	-17	
02	OREGON WATER CORP.(2)	21.0					70	75	39	-40	
02	OREGON WATER CORP.(3)	20.0					72	77	40	-39	
03	HOWARD HOLLIDAY	25.0	181	157	56		75	79	44	-36	
04	MAZAMA SCHOOL	61.0	93	129	126	96	133	129	105	13	
06	ABE BOEHM	25.0	114	132	87	57	137	133	110	17	
06	ABE BOEHM	25.0									58
06	DAN O'CONNER	24.0	254	207	91	34	94	96	63	-21	
06	JACK LISKEY	93.0	83	111	82		131(106)	128	104(76)	12	138
06	JACK LISKEY	22.0	85	121	115	38	137	133	110	17	
06	JACK LISKEY	25.0									93
06	O. H. OSBORN	90.0	87	113	83		131(65)	128	104(33)	12	135
07	OLENE GAP HOT SPRINGS	73.9	72	101	72		124	122	96	6	
07	OLENE GAP HOT SPRINGS	74.0	115	130	80	122	136	132	109	16	
07	OLENE GAP HOT SPRINGS	87.0									196
08	ROENICKE HOT SPRING	65.0	90	112	72	85	100	101	70	-16	
16	MELVIN FEIGI	31.0	71	103	80		143(132)	137	116(105)	22	
22	RAY SMITH WELL	25.0	145	143	68		102	103	72	-14	
23	KLAMATH ICE CO.	51.7					118(99)	117	90(69)		
24	J. K. O'NEIL		249	203	87	20	97	99	67	-18	
24	J. K. O'NEIL	23.0	230	194	88	cold	102	103	72	-14	

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Waters with magnesium-correction ratios > 50 are indicated by the term "cold"]

Map Code	Name	Measured	Na-K	Na-K-Ca 1/3	Na-K-Ca 4/3	Na-K-Ca Mg-corrected	SiO2 conductive	SiO2 adiabatic	SiO2 chalcedony	SiO2 opal	Sulfate-water
	LAKE COUNTY										
05	ANA RIVER SPRING	18.9	162	157	80	27	85	91	57	-26	
14	SUMMER LAKE HOT SPRING (WOODWARD)	46.7	76	130	182	113	135(123)	131	108(95)	15	
14	SUMMER LAKE HOT SPRING (WOODWARD)	43.0	61	112	149		134(127)	130	107(99)	14	189
23	HUNTERS HOT SPRINGS (LAKEVIEW)	98.0	125	148	120		159	151	135	37	
23	HUNTERS HOT SPRINGS (LAKEVIEW)	86.0	128	154	134	74	157	149	133	35	158
23	HUNTERS HOT SPRINGS (LAKEVIEW)	96.0	119	143	114		157	149	133	35	
24	LEITHEAD HOT SPRINGS (JOYLAND PLUNGE, LEO	69.4	69	96	61		115	114	86	-2	
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	85.0	107	140	130	102	157	149	133	35	
25	BARRY RANCH HOT SPRINGS (GUS ALLEN)	88.0	106	139	131		152	145	127	31	
28	ANTELOPE HOT SPRINGS	40.0	149	168	138	87	168	159	146	45	
32	FISHER HOT SPRINGS	68.0	165	169	112	123	123	121	95	4	
33	CRUMP SPRING	40.0	130	147	104	112	150	143	125	29	
33	CRUMP SPRING	78.0	117	144	122		173	162	151	50	202
33	CRUMP WELL (1)	99.0	118	150	141	144	169	159	146	46	
33	CRUMP WELL (2)	88.0	112								
	LANE COUNTY										
01	BELKNAP HOT SPRINGS	86.7	226	202	110	183	126	123	98	7	
01	BELKNAP HOT SPRINGS	71.0	87	113	82	34	135	131	108	15	148
02	FOLEY SPRINGS	80.6	91	106	52		111	110	82	-6	
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	44.0	74	95	48		102	103	72	-14	
03	COUGAR RESERVOIR HOT SPRINGS (RIDER)	42.0	86	103	51		99	100	69	-16	
04	WALL CREEK WARM SPRINGS	41.0	110	125	73		113	112	84	-5	
05	MCCREDIE SPRINGS	73.0	88	114	81	74	124	122	96	6	
05	MCCREDIE SPRINGS	71.0	104	125	86	84	115	114	86	-3	
06	KITSON SPRINGS	44.4	82	110	83		99	100	69	-16	
06	KITSON SPRINGS	43.0	77	107	81	71	97	98	67	-18	
08	BIGELOW HOT SPRINGS	61.0	104	125	85	120	117	116	89	-1	
	MALHEUR COUNTY:										
03	NEAL HOT SPRINGS	87.0	163	181	151		173	162	151	50	210
04	BEULAH HOT SPRINGS	60.0	103	124	85		169	159	146	46	
05	VALE HOT SPRINGS	73.0	132	157	135	150	152	145	127	31	201
05	VALE HOT SPRINGS	90.0									161
06	UNNAMED HOT SPRINGS NEAR LITTLE VALLEY	70.0	83	118	109		145(126)	139	119(98)	24	215
08	MITCHELL BUTTE HOT SPRINGS	62.0	70	99	72		134(118)	130	107(90)	14	
18	UNNAMED HOT SPRING AT THREE FORKS	35.0					96	97	66	-19	

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Map Code	Name	Measured	Na-K	Na-K-Ca 1/3	Na-K-Ca 4/3	Na-K-Ca Mg-corrected	SiO2 conductive	SiO2 adiabatic	SiO2 chalcedony	SiO2 opal	Sulfate-water
MALHEUR COUNTY											
18	UNNAMED HOT SPRING AT THREE FORKS	34.0	83	98	42		92	94	61	-23	
19	UNNAMED HOT SPRING NEAR MCDERMITT	53.5	66	107	109		131(101)	128	104(71)	12	
19	UNNAMED HOT SPRING NEAR MCDERMITT	52.0	45	90	104		120(106)	118	91(76)	1	
23	LUCE HOT SPRINGS	63.0	119	137	96		143	137	116	22	
24	JONESBORO WARM SPRING	44.5	53	89	73		118(70)	117	90(39)		
25	JUNTURA WARM SPRING #1	25.0	285	205	59		106(84)	106	77(53)	-10	
26	JUNTURA WARM SPRING #2	35.0	56	92	78		124(76)	122	96(44)	6	
27	ARTESIAN WELL	46.0	39	78	71		96(57)	97	65(24)	-19	
28	ALKALI FLAT GRADIENT WELL	24.0	68	108	109		82	85	51	-31	
29	NORTH HARPER BLM WELL	36.0	75	109	94	95	91	93	61	-23	
30	UNNAMED WARM SPRING NEAR BULLY CREEK	37.0	266	148	-24		137	132	110	16	
MARION COUNTY											
01	BREITENBUSH HOT SPRINGS	92.0	122	149	128		127	124	99	8	179
01	BREITENBUSH HOT SPRINGS -WELL	110.0	130	155	134		174(157)	163	152(133)	50	176
MULTNOMAH COUNTY											
01	CORBETT WARM SPRING	18.0	178	170	92	158	95	98	66	-19	
02	YMCA CAMP COLLINS	23.3	430	283	103	260	111(104)	110	81(75)	-7	
UMATILLA COUNTY											
01	BINGHAM SPRINGS	34.4	138	151	102	70	117(110)	115	88(81)	-1	
03	LEHMAN SPRINGS	61.0	66	97	72		96	97	66	-19	
UNION COUNTY											
01	COVE WARM SPRING	29.4	75	95	46		78(40)	82	47(7)	-34	
01	WELL	27.0	224	194	92	168	128	125	100	8	
01	WELL	25.0	215	190	94	81	120	118	91	1	
01	WELL	27.0	258	200	73	195	119	117	90	1	
02	HOT LAKE	80.0	85	114	89		100(62)	101	70(30)	-16	63
05	WAGNER WELL	29.0	203	183	93	94					
07	MEDICAL HOT SPRINGS	60.0	78	97	48		135	131	109	15	
07	MEDICAL HOT SPRINGS	60.0	114	125	66		125	122	97	6	
WALLOWA COUNTY											
01	COOK CREEK WARM SPRING	36.0	119	118	40		98	99	68	-17	
WASCO COUNTY											
01	KAHNEETAH HOT SPRINGS	52.0	56	102	120		139	135	113	19	
02	MILTON MARTIN WELL	22.2	220	188	84	89	128(124)	125	100(96)	8	
03	J. SANDOZ WELL	27.8	221	196	103	69	134	130	107	14	

to calcium ratios have long been considered a qualitative indicator of low reservoir temperature (Ellis, 1970; White, 1970). The recently developed Na-K-Ca-Mg geothermometer (Fournier and Potter, 1979) quantifies this observation and results in generally better agreement between the silica and cation geothermometers, particularly in the lower (<150°C) temperature range. The magnesium-corrected Na-K-Ca geothermometer was not calculated for samples with Na-K-Ca temperatures of less than 70°C.

To apply the magnesium correction, the ratio (R), defined by Fournier and Potter (1978) to be:

$$R = \frac{\text{millequivalents Mg} \times 100}{\text{millequivalents Mg} + \text{milliequivalents Ca} + \text{milliequivalents K}} \qquad (4)$$

was determined for all samples with magnesium, calcium, and potassium concentrations larger than the detection limits. If R was greater than 50, the sample was designated "cold" and no quantitative temperature was calculated. A magnesium-corrected temperature was calculated for all remaining samples, but was printed only if the corrected temperature was less than the uncorrected Na-K-1/3Ca temperature. The Na-K temperatures are based on the revised equation of Fournier (1979).

The sulfate-water isotope geothermometer (McKenzie and Truesdell, 1977) is based on the temperature-dependent fractionation of the isotopes of oxygen (O^{16}/O^{18}) between water and dissolved sulfate. McKenzie and Truesdell (1977) describe three end-member models for calculating reservoir temperatures with the sulfate-water isotope geothermometer: (1) conductive heat loss, (2) one-step steam loss, and (3) continuous steam loss. Samples from isolated springs with low flows and/or no steam loss, and condensed total-flow samples from wells, are assumed to have cooled conductively without any change in isotopic composition. One-step steam loss occurs in geysers and steam wells having two-phase flow from which only the water is collected. Continuous steam loss may occur in springs issuing in areas having fumaroles and steaming ground. If dilution occurs but is not detected, temperatures less than the actual reservoir temperature will be estimated. Generally, the continuous-steam-loss model is best for boiling springs and the conductive-heat-loss model for all other samples. Erroneous temperature estimates will be produced if nonthermal equilibrated sulfate is added by processes such as solution of gypsum, oxidation of sulfide to sulfate, or mixing with sulfate bearing brines.

Besides these quantitative indicators of subsurface temperature, the presence of travertine or siliceous sinter is generally a good qualitative indicator of temperature. Travertine indicates low temperatures, while siliceous sinter indicates temperatures of 180°C or more (White, 1970). Only Hot Lake and Mickey Springs in southern Harney County, and Neal Hot Springs in northern Malheur County, have large sinter deposits.

The following procedure is recommended to determine which estimated subsurface temperature (table 4) is best:

1. Examine the Mg-corrected Na-K-Ca and the Na-K-4/3Ca temperatures and select the lower temperature as the better estimate. If neither is less than 100°C, then select the Na-K-1/3Ca temperature as the best cation-based estimate of the last temperature of water-rock equilibrium.

2. If the spring is boiling, select the quartz adiabatic temperature as the best silica-based temperature indicator. Otherwise, selection of the best silica-based temperature depends on having some knowledge of the principal rock type in the area of the individual hot spring. In alkaline waters discharging from granite, quartz solubility seems to limit silica concentrations at temperatures as low as 75°C. In waters of neutral pH, quartz solubility limits silica concentrations at temperatures of more than 180°C in basalts, and 90°C in granite.

3. Consider the temperatures estimated from the sulfate-water geothermometer to be speculative. Although tantalizing, these temperatures must be substantiated by additional information.

After careful application of the geothermometers, some samples may remain which give inconsistent or otherwise doubtful results. For example, dissolution of glass from vitric or lapilli tuffs releases large quantities of silica which renders the silica geothermometer useless. The high silica concentration at Beulah Hot Springs in Malheur County and at the warm springs near Venator in Harney County may be meaningless since both springs issue from vitric tuffs. The low temperatures estimated from the Na-K-Ca geothermometers indicate that the springs are not an important geothermal resource.

The chemical composition of the thermal waters issuing along the shores of East Lake and Paulina Lake are also difficult to interpret. These springs have negligible flow rates, high silica concentrations (up to 200 mg/L), and issue from lapilli tuffs. Solution of glass from the lapilli tuffs could account for the large silica and relatively large magnesium concentrations. Since the temperatures of the springs increases as gas discharge increases, the "springs" are probably drowned gas vents. The concentrations of silica, sodium, potassium, and calcium in these thermal waters may be functions of the length of time that the heated lake water has been in contact with the tuff and may have no relationship to the temperature at depth. The relatively large magnesium concentration also favors a low-temperature system.

The sulfate-water isotope geothermometer produces considerably higher estimated temperatures of water-rock equilibrium than the chemical geothermometers in most systems. The high temperatures estimated from the sulfate-water isotope geothermometer may indicate that the systems have a deep reservoir in which isotopic equilibrium is being established, and a shallower, cooler reservoir in which chemical equilibrium is being established. This is possible because the rate of sulfate-water isotopic equilibrium is relatively slow. Times to achieve equilibrium depend on both temperature and pH (Lloyd, 1968). To achieve 99-percent equilibration at neutral pH's, 330 years would be required at 100°C, 52 years at 150°C, and 12 years at 200°C. However, it is possible that the sulfate is added to the system slowly as the fluids circulate, thus requiring longer times to achieve 99-percent equilibration. An alternate explanation for the high temperatures estimated in the Cascades is that the sulfate represents fossil sulfate associated with the mineralization which is common in the Western Cascades. However, until additional data are available, it will not be possible to determine if the high apparent temperatures of sulfate-water isotopic equilibrium are real or the result of solution of "fossil" sulfate, mixing of thermal and nonthermal waters, reduction of sulfate, membrane filtration, different rates of isotopic exchange between sulfate, water, and rock, or other nonthermal effects.

SUMMARY

Most of the thermal springs in the central and northern parts of the Cascades in Oregon contain ~~appreciable~~ connate marine water similar to cold connate marine waters discharged from mineral springs and deep wells in the Willamette Valley and the Coast Range. Thermal springs in the southern part of the Cascades discharge similar waters to which a significant amount of CO_2 has been added. Numerous cold CO_2-charged springs also issue in this area. Dilute, alkaline thermal waters issue from springs associated with granitic rocks, principally in northeastern Oregon. These waters are sufficiently alkaline to require that the silica geothermometer be corrected for the dissociation of silicic acid. Near-surface water-rock reactions have rendered the chemical composition of thermal water at Newberry Caldera useless for geothermal calculations. Based on the geothermometers, the following areas have the greatest geothermal potential: Alvord Area (including Mickey Springs, Alvord Hot Springs, and Hot Borax Lake), Vale Hot Springs, Neal Hot Springs, Crump Spring, Lakeview, and Breitenbush Hot Springs. Areas for which the geothermometers do not agree include Klamath Falls and part of the Cascades.

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Bruce

UNITED STATES DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY

Thermal System
230-240°C
Vapor-Res. over 6 km dia.

THE LASSEN GEOTHERMAL SYSTEM

by

L. J. Patrick Muffler, Nancy L. Nehring, Alfred H. Truesdell,
Cathy J. Janik, Michael A. Clynne, and J. Michael Thompson
U. S. Geological Survey

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Abstract. The Lassen geothermal system consists of a central vapor-dominated reservoir underlain by hot water that discharges peripherally at lower elevations. The major thermal upflow at Bumpass Hell (elevation 2,500 m) displays numerous superheated fumaroles, one of which in 1976 was 159°C. Gas geothermometers from the fumarole areas and water geothermometers from boiling Cl-bearing waters at Morgan Hot Springs (elevation 1,530 m; 8 km south of Bumpass Hell) and from 176°C waters in a well 12 km southeast of Bumpass Hell both indicate 230-240°C for the deep thermal water. With increasing distance from Bumpass Hell, gases are progressively depleted in H_2S relative to CO_2 and N_2, owing to oxidation of H_2S to pyrite, sulfur, and sulfates and to dilution with atmospheric N_2. H_2O/gas ratios and degree of superheat of fumaroles can be explained by mixing of steam of maximum enthalpy (2,804 J g^{-1}) with near-surface water and with the condensate layer overlying the vapor-dominated reservoir.

Introduction. The Lassen geothermal system is located in the southernmost part of the Cascade Range, a linear belt of Quaternary volcanoes that extends from southern British Columbia to northern California (Muffler, Bacon, and Duffield, 1982, figure 1). The Lassen geothermal system has by far the most conspicuous surface hydrothermal manifestations of any geothermal system in the Cascades. However, most of the system is located in Lassen Volcanic National Park (LVNP) and is therefore not available for commercial development except perhaps in peripheral, hot-water zones outside LVNP.

Geologic setting. The Cascade Range in the Lassen region is a broad ridge of late Pliocene and Quaternary volcanic rocks consisting primarily of pyroxene andesite flows and pyroclastic rocks with subordinate basalt flows, silicic flows, and silicic pyroclastic rocks. The regional basement probably consists of Mesozoic granitic and metamorphic rocks overlain by a thin sequence of Late Cretaceous marine sedimentary rocks which are in turn overlain by the Pliocene Tuscan Formation (Anderson, 1933; Lydon, 1968), a broad apron of andesitic debris flows with minor interbedded lava flows, ash-flow tuffs, and alluvial material deposited 3.5-2 m.y. ago (Lydon, 1961; Gilbert, 1969).

Late Pliocene and Holocene volcanic rocks overlying the Tuscan Formation were extruded primarily from long-lived major volcanic centers, at least three of which have been recognized in the Lassen region (figure 1).

- Dittmar volcanic center, active from perhaps 3.2 to 2.5 m.y.;
- Maidu volcanic center, active between 1.8 and 1.0 m.y. (Wilson, 1961);
- Lassen volcanic center, active from 0.6 m.y. to the present.

Each volcanic center evolved in three stages: (1) an initial cone-building period of andesite lava flows and pyroclastic rocks, (2) a later cone-building period of thick silliceous andesite lava flows, and (3) eruption of dacite to rhyolite domes and flows flanking the main composite cone. Silicic magma chambers related to the late domes and flows provided potent heat sources for hydrothermal convection systems within the cores of each of the main cones. However, the silicic magma chambers of the Dittmar and Maidu volcanic centers have cooled, and their hydrothermal systems are extinct. The present hydrothermal system at Lassen is associated with the active silicic volcanism of the Lassen volcanic center.

Flows and pyroclastic rocks of Stages 1 and 2 of the Lassen volcanic center were extruded primarily from a composite cone centered near Sulphur Works (Williams, 1932) during the period 0.6 to 0.35 m.y. (G. B. Dalrymple, personal commun., 1977-82). After a hiatus of approximately 0.1 m.y., at least 15 vents in a broad zone on the northeastern flank of this composite cone extruded flows and domes of dacite and rhyodacite, forming a dome field of approximately 130 km^2. The most recent events were the emplacement of the dacite dome of Lassen Peak approximately 11,000 years ago (Crandell, 1972), the eruption of rhyodacite pyroclastic flows and domes at Chaos Crags approximately 1,100 years ago (Crandell and others, 1974; D. A. Trimble, USGS, personal commun., 1982), and the relatively small eruption at the summit of Lassen Peak in 1914-1917 (Day and Allen, 1925; Loomis, 1926). Concurrent with this silicic volcanism, basalt and mafic andesite shield volcanoes grew to the north and east of the Lassen volcanic center, and mixing of silicic and basaltic magmas

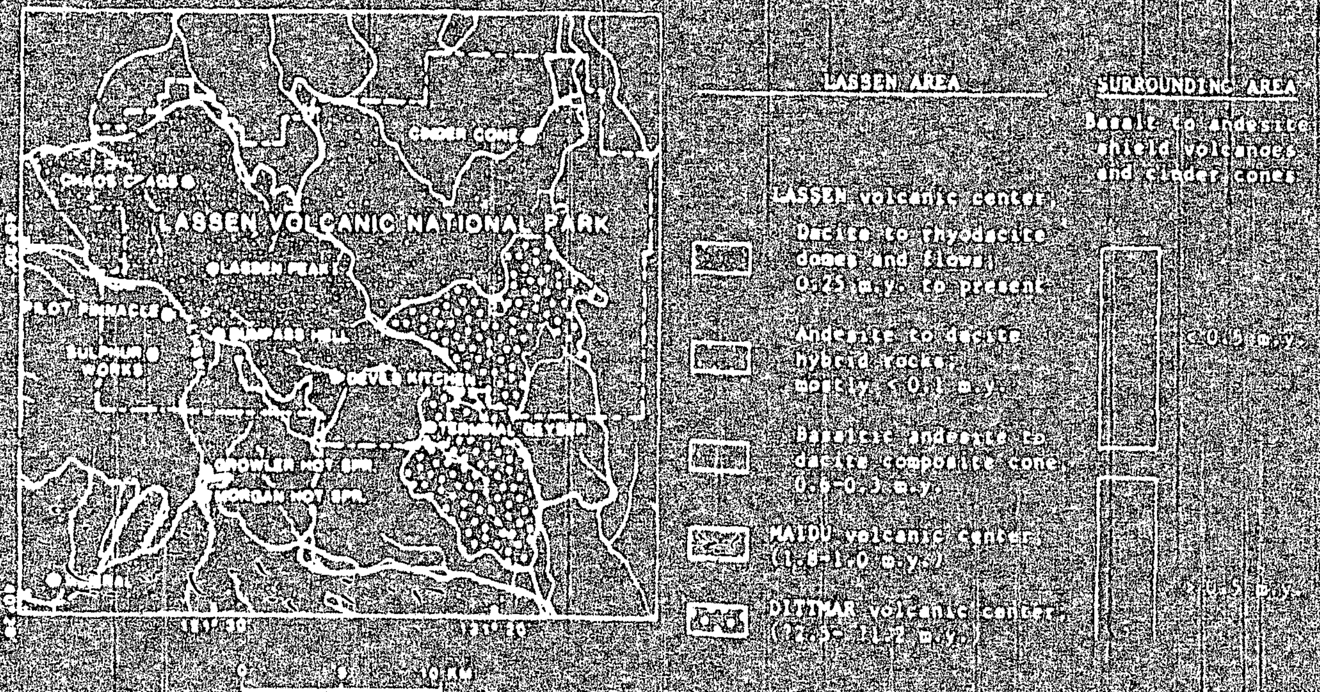

Figure 1.--Generalized geologic map of the Lassen region (adapted from Muffler, Clynne, and Cook, 1982). LHSV = Little Hot Springs Valley

produced intermediate lava flows on the east flank of the Lassen dome field (Eichelberger, 1975). The most recent eruption in this area was at Cinder Cone in 1850-51 (Finch and Anderson, 1930).

The long history of pyroclastic and dome-building eruptions in the Lassen dome field, the historical production of magma at two separate vents, and the existence of a major gravity low suggest that a partially molten silicic magma body still underlies the dome field (Heiken and Eichelberger, 1980).

The Lassen Geothermal System. Geological and geochemical observations in the Lassen region all fit a model originally suggested by D. E. White (written commun., 1971) of a single large geothermal system with a central vapor-dominated reservoir (or reservoirs) underlain by a reservoir of hot water discharging at lower elevations (figure 2). The focus and major thermal upflow of the Lassen geothermal system is at Bumpass Hell along the contact between the andesitic composite cone and the dacite dome field of the Lassen volcanic center. Some of the outflow of hot water reaches the surface at Morgan and Growler Hot Springs to the south of LVNP and has been produced from the geothermal well Walker "O" No. 1 at Terminal Geyser in the southeast corner of LVNP.

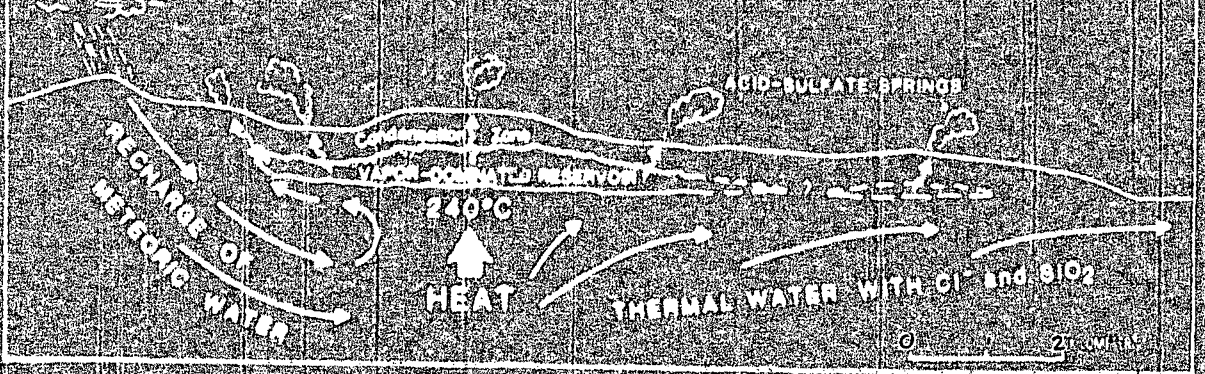

Figure 2.--Schematic cross-section of the Lassen geothermal system (adapted from Muffler, Clynne, and Cook, 1982)

Bumpass Hell (elevation 2,500 m) contains numerous superheated fumaroles, one of which in 1976 had a temperature of 159°C. Approximately 75 major fumaroles, acid-sulfate hot springs, and mudpots occur in Bumpass Hell (Muffler, Jordan, and Cook, 1982), plus a myriad of similar features too small to map. An area of approximately 0.13 km^2 is intensely altered to a white aggregate of opal and kaolinite ± alunite; the surface of the active part of Bumpass Hell is commonly covered with orange and yellow sulfates. Pyrite is common in many of the hot springs as linings of the vents and discharge channels, as scum floating on the surface of pools, and as dispersions in brown or black mudpots. Significant sinter does not occur, although a few springs show a weak deposit of silica around their rims and in the first few centimeters of their discharge channels. Silica is also found as bright red mixtures with iron oxides in some drainages in the forest below acid-altered bare ground. Neither of these occurrences is indicative of a hot-water geothermal system. The acid-sulfate water from Bumpass Hell (table 1) is typical of hot springs related to a vapor-dominated reservoir in having low pH, high sulfate, and no significant Cl.

Table 1.--Chemical analyses of waters from thermal springs in and near LVNP. Constituents in mg L-1, flow in L min-1, n.d. = not determined. BH, Bumpass Hell; DK, Devil's Kitchen; SW, Sulfur Works; LHSV, Little Hot Springs Valley; TG, Terminal Geyser; GHS, Growler Hot Spring; MHS, Morgan Hot Springs.

	BH	DK	SW	LHSV	TG	GHS	MHS
Date	8/76	9/76	7/75	9/79	8/76	8/79	8/79
Flow	20	8	seep	4	[illegible]	20	8
T(°C)	65	68	86	93	92	95	96
pH	1.2	2.5	1.9	5.65	1.9	7.45	7.25
SiO_2	[illegible]	191	213	223	186	172	[illegible]
Al	11.2	nd	nd	.4	nd	.1	.2
Fe	29	6.1	nd	.34	nd	.04	.01
Mn	0.12	0.08	nd	.15	nd	.01	.03
As	nd	nd	nd	nd	nd	1.1	1.6
Ca	9.9	10.5	6.8	26	9.2	81	94
Mg	5.05	6.4	9.8	4.1	1.9	.07	.17
Sr	nd	nd	nd	nd	nd	.9	1.1
Ba	nd	nd	nd	nd	nd	2.5	3.0
Na	6.1	2.4	11	87	8	1140	1260
K	6.0	7.2	2.3	12	3	171	162
Li	.04	0.015	0.01	.02	.01	6.3	6.1
Rb	nd	nd	nd	nd	nd	1.0	1.2
Cs	nd	nd	nd	nd	nd	.6	[illegible]
NH_4	nd	nd	30	3.6	nd	9.5	13
HCO_3	0	0	0	19	93	58	68
SO_4	364	226	938	301	48	110	123
Cl	5.7	0.5	0.9	9.2	3	2370	2210
F	0.11	0.17	0.35	.04	0.1	2.3	3.0
Br	nd	nd	nd	nd	nd	10	14.5
B	1.1	0.3	4.4	4.2	1.6	64	nd
H_2S	nd	nd	0.2	.03	nd	.02	.01
Calculated Geothermometer Temperatures							
Quartz Adiabatic[a]				158		187	176
Chalcedony Conductive[a]				160		205	180
Na-K-Ca[b]				95		273	219

a. Equation from Truesdell, 1976
b. Equation from Fournier and Truesdell, 1973

Fumaroles, acid-sulfate springs, and mudpots also are abundant in Little Hot Springs Valley just to the west and 230-400 m lower than Bumpass Hell. Several fumaroles in Little Hot Springs Valley are superheated, with a highest temperature of 125°C measured in 1976.

Devil's Kitchen (1,835 m) is an area of intense fumaroles, acid-sulfate springs, and mudpots (Muffler, Jordan, and Cook, 1982). Although a temperature of 106.6°C was measured in 1947 by D. E. White (written commun., 1982), at present the hottest fumaroles are superheated only by a degree or two. Several centimeters of sinter at two spots along the stream flowing through Devil's Kitchen indicate discharge of hot thermal water in the recent past.

Several other geothermal areas in LVNP also are characterized by fumaroles, mudpots, and acid-sulfate hot springs (see chemical analyses in table 1). Conspicuous among these are Sulphur Works (elevation 2,124-70 m), Pilot Pinnacle (2,516 m), Boiling Springs Lake (1,798 m), and Terminal Geyser (1,797 m). Steam discharging currently from these areas is either saturated or only slightly superheated.

Several springs near Sulphur Works and in Little Hot Springs Valley are relatively rich in HCO_3 and deposit travertine ($CaCO_3$). These springs are interpreted to be surface discharge from the zone of steam condensate that overlies the vapor-dominated reservoir.

Natural discharge from the hot-water part of the Lassen geothermal system occurs only at Morgan Hot Springs and Growler Hot Spring, both located in the canyon of Mill Creek at elevations of 1,530 and 1,570 m, respectively. These springs discharge moderate amounts of near-neutral water with significant Cl (table 1) and deposit conspicuous sinter. Na-K-Ca, sulfate-water isotope, and mixing model geothermometers indicate that the deep thermal water feeding these springs has a temperature of 220-240°C. Both Cl and SiO_2 concentrations decrease systematically south-southwest from Growler Hot Spring through Morgan Hot Springs (Thompson, 1982).

High-Cl thermal water from the Lassen geothermal system has also been found in the Walker "O" No. 1 well (Beall, 1981) at Terminal Geyser. Samples taken during flow of the well on 10-11 October 1978 show Na, K, and Cl increasing with time to maximum values of 1,300, 160, and 2,200 mg L-1, respectively. Flow tests were terminated before the chemical constituents reached constant values. Measured pH ranged from 8.1 to 8.6. Temperatures taken in the plugged liner 10 months after the well was flowed reach a maximum of 176°C between 603 and 640 m and then decrease gradually to 126°C at the well bottom (1,222 m).

The Cl-bearing water found in Walker "O" No. 1 does not discharge in Terminal Geyser. This vent is not a true geyser but is a fumarole discharging into a small surface stream. Water discharged by Terminal Geyser (table 1) appears to be local precipitation heated by steam.

Thermodynamic evidence for steam sources. High-temperature superheated geothermal fumaroles are uncommon, but during the California drought of 1976-77 high degrees of superheat were observed in three areas of LVNP. In late 1976 Big Boiler fumarole in Bumpass Hell reached 159°C, to our knowledge the highest temperature ever recorded from a geothermal (non-volcanic) fumarole. This temperature is close to the temperature (163°C) of steam decompressed adiabatically to Lassen surface pressure (0.75 bar abs) from saturated steam of maximum enthalpy (2,804 J g-1 at 235°C and 31 bar abs; figure 3). Steam of higher temperature and enthalpy (up to 260°C and 2,980 J g-1 at 5 bars abs, Truesdell and White, 1973) has been produced from wells at Larderello, Italy, by the isothermal decompression of saturated steam in the reservoir (flow in the wells is adiabatic). This isothermal decompression, however, is a result of drastically reduced pressures caused by rapid withdrawal of steam through wells. Isothermal decompression is unlikely to occur in a natural system because cooler rocks between the reservoir and the surface can be heated only to the temperature of the steam. Thus the limiting process in nature is adiabatic (isoenthalpic) decompression.

The range of superheat in the Lassen steam samples could have resulted from two processes, (1) adiabatic decompression of saturated steam with different temperatures, or (2) mixing of highly superheated steam with liquid water or with saturated steam of lower temperature. After mixing, the resulting steam would undergo further decompression to reach surface conditions. This second process is the simpler explanation and is in accord with the observed H_2O/gas ratios.

On a plot of H_2O/gas ratio vs. enthalpy (figure 4), the Lassen data fall on two trend lines that intersect at the point of maximum steam enthalpy (2,804 J g-1). Line A consists of Big Boiler (Bumpass Hell) samples and trends toward a relatively high H_2O/gas end member. Line B (from Bumpass Hell and other areas) trends toward a relatively low H_2O/gas end member. These two trends are also distinguished on a plot of percent H_2 vs. H_2O/gas ratio (figure 5). In this plot, one trend has a slope of 1, suggesting that H_2 was in equilibrium with H_2O (at constant temperature and P_{CO_2}), and the other has a slope of infinity, suggesting lack of equilibrium due to short reaction times or low

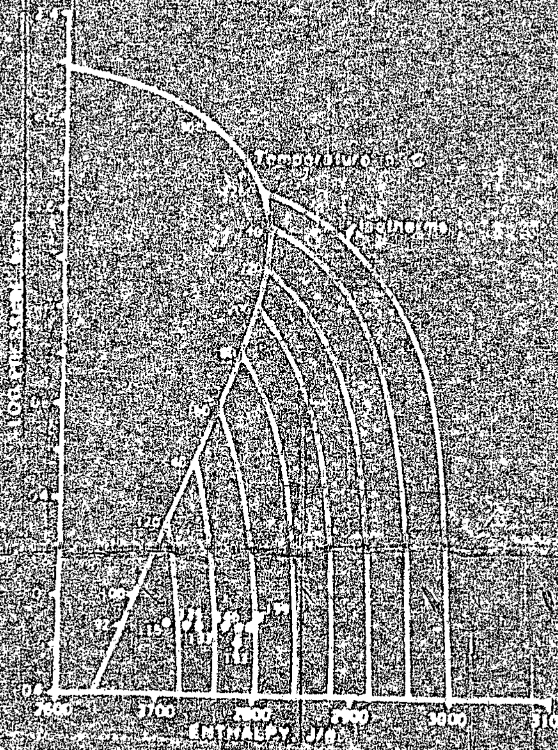

Figure 3.--Diagram showing the relations between saturated steam, the isothermal decompression paths of superheated steam, and the surface enthalpy, temperature, and pressure of superheated fumarolic steam from LVNP. Numbers give temperatures in °C.

Figure 4.--Diagram showing the relations between H_2O/gas and enthalpy of steam samples from LVNP. Numbers give temperatures in °C. See figure 6 for explanation of symbols. Line A trends towards 235°C liquid water with 0.7 bar P_{CO_2} and 7,900 H_2O/gas. Line B trends towards 90°C liquid water with 1.1 bar P_{CO_2} and 3,900 H_2O/gas.

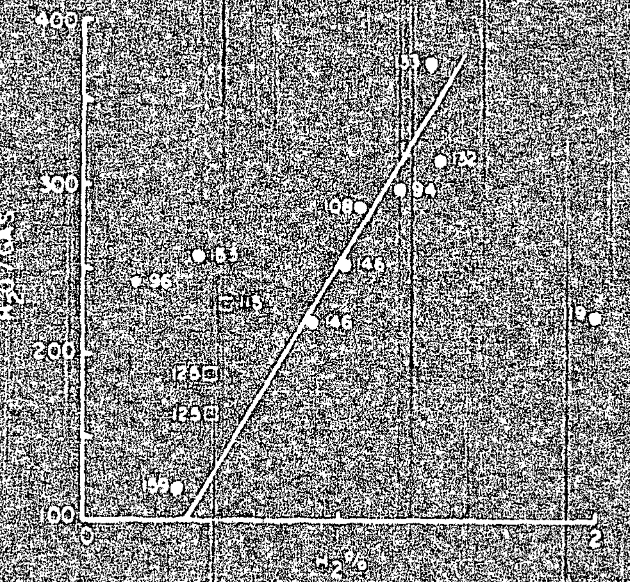

Figure 5.--Diagram showing relations between H_2O/gas and H_2 content of gas samples from fumarole areas in LVNP. Numbers give temperature in °C. See figure 6 for explanation of symbols. Hydrogen in geothermal systems appears to be generated by the dissociation of water ($H_2O = H_2 + 1/2\ O_2$) with the pressure (fugacity) of oxygen controlled by mineral reactions.

temperature. Although the correspondence is not complete, 5 of the 7 points on the line with a slope of 1 lie on line A of figure 4, and 4 of the 5 points with a slope of infinity lie on line B.

This behavior of H_2 strongly suggests that steam samples falling along line B resulted from mixture of superheated steam and liquid water near the surface, where residence times were too short for H_2-H_2O equilibration. A possible low-temperature end-member would be 90°C water in equilibrium with CO_2 at 1.1 atm pressure and with a H_2O/gas ratio of 3,600. This heated, gas-charged water might reasonably saturate the near-surface zones of the fumarolic areas and be entrained into superheated steam as it flowed upward. The total pressure (water vapor + CO_2) of this liquid water would be 1.8 bars, which would allow the mixing to occur within 8 m of the surface by boiling-point-to-depth relations.

Steam samples along line A (figure 4) must mix at greater depths, where H_2 and H_2O can equilibrate after mixing. If this mixing occurs in the upper part of the deep reservoir near 235°C, the H_2O/gas ratio of the liquid water mixing with steam would have been 7,900 and the P_{CO_2} about 0.7 bar. The H_2O/gas ratio of reservoir steam with $P_{CO_2} = 0.7$ bar would be 50, close to the ratio of the hypothetical deep steam (H_2O/gas = 85).

Using these end members, we find that the steam samples along trend A are mixtures of superheated steam (2,804 J g^{-1} and 85 H_2O/gas) with 0.5-4.0 percent liquid water at 235°C, 1,014 J g^{-1} and 7,900 H_2O/gas. Those samples along trend B are mixtures of superheated steam with 2-6 percent liquid water at 90°C, 377 J g^{-1}, and 3,600 H_2O/gas. These fractions of liquid are so small they might not be detected by isotopic methods, but owing to the high gas content of the deep steam are readily distinguished by H_2O/gas ratios.

Stable isotopes of hydrogen and oxygen. Isotopic analyses of samples collected from 1977 to 1981 provide extensive data supporting interpretations made by Truesdell and Hulston (1980) on limited data. The isotopic compositions of D and 18O of meteoric waters in the Lassen region fall along a line defined by $\delta D = 8\ \delta^{18}O + 12$ (figure 6). This pattern largely reflects the prevailing south-southeast to north-northwest regional storm direction and is only locally affected by depletion of D and 18O with increasing elevation. Cold waters southwest of the LVNP near Mineral are significantly heavier than spring waters north of the thermal features.

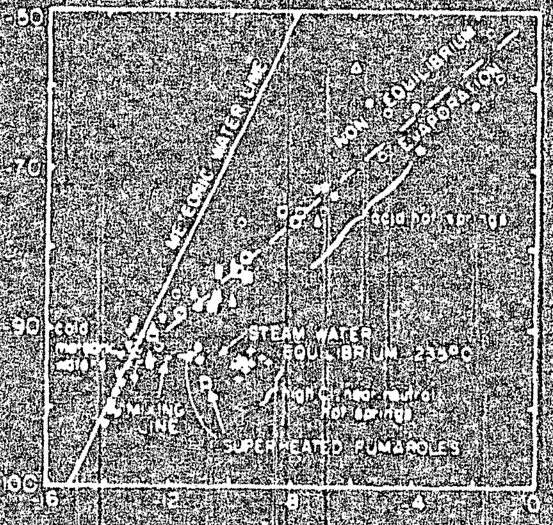

Figure 6.--Diagram showing relations between deuterium and 18O for water and steam samples from LVNP and vicinity. ● , Bumpass Hell; ◻ , Lower Little Hot Springs Valley; ☆ , Pilot Pinnacle and upper Little Hot Springs Valley; ○ , Sulphur Works; △ , Cold Boiling Lake; ▲ , Devil's Kitchen; ★ , Boiling Springs Lake; ■ , Terminal Geyser; + , Growler and Morgan Hot Springs; ▼ , meteoric water.

The thermal waters issuing from Morgan and Growler Hot Springs have δD values similar to meteoric waters on the andesitic composite cone, suggesting that recharge to the Lassen geothermal system occurs on the composite cone. These thermal waters exhibit an oxygen isotope shift of up to [illegible]°/oo due to water-rock isotopic exchange at high temperature.

If, as shown above, the most superheated steam from Bumpass Hell is derived directly from a 235°C vapor-dominated reservoir by adiabatic expansion, steam in the reservoir would have the same isotopic composition as the highest-temperature samples (average $\delta D = -93.4$ and $\delta^{18}O = -10.93$). The calculated composition of water in equilibrium with this steam at 235°C is $\delta D = -95.0$ and $\delta^{18}O = -9.09$ (data in Truesdell et al., 1977). These calculated values are very similar to those measured for Growler Hot Spring waters (average $\delta D = -94.6$ and $\delta^{18}O = -9.27$), indicating that the water of Growler Hot Spring is deep reservoir water mixed with only a minor amount of local meteoric water. A balance calculation based on the ^{18}O data indicates that the thermal component is about 93%. Morgan Hot Springs have $\delta^{18}O = -9.7$, which corresponds to 84% thermal water.

Waters from the acid-sulfate hot springs and drowned fumaroles define a line of nonequilibrium surface evaporation of steam at temperatures of 70-90°C (figure 6; Craig, 1963; Truesdell and Hulston, 1980).

Gas Geochemistry. Analyses of major gases from fumarole areas of LVNP are depicted on figure 7. The gas compositions can all be derived by two major near-surface processes that remove H_2S from a reservoir gas composition very near to the composition of gas from Big Boiler in Bumpass Hell. The first process is oxidation of H_2S either to pyrite (FeS_2) or to elemental sulfur without involving oxygen from air (either directly or dissolved in water). The second

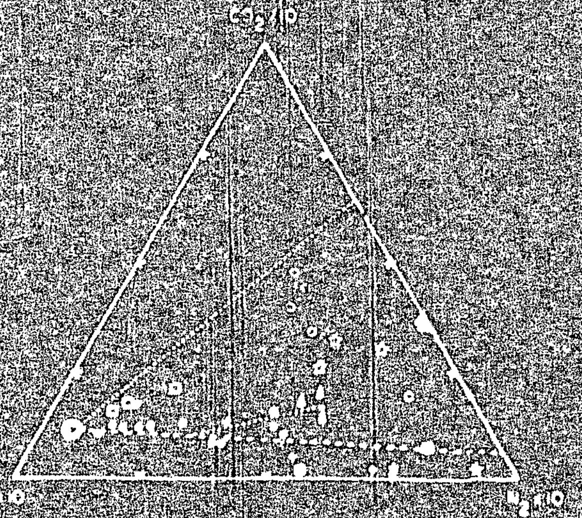

Figure 7.--Triangular plot of CO_2-H_2S-N_2 in gas samples from LVNP and vicinity. ✪, reservoir gas composition; ......, oxidation of H_2S to pyrite or elemental sulfur; - - - -, oxidation with air or air dissolved in water to produce sulfates; , near-surface addition of air without reaction with H_2S. See figure 6 for explanation of other symbols.

process involves oxidation with air or air dissolved in water to produce sulfates; this reaction is accompanied by admixture of N_2. The intersection of the lines representing these processes gives an estimate of the ratio of CO_2-H_2S-N_2 in the reservoir. The three samples plotting nearest the reservoir composition are from the hottest fumaroles in Bumpass Hell and Little Hot Springs Valley; all are over 125°C. The reconstructed composition of the gas in the vapor-dominated reservoir (from figures 5 and 7) is (in mol percent) CO_2, 92.7; H_2S, 6.6; H_2, 0.01; NH_3, 0.075; N_2, 0.6; Ar, 0.013; O_2, 0.0; and CH_4, 0.05; with a H_2O/gas ratio of 85 (figure 4).

Gases from Boiling Springs Lake, Terminal Geyser, Growler Hot Spring, and Morgan Hot Springs appear to originate from the hot-water reservoir rather than the vapor-dominated reservoir. High H_2O/gas ratios (2,000-4,000) and high H_2S/CO_2 ratios indicate that the water has previously been degassed by formation of a vapor phase at high temperature (235°C). When this degassed water approaches the surface and boils a second time, the steam that is formed is depleted in total gas and in CO_2 relative to H_2S (the latter because H_2S is more soluble in water than is CO_2).

Temperatures calculated using the gas geothermometer of D'Amore and Panichi (1980) are given in table 2. Within the uncertainties in the calculation (± 15°C), the temperature determined from the calculated reservoir gas composition is compatible with the 220-240°C calculated from Na-K, Na-K-Ca, and sulfate isotope relations for Growler Hot Spring waters. The temperatures from Little Hot Springs Valley and Bumpass Hell appear somewhat high, probably due to near-surface loss of CH_4. Temperatures from Sulphur Works and Pilot Pinnacle are somewhat low, apparently due to the great loss of H_2S (see figure 7).

Table 2.--Temperatures in °C calculated by the geothermometer of D'Amore and Panichi (1980) for gases from fumaroles and hot springs in LVNP and vicinity. Temperature for the reservoir is calculated from the reservoir gas composition given in the text.

Reservoir	Bumpass Hell	Little Hot Springs Valley	Sulphur Works
244	248	265	201

Pilot Pinnacle	Devil's Kitchen	Terminal Geyser	Growler Hot Spg
212	237	253	242

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A physical model for the Lassen geothermal system. New geologic, chemical, and isotopic data combined with thermodynamic and physical constraints on the production of superheated steam allow us to add considerable detail to the previously suggested model of the Lassen geothermal system as a central vapor-dominated reservoir underlain by hot water that discharges peripherally at lower elevations. The critical observations are:

1. Oxygen isotopic data suggest that recharge to the Lassen geothermal system is local and probably on the composite cone of Lassen volcanic center.
2. These data further suggest that the Morgan-Growler water and the Bumpass Hell superheated steam separated at about 235°C and have undergone little alteration in isotopic composition during passage to the surface.
3. Considerations of the H_2O/gas and H_2O/H_2 ratios and the temperatures of the superheated steam suggest that the highest temperature samples (mostly from Big Boiler at Bumpass Hell) consist of adiabatically decompressed samples of saturated 235°C reservoir steam with small (≤ 0.5%) additions of condensate from the top of the reservoir.
4. Gas chemistry suggests that this highest-temperature steam is the least altered sample of deep steam; gas equilibration temperatures are near 235°C.
5. Hot water compositions at Morgan and Growler Hot Springs give geothermometer temperatures of 220-240°C and show progressive dilution away from LVNP.

These observations support a model in which cold meteoric water from the composite cone of the Lassen volcanic center in LVNP flows underground and is heated by a cooling intrusion related to the silicic volcanic activity of the past 0.25 m.y. Geothermal liquid at approximately 235°C at depth boils to form an overlying vapor-dominated reservoir, steam from which leaks upward to feed the fumaroles in LVNP. Part of the geothermal water flows laterally to the south to feed the Morgan and Growler Hot Springs and to the southeast where it is encountered in the Walker "O" No. 1 well at Terminal Geyser. Most of the steam that flows to the thermal areas of LVNP mixes with local ground water to form acid hot springs, but some steam in relatively large conduits undergoes adiabatic decompression with small addition of deep or surface waters to form superheated fumaroles. Assuming boiling point-depth relations in the condensate layer, the top of the 235°C vapor-dominated reservoir is probably near 2,100 m elevation. The bottom of the vapor-dominated reservoir is roughly constrained by the elevation of the springs at Growler Hot Spring (1,570 m). This gives a thickness of the two-phase vapor-dominated zone at Lassen of only 500-600 m, comparable to parts of Larderello, Italy, but much thinner than the two-phase reservoir at The Geysers, California.

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mineral resource potential map
of the Three Sisters Wilderness,
Deschutes, Lane, and Linn Counties, Oregon

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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 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 Three Sisters Wilderness (NF083), Deschutes and Willamette National Forests, Deschutes, Lane, and Linn Counties, Oregon. The Three Sisters Wilderness was established by Public Law 88-577, September 3, 1964, and the Endangered American Wilderness Act (PL95-237), March 1, 1979.

SUMMARY STATEMENT

The Three Sisters Wilderness contains pumice deposits and may have geothermal resources; it has no known metallic-mineral or hydrocarbon deposits. Investigations indicate 900,000 tons of block pumice suitable for decorative stone and other commercial uses occur at Rock Mesa in the wilderness. A broad area centered around South Sister volcano is among the most geologically favorable localities for geothermal resources in the Oregon Cascade Range, based on the large volume of silicic volcanic rocks that occur in this area and the very young age of some of these rocks. However, no drill hole information is available with which to evaluate the existence or magnitude of the geothermal resource. The rare mineral osumilite, which occurs at a mining claim in the wilderness, is of interest to some mineral collectors.

INTRODUCTION

The Three Sisters Wilderness straddles the crest of the Cascade Range in Deschutes, Lane, and Linn Counties of central Oregon (fig. 1). It includes 245,302 acres in the Willamette and Deschutes National Forests. Established as a primitive area of 196,708 acres in 1937, it was classified as wilderness in 1957 and included in the National Wilderness Preservation System in 1964 (Public Law 88-577). Subsequently, the Endangered American Wilderness Act (Public Law 95-237) added another 48,594 acres, most of which was part of the French Pete Proposed Addition.

The U.S. Bureau of Mines spent 80 days in 1980 examining prospects and obtaining pan-concentrates of sediments from streams draining the Three Sisters Wilderness. The only previous detailed studies of the mineral resources dealt solely with the pumice deposits at the Hermana Group claims (fig. 2) and are described in U.S. Forest Service internal reports by Suchy (1963) and Ball (1972) and contracted reports by Richards (1972), Stoeser and Swanson (1972), Grant (1976), Magill (1976), and Kolberg (1976).

The U.S. Geological Survey mapped the geology of the wilderness in the summer and fall of 1978 and 1979 (Taylor and others, 1983) and conducted geophysical surveys in 1980 and 1981. There are no prior detailed geologic maps of the entire wilderness, although all of it has been studied in reconnaissance and some of it in detail. Prior studies of the wilderness and adjacent areas include: Williams (1944, 1957); Peck and others (1964); Taylor (1965, 1967, 1968, 1978, 1981); Anttonen (1972); Peterson and others (1976); Brown and others (1980); and Flaherty (1981). Gravity and aeromagnetic maps by Pitts and Couch (1978) and Couch and others (1978) include the wilderness area.

LOCATION AND GEOGRAPHY

The Three Sisters Wilderness is the southernmost of three nearly contiguous wilderness areas that occupy most of a 65-mile-long north-south stretch of the High Cascade physiographic province in central Oregon (fig. 1). A narrow corridor occupied by Oregon State Highway 242 separates the Three Sisters Wilderness from the Mount Washington Wilderness; the Mount Jefferson Wilderness is only a short distance farther north.

The Three Sisters Wilderness is approximately 45 mi east of Eugene and 30 mi west of Bend, Oregon (fig. 1). Access from Eugene is by Oregon State Highway 126 and Forest Service roads branching from it; access from Bend is by U.S. 20 and Oregon State Highways 46, 126, and 242 and by Forest Service roads branching from these highways. A 50-mile-long segment of the Pacific Crest National Scenic Trail extends north-south through the wilderness.

The wilderness is mostly in the High Cascade physiographic province of the Cascade Range (fig. 2). This section of the High Cascades consists of a volcanic highland that slopes gently east and west from the Cascade crest, typically at an elevation of about 6,000 ft; the western slopes are dissected by deep canyons. The Three Sisters (South Sister, 10,358 ft; Middle Sister, 10,047 ft; North Sister, 10,085 ft) and Broken Top (9,175 ft) are four large contiguous stratovolcanoes on this highland. No other part of the High Cascades contains such a cluster of stratovolcanoes, and the range is especially wide in this area. The western part of the wilderness (French Pete Addition) is in the Western Cascade physiographic province and is a mountainous terrain cut by deep canyons. Total relief in the wilderness is about 8,300 ft.

Higher areas of the wilderness around the four stratovolcanoes are above timberline, but the western areas are brushy and thickly forested, and the remainder is mostly open forest. Numerous lakes occur in the wilderness, especially in the southern half.

GEOLOGY

The Three Sisters Wilderness is underlain entirely by volcanic rocks of late Cenozoic age and sediments derived from them (Taylor and others, 1983). Gently dipping flows and pyroclastic rocks that crop out in the western part of the wilderness in the Western Cascade province are the oldest rocks. They have yielded K/Ar ages mostly between 10 and 16 m.y. (Flaherty, 1981; Priest and Vogt, 1982, Appendix A; R. A. Duncan, 1982, written communication); a few ages as young as 8 m.y. are probably a consequence of rock alteration. They are overlain by a discontinuous sequence of epiclastic sediments capped by flat-lying basalt and andesite flows. These flows, which form the tops of most ridges in the French Pete Addition, have yielded K/Ar ages of 6 to 10 m.y. (Flaherty, 1981; Priest and Vogt, 1982).

The High Cascade part of the Three Sisters Wilderness is formed of upper Pliocene, Pleistocene, and Holocene volcanic rocks, glacial deposits, and alluvium. The oldest rocks in this part of the wilderness are basalt and basaltic andesite flows exposed in deep canyons, such as along Separation Creek, that dissect the western side of the High Cascades (fig. 2). K/Ar ages of these flows range widely. Most of them are probably 1 to 3 m.y. old, but ages of as much as 8 m.y. have been obtained on some of them (Priest and Vogt, 1982, Appendix A). If the older determined ages are not due to contamination or initial inclusion of radiogenic argon, then some of these flows may correlate with the ridge-capping flows in the Western Cascade part of the wilderness. Pleistocene basalt and basaltic andesite flows younger than 2 m.y. are the dominant rock type in the wilderness. Basaltic andesite (53 to 58 percent SiO_2) is generally more abundant than basalt (less than 53 percent SiO_2) except in the lower parts of the pile. The flows are glaciated and commonly covered by a discontinuous veneer of glacial outwash and till. Vents, including cinder cones, small to large stratovolcanoes, and lava shields are abundant, especially near the axis of the range. The vents are variably glaciated. Some retain most of their original form, others are so deeply glaciated that little remains to indicate their location except for remnants of the core plugs and dikes that once laced them.

Intermediate and silicic volcanic rocks of Pleistocene age are interlayered with and overlie the more widespread flows of basaltic andesite and basalt in a broad region extending from Obsidian Cliffs (west of North Sister) southward to Kokostick Butte (south of South Sister) and eastward to the area surrounding Broken Top (fig. 2). They consist of andesite, dacite, and rhyodacite flows, domes, and pyroclastic rocks.

North Sister, Middle Sister, South Sister, and Broken Top stratovolcanoes are formed of interlayered thin flows and pyroclastic deposits and of dikes and plugs. They formed during the Pleistocene, probably during the last several hundred thousand years. Andesite flows and pyroclastic rocks, however, were erupted from the summit of South Sister during the Holocene. Active glaciers and large areas of permanent snowfield are present on the stratovolcanoes.

Holocene mafic and intermediate flows and related cinder cones and fissure vents are widespread in a broad area generally west of North Sister and south of South Sister and Broken Top. Some of these flows were erupted less than 2,600 years ago (Taylor, 1981).

Holocene silicic flows, domes, and pyroclastic rocks occur around the southern and eastern sides of South Sister. Rock Mesa is a thick stubby rhyodacite flow south of South Sister (fig. 2), and small domes and pyroclastic vent deposits occur less than one mile northeast. A belt of rhyodacite flows, domes, and pyroclastic deposits extends northward from State Highway 46 near Devils Hill up and across the east flank of South Sister. Pumiceous pyroclastic deposits related to the rhyodacite flows and domes are thick near the vents, but also occur as air-fall deposits that discontinuously veneer most of the southern and eastern parts of the wilderness. Carbon derived from peat deposits interlayered between these air-fall deposits have yielded ^{14}C ages of 2,000 to 2,900 years (Taylor, 1978; D. R. Mullineaux, 1979, written communication).

Considering the youthfulness of volcanic activity, the highlands around the four major stratovolcanoes likely will continue to have eruptions in the future. Three of the stratovolcanoes have not erupted during the Holocene and may have no future activity. South Sister has been active during the Holocene and is capable of future eruptions. The area around the Three Sisters and Broken Top is geologically similar to that of Mount Mazama before the climactic eruptions that produced Crater Lake (see Bacon, 1983).

Most rocks in the Three Sisters Wilderness are not tectonically deformed. The older volcanic rocks of the French Pete Addition are locally faulted, but the displacement is not large. A large north-south-trending east-dipping normal fault has been mapped adjacent to the wilderness in the vicinity of Horse Creek (fig. 2) near the boundary between the Western Cascade and High Cascade provinces (Flaherty, 1981). The Pliocene and Pleistocene basalt and basaltic andesite flows of the High Cascades province in the wilderness may bank against a fault line scarp, with the actual fault trace buried by flows younger than the fault. Faults were not observed in the High Cascades part of the wilderness. Alignments of vents may define the location of buried inactive faults, but are more likely a response to the regional stress field (Nakamura, 1977).

Younger rocks in the wilderness are mostly fresh; older rocks show variable alteration (clay minerals and zeolites) similar to that found in many other areas of the Western Cascade province. Hematite and limonite, and very rare pyrite, chalcopyrite, and malachite were noted along fractures in the volcanic rocks in vent deposits at scattered localities in the High Cascades. Similar alteration occurs at many other vents in the High Cascades and is interpreted to result from volcanic exhalative processes.

MINERAL RESOURCES

No resources of base or precious metals were identified in the Three Sisters Wilderness. The area contains no base- or precious-metal mines; the nearest mines, in the Blue River and Fall Creek districts 10 miles west of the wilderness, contain vein deposits of gold with some silver, copper, and lead (Brooks and Ramp, 1968). Thirteen base- or precious-metal claims have been staked within the wilderness; 12 of these are placer claims. The Pat Creek claim (fig. 3), located in 1969 by Marcus Jones and Joe Reynolds, is in a poorly exposed shear zone and contains trace gold and 0.4 oz silver/ton. The claim is apparently abandoned. The placer claims are located along streams in the wilderness.

As part of this mineral investigation, stream-sediment samples were collected from streams near the border of the wilderness and analyzed for their content of trace elements. Locations of the samples are shown on Figure 2 and the analyses are listed in Table 1; sample locations are unevenly distributed because of the paucity of streams in some areas. At each location two samples of fine sediment were collected, one of bulk sediment, the other a pan concentrate of the heavy-mineral fraction of the sediment. In the laboratory each sample was dried, sieved to minus-80 mesh, and split. The heavy minerals in the pan-concentrate samples were further concentrated by settling in bromoform (specific gravity, 2.8) and separated into magnetic and non-magnetic fractions.

Samples of stream sediments and non-magnetic heavy mineral concentrates were then pulverized before analysis by standard semiquantitative emission spectrography and by fluorimeter (U), Hg detector (Hg), and atomic absorption (Zn, Au). The analyzed sediments from steams draining the wilderness show concentrations of metallic elements similar to those commonly found in volcanic rocks. No anomalous concentrations of any elements were found. Gold was observed in trace amounts in pan concentrates from many streams, but it constitutes only a few parts per billion of the alluvium. 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.

Pumice deposits at the Hermana Group claims on Rock Mesa (fig. 3) are the only industrial mineral resource identified in the wilderness. The pumice occurs as an irregular blocky capping of the glassy rhyodacite flow that forms Rock Mesa. This deposit has never been mined, but has been studied in detail. The deposit contains 900,000 tons of commercial grade pumice, 50 percent of which is estimated to be recoverable (Richards, 1972; Grant, 1976). Pumice samples totaling 0.75 tons from the Hermana Group claims were examined during patent investigation. The pumice would be used primarily for decorative stone.

Magill (1976) recommended that mining be done at the Hermana Group claims with crane and bucket. He assumed a yearly production rate of 12,000 tons, equal to that at U.S. Pumice Company's Mono Craters, California deposit. Because of snowfall on Rock Mesa, mining would be done only during the summer. According to the company, the deposit would not be worked until after the deposit at Mono Craters is exhausted. The sale of 12,000 tons of pumice would be worth $1,155,960 at 1981 prices; operating costs would be $823,962 per year according to Magill (1976).

Other pumice deposits located between Devils Lake and Green Lakes (fig. 2) were examined, but the amount of block pumice at rhyodacite domes and flows there is small.

Specimens of the rare mineral osumilite from the Betsy Girl claim at Obsidian Cliffs (fig. 3) have been sold to Ward's Natural Science Establishment, Inc., Rochester, N.Y. The claim, located by M. M. Groben in 1977 and currently held by assessment work, is on a thick rhyodacite flow that contains black euhedral crystals of osumilite $[K(MgFe,Mn)_2(Al,Fe)_3(Si,Al)_{12}O_{31}]$ in vesicles. The crystals, mostly less than 0.1 inches in diameter, are of interest to some mineral collectors, but are not a major economic commodity.

Large amounts of cinders and stone occur in the wilderness, but numerous other deposits are closer to markets.

Hydrocarbon deposits (oil, gas and coal) do not occur within the Three Sisters Wilderness. Cenozoic volcanic rocks many thousands of feet thick underlie the wilderness and have no hydrocarbon potential.

The High Cascades physiographic province is an area of interest for geothermal exploration, but the magnitude of the geothermal resource is not known. Possible geothermal resources are suggested by the abundance of Quaternary volcanic rocks, relatively high heat flow, and hot springs.

The Belknap-Foley Known Geothermal Resource Area (KGRA) is just northwest of the Three Sisters Wilderness. Belknap Hot Springs and Foley Hot Springs (fig. 2) are about 5 mi from the wilderness and yield 25 to 75 gallons of water per minute with a temperature of 147° to 180°F

(Waring, 1965); other hot springs are a few miles farther west. Hot springs near the western edge of the High Cascade province are interpreted to be the result of lateral flow of warm or hot water from heat sources beneath the High Cascades (Blackwell and others, 1978; Black and others, 1982).

Several heat-flow holes have been drilled near the western border of the Three Sisters Wilderness. These have yielded temperature gradients of 147 to 332 °F/mi (Brown and others, 1980; Priest and Vogt, 1982, appendix D). No heat-flow holes have been drilled in the wilderness itself.

The geology of the Three Sisters Wilderness suggests that parts of it have a higher geothermal resource potential than most other areas in the Cascade Range. Geothermal resources in the range are likely to be of two general types. The first is a possible regionally extensive deep resource related to influx of mafic magma into the upper crust during the development of the young mafic volcanic pile that forms the range. This resource may be too deep for development using current technology. Also, even if hot rocks are present at exploitable depths, permeability and porosity may be too low to yield adequate hydrothermal fluids for conventional methods of electric power generation. This type of deep resource may occur along the axial part of the High Cascades province in the Three Sisters Wilderness, but may also be present in many other areas of the range outside the wilderness.

The second, and probably more important, geothermal resource type is related to large silicic magma bodies or still hot, but solidified, silicic intrusions. Silicic intrusive bodies commonly are larger in the shallow crust than are mafic bodies, and commonly are associated with developed geothermal resources in other areas in the world. Smith and Shaw (1975) consider areas of young silicic volcanic rocks to be the most favorable for geothermal resources. The Three Sisters Wilderness contains relatively abundant silicic volcanic rocks. Dacite and rhyodacite domes and flows are more common in a broad area centered around South Sister volcano than in any other part of the Oregon Cascade Range, with the possible exception of the Crater Lake area. Furthermore, the Holocene rhyodacite flows and domes on the south to east sides of South Sister volcano are the youngest rhyodacites known in the Oregon Cascades.

On the basis of the distribution of silicic volcanic rocks, a broad area around South Sister (fig. 3) is one of the most favorable targets for geothermal resources in the Cascade Range of Oregon. Without drill-hole data, the area of geothermal interest can only be rudely defined, and it is here delineated on the basis of distribution of silicic vents around North Sister, Middle Sister, South Sister, and Broken Top stratovolcanoes. The most geologically favorable site for geothermal resources in this area is on the south and east sides of South Sister where Holocene rhyodacite vents are located.

The Three Sisters area is one of three in Oregon estimated by Smith and Shaw (1979, Table 3) to have large amounts of available thermal energy and is among the most geologically favorable sites for geothermal resources in Oregon according to Priest and Vogt (1982). However, no holes have been drilled to determine temperature gradients in this area, nor is there other surface evidence, such as hot springs or extensive areas of hydrothermal alteration, that might indicate a potential resource.

If high temperatures are present in this area at exploitable depths, development could be hampered by two factors. First, the porosity and permeability of the rocks at depth may be so low that fluids may be insufficient for direct hydrothermal power production. If so, techniques for transport of heat at depth to surface generating facilities would have to be different than in existing geothermal fields where electric power is generated by direct or indirect use of geothermal fluids. Second, this area has had numerous Holocene eruptions and future eruptions can be expected. Eruption of silicic magma is commonly explosive and capable of destroying nearby structures, such as power generation plants.

In summary, geothermal resources may occur in the Three Sisters Wilderness, but available information confirms neither their existence nor magnitude. Nevertheless, a broad area centered around South Sister volcano is among the most geologically favorable targets for geothermal resources in Oregon.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

The principal known mineral resource in the Three Sisters Wilderness is pumice. The pumice deposits occur at Rock Mesa on the south side of South Sister. Availability of other sources of similar pumice and environmental concerns have inhibited their development.

On the basis of the abundance of young silicic volcanic rocks, a broad area around South Sister volcano is among the most geologically favorable areas for geothermal resources in Oregon. However, no drill data exists with which to evaluate this resource, if present.

The rare mineral osumilite, which occurs at Obsidian Cliffs, is of interest only to mineral collectors, is not a major commodity, and has low mining potential. There are no known precious- or base-metal deposits or hydrocarbon deposits in the Three Sisters Wilderness.

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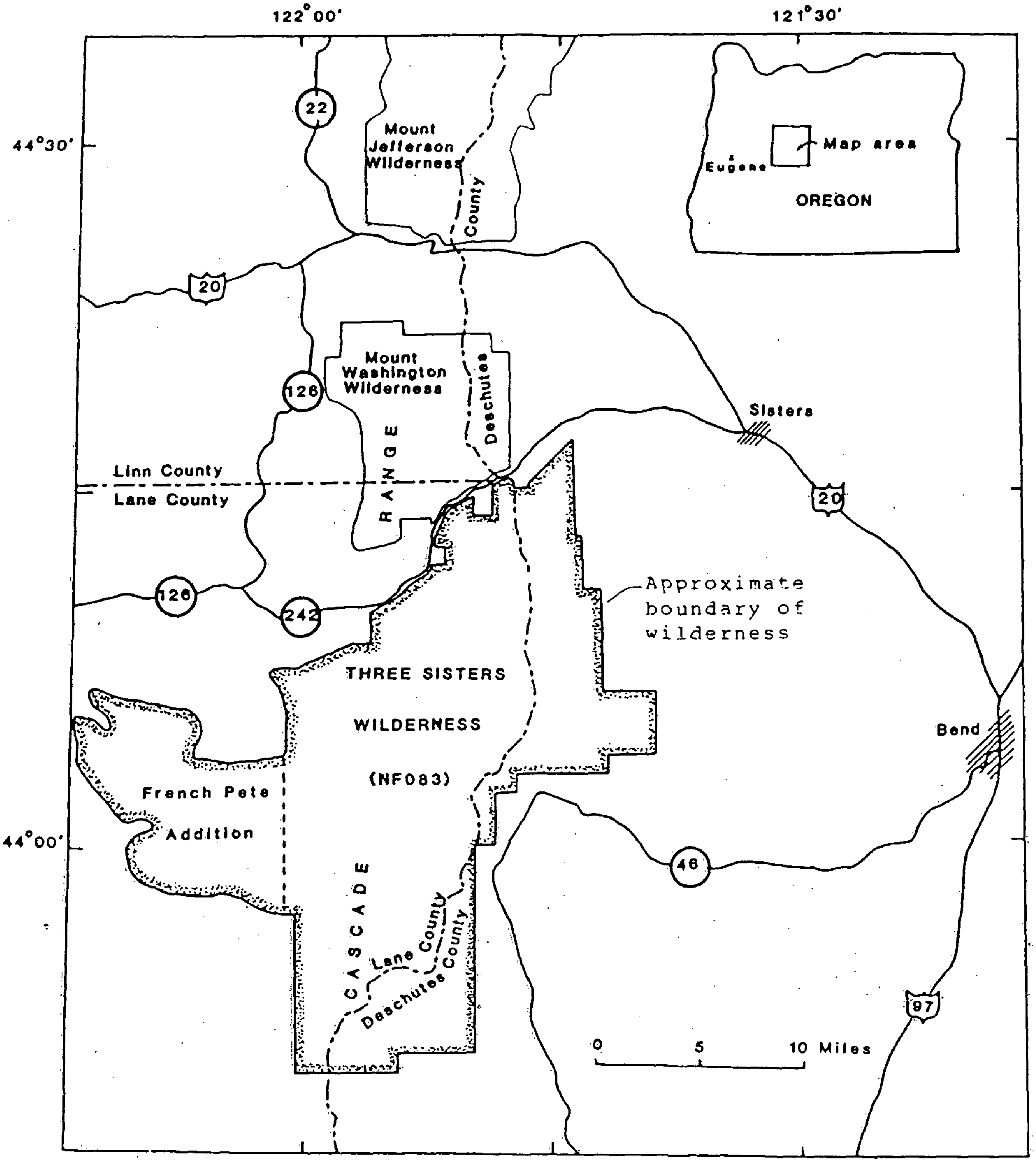

Figure 1. Map showing the location of the Three Sisters Wilderness, Deschutes, Lane, and Linn Counties, Oregon.

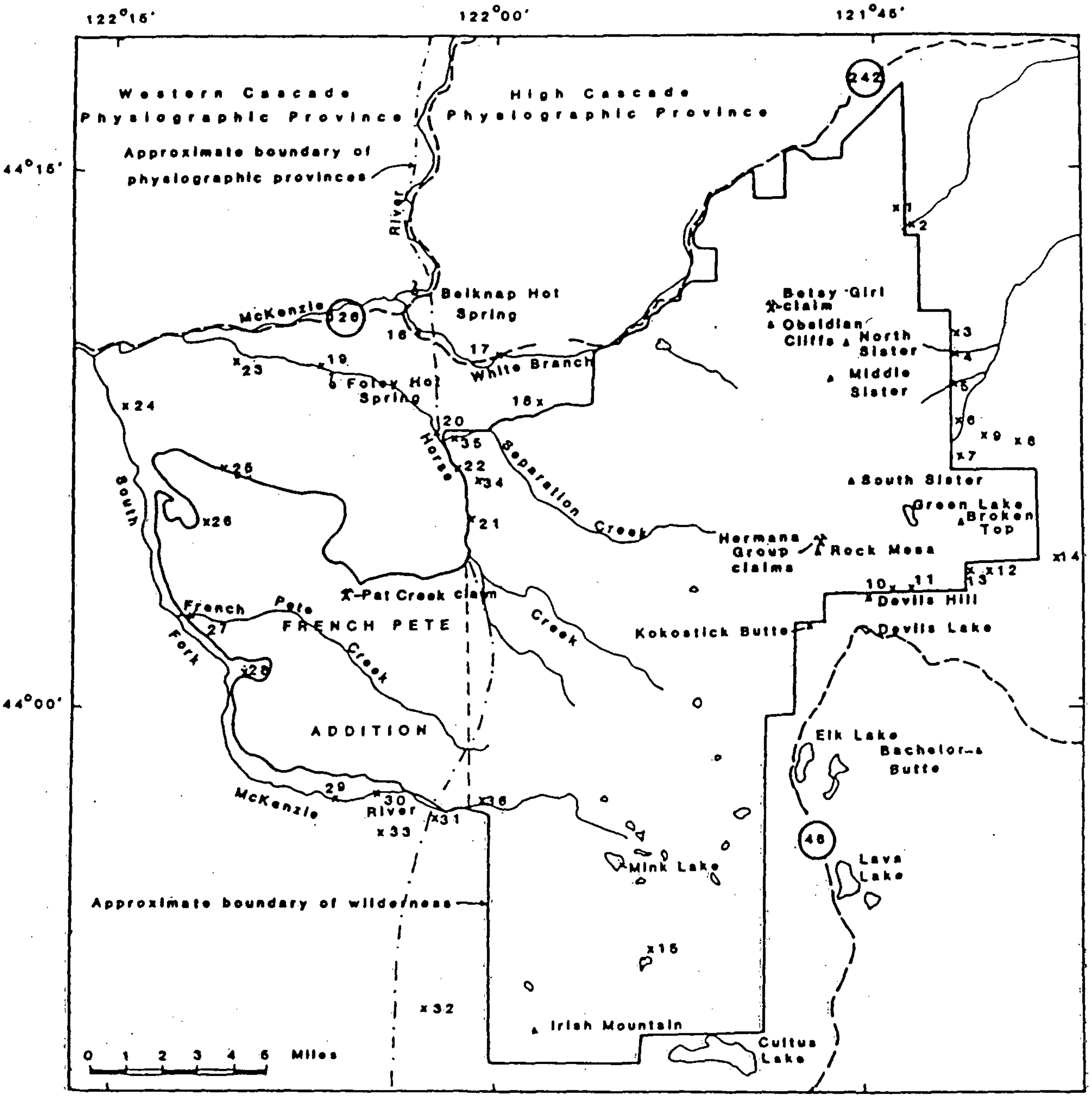

Figure 2. Map showing locations of geographic features in the Three Sisters Wilderness, Oregon, and locations (X) of analyzed stream-sediment samples for which analyses are listed in Table 1.

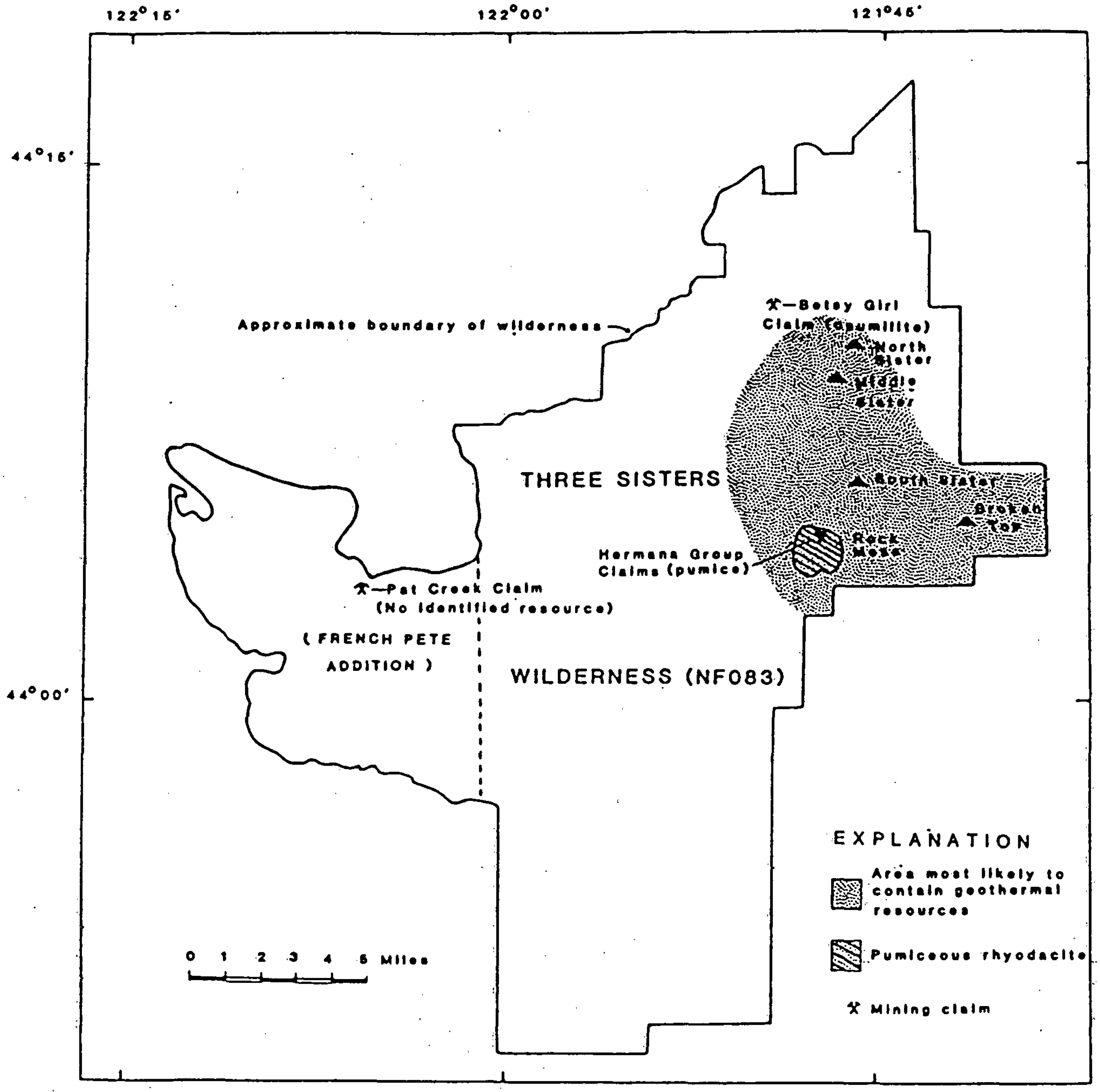

Figure 3. Mineral resource potential map of the Three Sisters Wilderness, Deschutes, Lane, and Linn Counties, Oregon.

Table 1. Analytical data for stream-sediment samples from Three Sisters Wilderness, Oregon. Sample locations are shown on Figure 2. Analyses are by C. Forn, B. Arbogast, and J. Viets, U.S. Geological Survey, 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 concentrate)

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
MTS8- 1	1	5	1.5	2	0.3	1000	15	300	20	500	100	20	30	L	20	500	300	20	50	45	-	-
MTS8- 2*	1	7	10	2	.3	2000	L	150	200	700	15	L	1000	20	20	N	100	L	20	65	0.24	0.04
MTS8- 3	2	7	2	3	.3	1000	10	700	30	500	100	20	100	10	20	500	300	20	50	35	-	-
MTS8- 4*	2	7	10	1.5	.2	2000	L	100	150	700	15	L	700	L	15	N	50	L	L	60	.23	.02
MTS8- 5	3	5	2	5	.3	1000	10	700	20	500	100	20	70	L	20	500	200	15	50	20	-	-
MTS8- 6*	3	7	10	0.2	.05	1500	L	100	100	500	10	L	700	L	L	N	20	L	L	80	.28	N
MTS8- 7	4	7	2	7	.5	1000	10	1000	30	150	150	20	30	L	30	700	300	30	70	15	-	-
MTS8- 8*	4	7	10	3	.2	3000	L	200	100	500	70	L	300	20	30	N	100	L	100	75	-	-
MTS8- 9	5	7	2	2	.5	1000	10	1000	20	100	30	20	20	L	20	300	300	20	50	15	-	-
MTS8-10*	5	10	7	5	1	3000	L	150	50	500	30	L	70	20	50	N	200	L	20	15	.42	N
MTS8-11	6	10	2	2	.7	1500	L	700	70	150	100	L	30	L	30	300	1000	20	30	30	-	-
MTS8-12*	6	7	7	5	.7	3000	L	150	50	200	20	L	100	L	50	N	200	L	L	10	.27	N
MTS8-13	7	5	2	5	.5	1000	20	1000	20	500	70	20	70	L	20	500	200	20	50	20	-	-
MTS8-14*	7	5	7	3	.2	3000	L	300	70	1000	15	L	300	L	30	N	100	L	L	30	.33	.04
MTS8-22	8	7	3	3	.5	1000	10	1000	50	500	100	L	150	10	20	500	300	20	50	30	-	-
MTS8-23*	8	10	10	1.5	.2	3000	L	150	150	1000	15	L	700	20	20	N	50	L	20	55	.33	.02
MTS8-24	9	5	2	5	.5	1000	15	700	20	200	100	20	70	L	20	500	200	30	50	30	-	-
MTS8-25*	9	7	10	2	.2	5000	L	700	70	700	50	L	300	20	20	N	100	L	L	40	.24	.26
MTS8-26	10	5	1.5	1	.3	1000	10	1000	15	150	10	20	20	L	10	300	200	15	50	20	-	-
MTS8-27*	10	7	7	3	.5	5000	L	200	50	500	15	L	150	50	50	N	150	L	50	15	.34	.02
MTS8-28	11	7	2	3	.5	1500	20	1000	20	200	50	20	50	15	20	500	300	20	70	30	-	-
MTS8-29*	11	7	10	5	.5	3000	L	150	50	700	20	L	500	20	30	N	150	L	20	30	.35	L
MTS8-30	12	5	2	5	.3	1500	L	700	30	700	100	20	100	10	15	500	200	20	30	25	-	-
MTS8-32	13	5	2	7	.5	1000	15	1000	30	300	100	20	70	10	20	700	200	20	50	20	-	-
MTS8-33*	13	7	7	2	.3	3000	L	300	50	1000	50	L	200	20	30	N	150	L	L	30	.25	.35

Table 1. Continued

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
3S-013A	28	15	5	1.5	.7	2000	10	100	30	500	70	N	150	L	30	100	300	15	30	70	-	-
3S-013B*	28	5	7	1.5	.2	1000	L	50	50	700	15	N	700	N	30	L	100	15	30	40	.3	N
3S-014A	29	5	3	1.5	.3	1500	10	100	30	700	70	N	100	15	30	150	150	15	30	75	-	-
3S-014B*	29	3	5	7	.3	1000	L	50	20	1500	30	N	150	50	70	70	150	15	15	15	.1	N
3S-015A	30	7	3	1.5	.7	2000	L	100	30	500	70	N	150	L	20	200	200	15	30	90	-	-
3S-015B*	30	5	7	1.5	.2	1000	L	50	50	700	15	N	700	N	15	L	50	10	10	70	.2	L
3S-016A	31	5	5	2	.5	1500	10	200	30	500	70	N	150	L	30	300	150	15	30	85	-	-
3S-016B*	31	7	7	2	.3	1500	L	70	30	1000	20	N	700	L	20	100	100	10	15	55	.2	L
3S-017A	32	7	5	1	.3	1500	L	50	30	300	20	N	100	L	20	L	70	15	30	85	-	-
3S-017B*	32	7	7	2	.5	1500	L	70	50	1000	30	N	700	20	30	150	100	15	20	60	.5	.02
3S-018A	33	7	5	3	.5	1500	10	150	30	500	70	N	100	L	20	300	200	15	30	60	-	-
3S-018B*	33	5	7	5	.3	1500	L	50	30	1000	20	N	150	N	50	150	100	15	30	35	.2	L
3S-019A	34	7	5	1.5	.7	1500	10	150	30	500	70	N	150	L	20	200	200	20	50	75	-	-
3S-019B*	34	7	7	3	.3	1500	L	50	50	1000	30	N	500	N	30	L	150	15	30	80	-	.04
3S-020A	35	10	5	1.5	.7	2000	10	70	30	300	70	N	100	L	30	100	300	15	30	70	-	-
3S-020B*	35	5	3	1.5	.5	700	L	300	30	500	70	N	200	N	30	L	70	10	50	60	.4	.10
3S-021A	36	7	5	1.5	.3	1000	10	100	30	500	70	N	200	L	15	300	100	15	30	65	-	-
3S-021B*	36	7	5	1	.3	700	L	50	50	700	30	N	700	N	20	L	70	10	20	65	.3	L
Lower limit of detection:		.05	.02	.05	.002	10	10	20	5	10	5	20	5	10	5	100	10	10	10	10	.1	.02

Analyzed for but below limit of detection (indicated as ppm in parentheses): antimony (100), arsenic (200), beryllium (1), bismuth (10), cadmium (20), gold (0.1), molybdenum (5), silver (0.5), thorium (100), tin (10), and tungsten (1).

Table 1. Continued

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
MTS8-34	14	5	1.5	2	.3	1000	L	1000	20	200	70	20	50	10	20	500	200	30	50	40	-	-
MTS8-35*	14	5	10	1	.2	2000	L	300	50	700	20	L	300	20	15	N	50	L	20	60	.35	.45
MTS8-40*	15	7	2	5	.7	1000	L	700	30	500	70	L	70	10	20	700	300	15	30	25	-	-
MTS8-41	15	5	2	3	.5	1000	20	700	20	700	50	20	50	10	15	500	200	15	30	35	-	-
3S-001A	16	7	5	1.5	.7	2000	L	100	30	200	50	N	100	L	15	200	100	15	30	45	-	-
3S-001B*	16	7	7	1.5	.3	1500	L	70	30	700	50	50	300	10	15	150	70	15	30	100	1.4	.02
3S-002A	17	7	7	1.5	.5	1500	L	150	30	150	50	N	150	L	15	300	100	15	30	55	-	-
3S-002B*	17	7	7	1	.2	1500	L	50	50	500	20	N	700	50	15	100	50	10	20	90	.4	.02
3S-003A	18	7	5	1.5	.7	1500	L	70	30	200	30	N	70	L	20	150	150	15	30	70	-	-
3S-003B*	18	5	5	3	.3	1500	L	50	30	700	50	N	200	N	30	200	100	15	30	50	.6	L
3S-004A	19	10	5	1.5	.7	2000	10	70	30	300	50	N	70	L	30	L	300	15	30	50	-	-
3S-004B*	19	7	5	3	.3	1500	L	70	30	500	20	N	150	N	50	100	100	15	30	25	.3	N
3S-005A	20	10	5	1.5	.5	2000	10	70	30	150	30	N	70	L	30	L	200	15	30	35	-	-
3S-005B*	20	7	5	3	.5	2000	L	100	30	700	20	N	150	N	30	100	100	15	30	50	-	L
3S-006A	21	10	5	2	.7	3000	10	100	30	300	70	N	70	L	30	100	300	15	30	45	-	-
3S-006B*	21	5	5	3	.3	2000	L	70	30	500	30	N	150	N	30	150	100	15	30	35	-	N
3S-007A	22	10	5	1.5	.7	2000	10	100	30	500	70	N	100	L	30	100	300	15	30	90	-	-
3S-007B*	22	7	7	3	.3	1500	L	70	30	700	30	N	300	N	30	100	150	15	50	60	.2	.02
3S-008A	23	10	3	1.5	.7	2000	10	50	30	300	70	N	70	L	30	N	300	15	30	35	-	-
3S-008B*	23	5	5	2	.5	2000	L	50	30	150	30	N	70	N	30	L	100	15	30	15	.1	N
3S-009A	24	15	5	1.5	.7	2000	10	70	30	500	70	N	70	L	30	N	500	15	30	60	-	-
3S-009B*	24	7	5	2	.3	2000	L	50	30	200	30	N	100	15	30	L	150	15	30	15	.2	.04
3S-010A	25	10	5	1.5	.7	2000	10	70	30	300	70	N	70	L	50	N	300	15	30	50	-	-
3S-010B*	25	5	5	3	.5	1500	L	70	30	150	30	N	150	N	30	L	70	15	30	25	.1	N
3S-011A	26	10	5	1.5	.5	1500	10	100	30	500	70	N	150	L	30	150	150	15	30	95	-	-
3S-011B*	26	7	7	2	.3	1500	L	70	50	700	30	N	500	N	30	L	150	15	20	75	.4	.02
3S-012A	27	10	5	1.5	.5	1500	10	70	30	300	50	N	100	L	20	L	300	15	30	85	-	-
3S-012B*	27	5	5	2	.2	1500	L	70	30	700	30	N	500	N	30	L	70	15	20	45	.2	N

Lakeview Mtn
Intrusive

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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1983

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.

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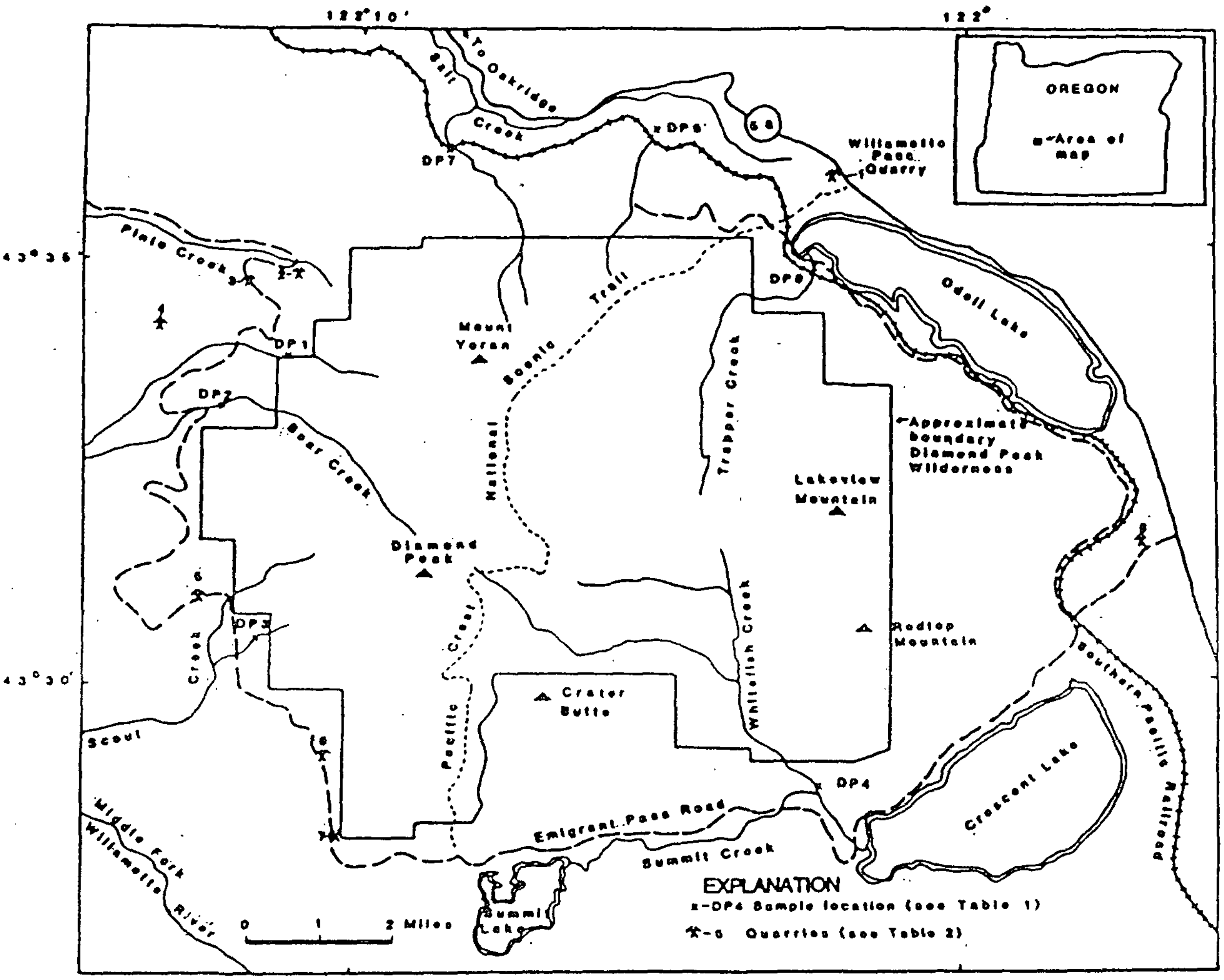


Figure 1. Location of the Diamond Peak Wilderness (NF017), Cascade Range, Lane and Klamath Counties, Oregon.

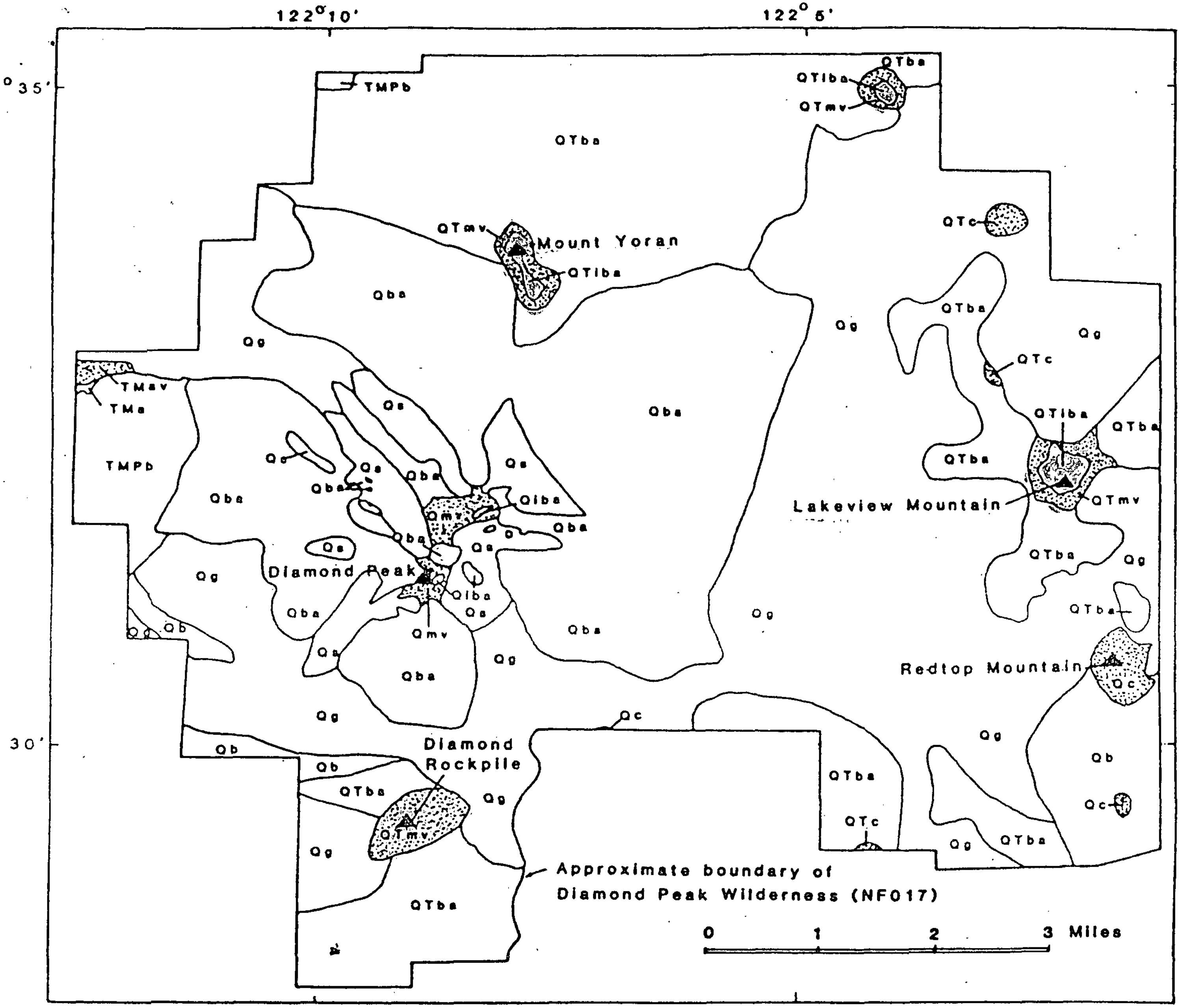
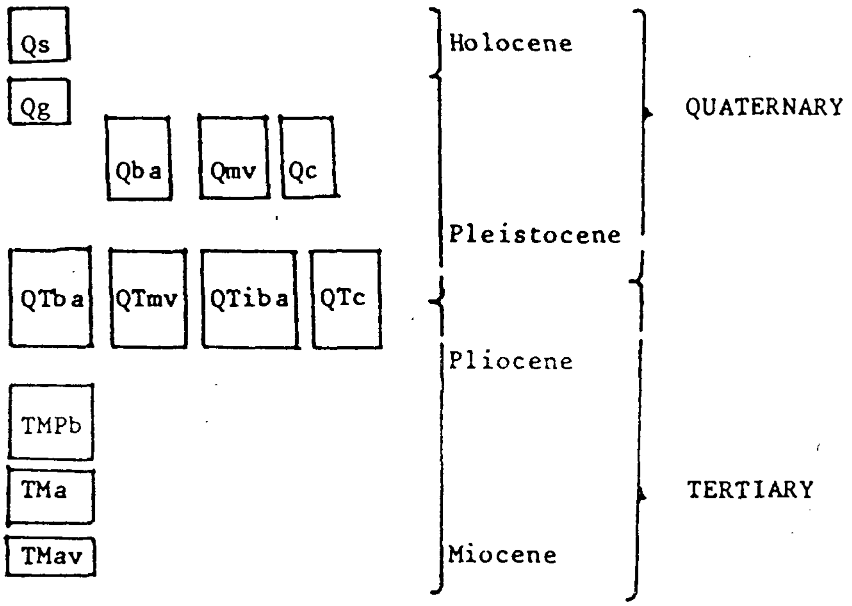


Figure 2.--Geologic map of the Diamond Peak Wilderness, Oregon. Geology by David R. Sherrod, 1981, 1982.

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).

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geology and mineral resource potential map of the Mount Washington Wilderness, Deschutes, Lane, and Linn Counties, Oregon

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1983

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 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 Mount Washington Wilderness (NF086), Deschutes and Willamette National Forests, Deschutes, Lane, and Linn Counties, Oregon. The Mount Washington Wilderness was established by Public Law 88-577, September 3, 1964.

SUMMARY

The Mount Washington Wilderness is devoid of mines, claims, and mineral prospects. The results of this survey further indicate that the area does not contain any metallic-mineral deposits or mineral fuels. Over 200 million yd^3 of cinder resources occur in the wilderness, but no future demand for the deposits is anticipated owing to numerous other nearby sources. The area may have geothermal resources, but available data are insufficient to define either their existence or magnitude.

INTRODUCTION

The Mount Washington Wilderness (fig. 1) encompasses 46,655 acres (73 mi^2) along the crest of the Cascade Range, between McKenzie and Santiam Passes, in the Deschutes and Willamette National Forests, 32 mi northwest of Bend, Oregon.

The mineral resource potential survey of the Mount Washington Wilderness included geologic mapping, a geochemical survey of stream-sediment samples, and gravity and aeromagnetic surveys by the U.S. Geological Survey. The U.S. Bureau of Mines was responsible for analysis and evaluation of identified mineral resources in the wilderness.

Large scale geologic maps of the Mount Washington Wilderness have not been published previously, although the geology of parts of the wilderness is presented by Taylor (1968, 1981) and most of the area in theses by Brown (1941) and Taylor (1967). Reconnaissance geologic maps of the central part of the Cascade Range by Williams (1957) and of Deschutes County by Peterson and others (1976) include the area. Regional gravity anomaly and aeromagnetic maps, which cover the Mount Washington Wilderness, have been published by Pitts and Couch (1978), Couch and others (1981), and U.S. Geological Survey (1982). Results of geothermal gradient drilling immediately west of the wilderness are discussed by Youngquist (1980).

LOCATION AND GEOGRAPHY

The Mount Washington Wilderness is the smallest of three nearly contiguous wilderness areas that occupy most of a 65-mile-long north-south segment of the High Cascade Range in central Oregon (fig. 1). The wilderness is separated from the Three Sisters Wilderness, to the south, by the narrow corridor along the McKenzie Highway (Oregon State Highway 242), and from the Mount Jefferson Wilderness, to the north, by a wide corridor occupied by the Santiam Highway (U.S. 20). Access to the Mount Washington Wilderness is provided by these highways and by gravel roads that lead from them. The crest of the Cascade Range has a thick snowpack in winter and the McKenzie Highway is not passable from late fall to late spring; the Santiam Highway is an all-weather road. The Pacific Crest National Scenic Trail extends north-south through the wilderness.

The nearest town is Sisters, 12 mi east of the wilderness. Hoodoo Butte, 3 mi north of the wilderness, is the site of a small ski resort. Dee Wright Observatory, at McKenzie Pass, is a popular tourist stop for spectacular views of stark young lava flows, Mount Washington, and the Three Sisters stratovolcanoes.

Mount Washington, rising to an elevation of 7794 ft, is one of the smaller of the stratovolcanoes that form the prominent peaks of the Cascade Range in Oregon. Other volcanoes in the wilderness are all small, ranging from cinder cones a few tens of feet high to broad lava cones, such as Belknap Crater, which rises about 1600 ft above the surrounding terrain. The lava platform on which the volcanoes rest, mostly at an elevation of 4000 to 5000 ft, slopes gently westward to the McKenzie River and merges eastward with the Deschutes Plateau.

GEOLOGY

The Mount Washington Wilderness is in the High Cascade physiographic province of the Cascade Range, Oregon. This province is a narrow north-south-trending belt of Pliocene and Quaternary lava flows and related cinder cones and fissure vents that is studded by large stratovolcanoes spaced at irregular intervals. Most of the volcanic rocks in this belt were erupted during the last four million years. Faults bound the High Cascades both east and west of the Mount Washington Wilderness (Williams, 1957; Brown and others, 1980; Taylor, 1981). The graben resulting from these faults has been filled by flows and related vent deposits that comprise the Mount Washington Wilderness. The oldest part of the sequence is composed dominantly of basalt, and younger, overlying rocks are basalt and basaltic-andesite (fig. 2). Although andesite and more silicic volcanic rocks occur both south and north, they do not crop out in the wilderness.

All rocks within the wilderness are Quaternary in age. With the exception of the oldest flows at the westernmost margin of the wilderness, all flows show normal magnetic polarity and thus are likely less than 0.7 m.y. old. The flows and vents are readily divisible into Pleistocene and Holocene sequences.

The Pleistocene flows are glaciated and commonly covered by several feet of ground moraine or outwash deposits. These older flows were derived from cinder cones, fissure vents, and small composite volcanoes which have been modified by glacial scouring; in the cores of some cones the feeder dikes and plugs are exposed.

Mount Washington is a glacially-gutted Pleistocene stratovolcano composed of basaltic andesite flows and pyroclastic rocks (cinders, scoria, palagonite tuff, and breccia). A plug forms the summit and the upper flanks are cut by a north-south-trending swarm of basaltic andesite dikes. Mount Washington has no Holocene flows or pyroclastic rocks and probably is no longer active. The volcano is similar in erosional form to

Mount Thielsen farther south in the Cascade Range, which has yielded a K/Ar age of 0.3 m.y. (J. G. Smith, oral coummunication, 1983).

Glacial deposits within the wilderness consist mostly of ground moraines and glacial outwash. Terminal, recessional, and lateral moraines are locally present, but are better developed east and west of the wilderness. Most glacial deposits in the wilderness formed during the last major glacial advance (Cabot Creek glaciation of Scott, 1977) in the late Pleistocene. Older glacial deposits beyond the wilderness probably formed during the earlier Jack Creek glaciation of Scott (1977). Holocene neoglacial deposits occur locally on Mount Washington.

Holocene flows cover approximately half of the Mount Washington Wilderness and extend beyond it several miles to the northwest and south. Few other areas in the Cascade Range have such areally extensive young flows. Earlier flows from individual vents are commonly basalt, and later flows basaltic andesite. Charcoal from beneath many of the flows has yielded ^{14}C ages of about 1,500 to 3,000 ^{14}C years (Taylor, 1965, 1981). The rugged surfaces of flows are mostly free of vegetation, but even the youngest flows where covered by cinders from nearby vents have trees growing on them. The flows were erupted from a series of alined cinder cones and composite vents that probably were fed by enechelon fissures. The cinder cones are typically 150 to 300 ft high and consists of gray to red cinders, scoria, and agglutinate (welded spatter). The largest of the volcanic edifices is Belknap Crater, a lava shield with summit cinder cone.

MINERAL RESOURCES

No evidence of metallic-mineral deposits was found in the Mount Washington Wilderness. The young volcanic rocks of the High Cascade province in Oregon, of which the wilderness is a part, have no known deposits of metallic minerals. The wilderness has no recorded mineral production, mining districts, or claims. The nearest mines (for gold, silver, copper, and lead) occur in older rocks of the Western Cascades about 20 miles west of the wilderness in the Blue River District (Brooks and Ramp, 1968).

As part of this mineral investigation, stream-sediment samples were collected from small intermittent streams near the border of the wilderness and analyzed for their content of base metals and other elements. Sample locations are shown on Figure 2 and analytical data given in Table 1. Two samples of sand- and silt-size sediment were collected at most sites, one of bulk sediment, the other a pan-concentrate of the heavy-mineral fraction of the sediment. Pan-concentrate samples could not be obtained from some streams owing to the paucity of fine sediment. In the laboratory 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 for 31 elements. The analyzed sediments from streams draining the wilderness show concentrations of metallic elements similar to those commonly found in basaltic volcanic rocks. No anomalous concentrations of any elements were found.

The only mineral resource identified by this study is volcanic cinders. Estimates of the minimum volume of cinders at cinder cones within the wilderness are: Belknap Crater - 75 million yd^3; Twin Craters - 15 million yd^3; Scott Mountain - 20 million yd^3; Sand Mountain Craters - 50 million yd^3. An additional 50 million yd^3 may be obtained from other small cinder cones. Cinders are presently being quarried from deposits that occur near the wilderness. Little Nash Crater, about 4 mi north of the area, supplies about 80,000 yd^3 of cinders per year for local use in road construction. An estimated 30 million yd^3 remain at this site. Some past production has been reported from a source near Little Cache Mountain, 1.5 mi northeast of the wilderness. Because large quantities of cinders are more accessible elsewhere, utilization of cinder deposits from within the wilderness is unlikely. "Lava rock" for building stone is of low quality even though the study area is extensively covered with basalt and basaltic andesite flows. Building stone is abundantly available in other nearby areas which are closer to markets.

Hydrocarbon deposits, such as oil, gas and coal, do not occur within the wilderness. Upper Eocene to Pliocene volcanic rocks, similar to those exposed in the adjacent Western Cascades, underlie the Pleistocene and Holocene flows and vents of the Mount Washington Wilderness. The volcanic rocks have a thickness of many thousands of feet and have no hydrocarbon potential.

The High Cascade province of the Cascade Range in Oregon is of interest for geothermal exploration, but the magnitude of the geothermal resource is not known. Hot springs are rare in the High Cascades, but occur locally along or just beyond its margins, particularly on the west side. The hot springs emerge mostly along valley floors and commonly occur along or near faults. Belknap Hot Springs, about 4 miles southwest of the wilderness, yields about 75 gallons of water per minute with a temperature of 180°F (Bowen and Peterson, 1970). These hot springs are interpreted to be the result of lateral flow of hot water from heat sources beneath the High Cascades (Blackwell and others, 1978). No hot springs, fumaroles, or recently active thermal areas exist within the wilderness. The lava flows and interbedded breccias and other pyroclastic rocks are so permeable and porous that shallow lateral flow of cold ground water probably masks any deep geothermal anomalies that may exist.

Scattered relatively shallow heat flow holes drilled mostly along the margins of the High Cascades suggest that this part of the Cascade Range has higher than normal heat flow (Blackwell and others, 1978; Riccio, 1979). The nearest geothermal drill hole is about 2 mi northwest of the wilderness and yielded a temperature of only 77°F at a depth of 1837 feet (Youngquist, 1980). Owing to the paucity of deep holes drilled within the High Cascades, it is not possible to realistically extrapolate possible geothermal potential on the basis of results of deep drilling in similar environments. The areally extensive Holocene basalt and basaltic andesite flows of the Mount Washington area may lead to falsely optimistic estimates of geothermal resources. These flows are derived mostly from alined vents that likely are the surface manifestations of buried feeder dikes. In areas of intensive glaciation in the Cascade Range where surface rocks are deeply eroded, most exposed basaltic feeder dikes are only 3 to 10 ft wide. The dikes for the Holocene flows in the

Mount Washington Wilderness likely did not contribute major amounts of heat to the shallow crust and this heat likely has been lost by conduction and ground water flow since they formed. In contrast to the Mount Washington area, some parts of the High Cascade province contain relatively abundant silicic rocks. These areas likely have a higher geothermal potential because silicic intrusive bodies commonly are larger in the shallow crust than are mafic bodies (Smith and Shaw, 1975). Other areas in the world where geothermal resources are associated with basaltic volcanism, such as Iceland and Hawaii, have much greater rates of lava production than in the Mount Washington Wilderness.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

More than 200 million yd^3 of cinder resources occur in the wilderness. No future demand for these cinders is anticipated because other large unmined deposits are more accessible. There is no evidence of a potential for metallic mineral resources, building stone, or mineral fuels.

Geothermal resources may occur in the wilderness, but available information is insufficient to confirm their existence or magnitude. The High Cascade province is a favorable geologic environment for geothermal resources, but few deep holes have been drilled from which meaningful extrapolations of potential can be made. The most favorable areas within the High Cascades are likely those in which there are abundant young silicic rocks, none of which occur in the Mount Washington Wilderness.

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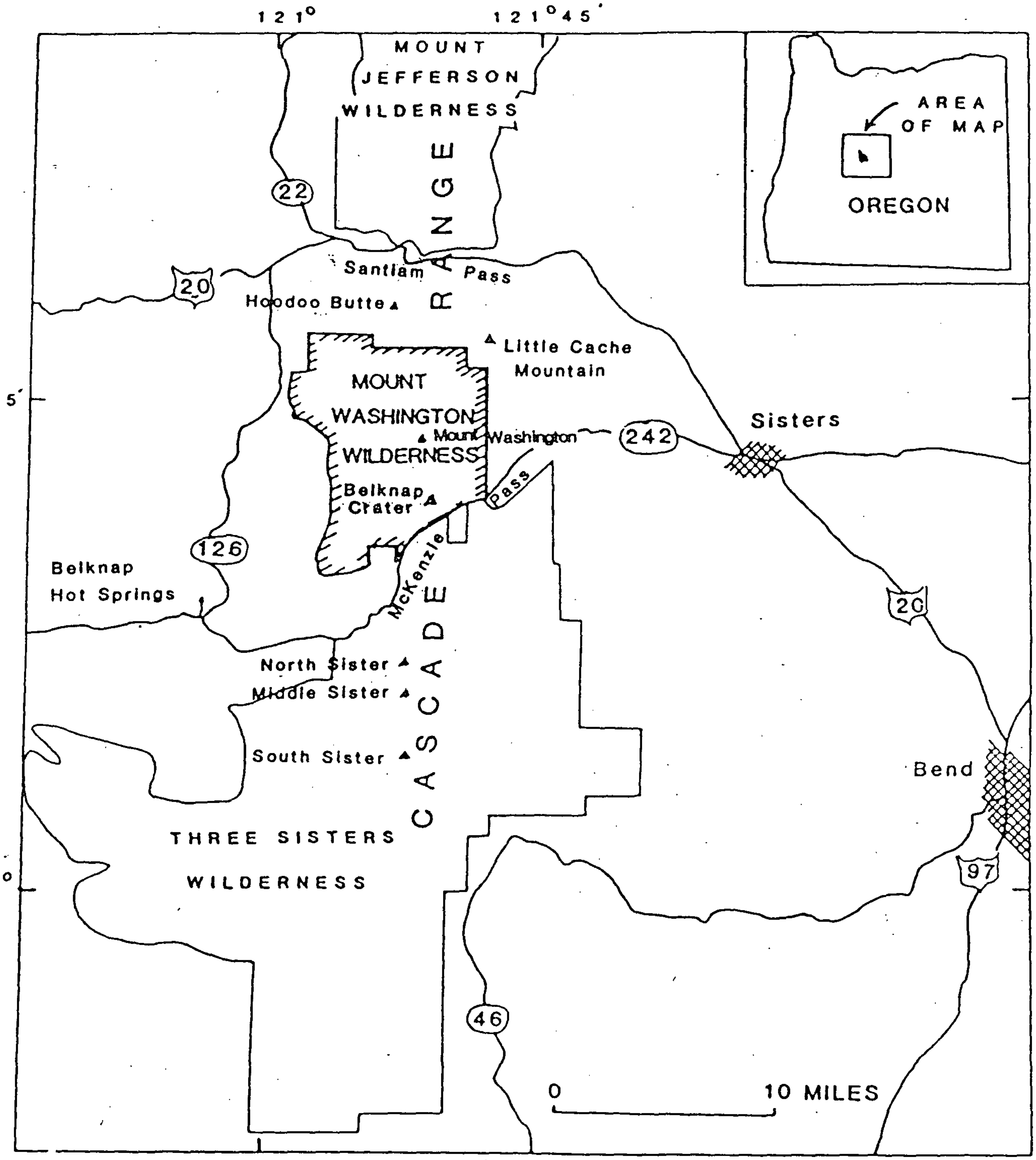
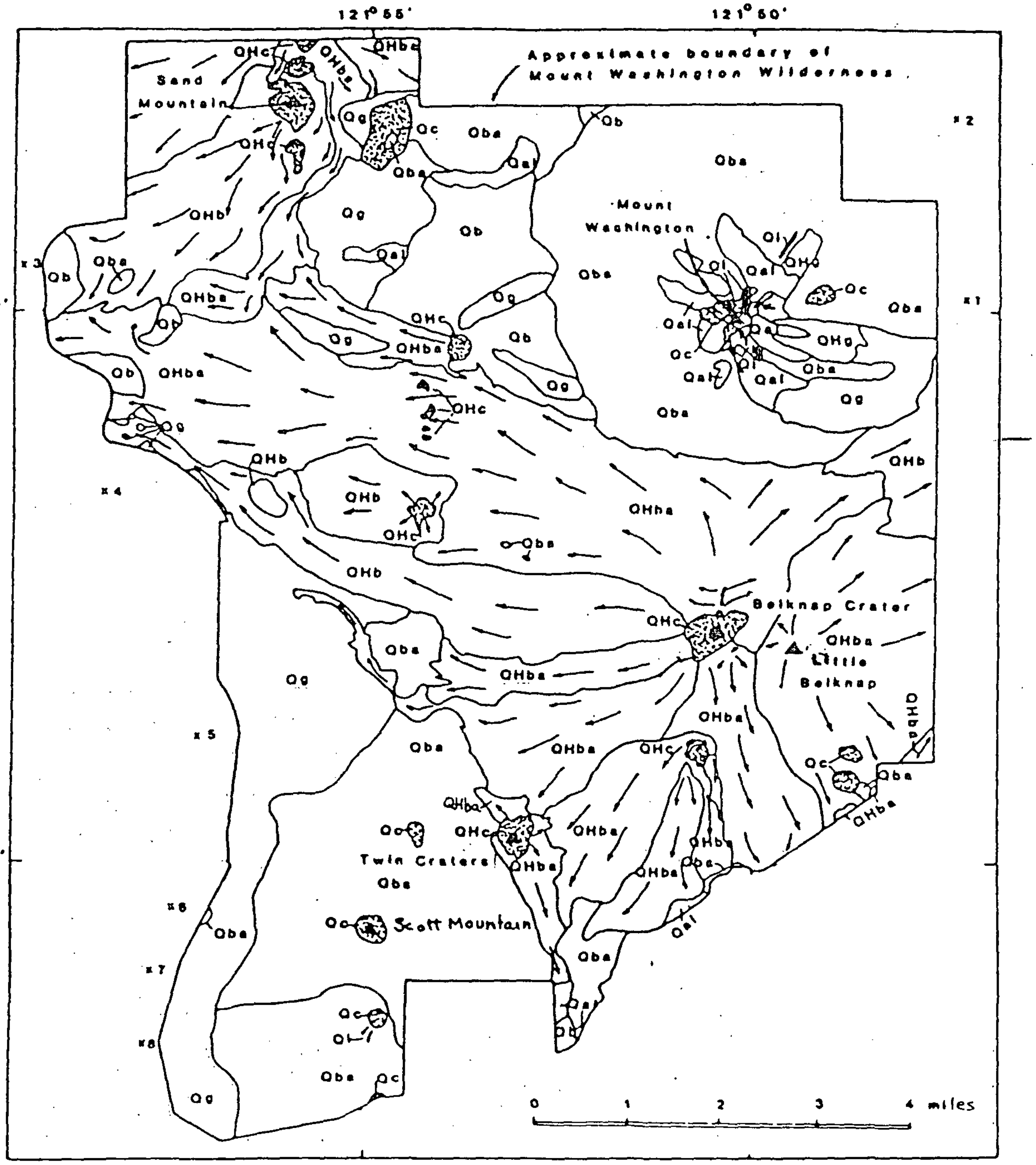
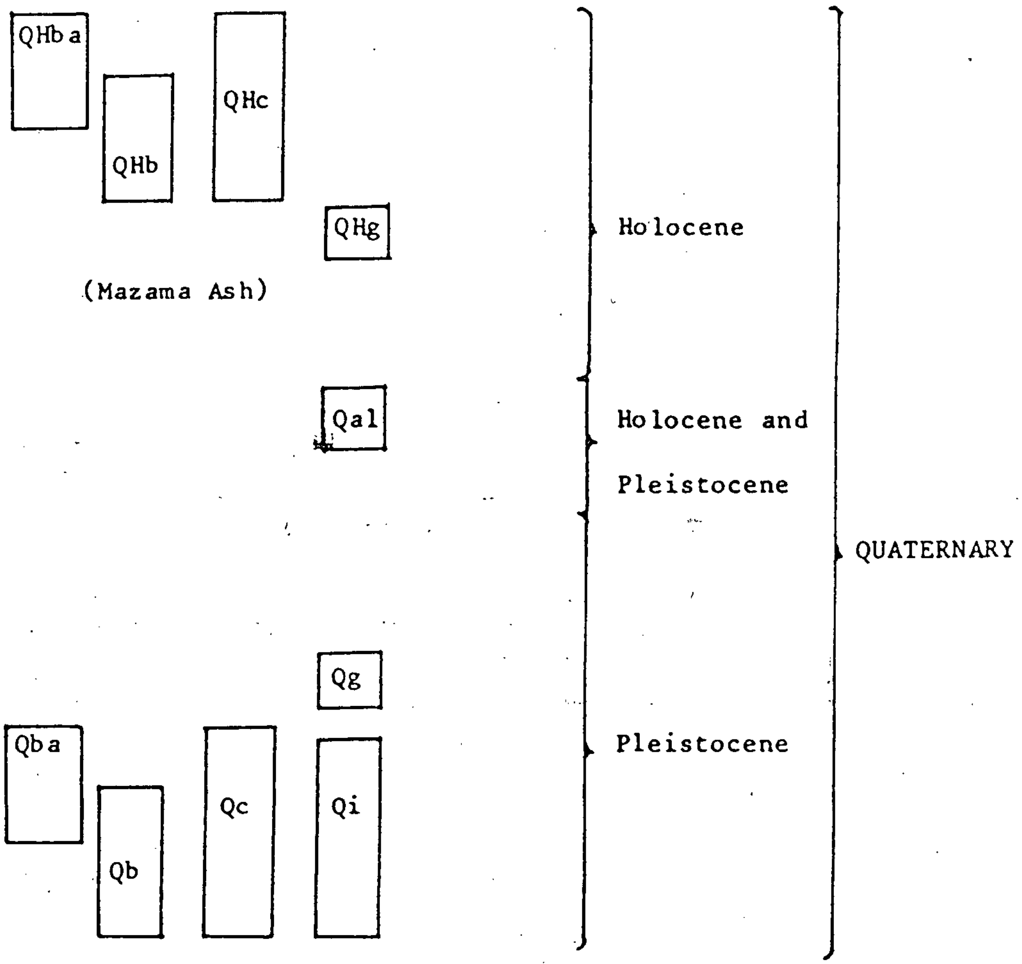


Figure 1.--Location of the Mount Washington Wilderness (NF086) in the Cascade Range, Deschutes, Lane, and Linn Counties, Oregon.


121°55'
121°50'
44°20'
44°15'
Approximate boundary of Mount Washington Wilderness
Sand Mountain
Mount Washington
Belknap Crater
Little Belknap
Twin Craters
Scott Mountain
QHc
QHb
QHba
QHha
QHg
Qb
Qba
Qg
Qc
Qal
Ql
x 1
x 2
x 3
x 4
x 5
x 6
x 7
x 8
0
1
2
3
4 miles

EXPLANATION FOR FIGURE 2

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

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

QHba YOUNGER BASALTIC ANDESITE FLOWS (HOLOCENE)--Fresh, unglaciated basaltic andesite flows derived from vents at Belknap Crater, Little Belknap, south of Belknap Crater, Twin Craters, unnamed vents southwest of Mount Washington, and Sand Mountain cinder cone chain. Younger than the Mazama ash, except those from unnamed vents southwest of Mount Washington. Age of 1,500 to 3,000 ^{14}C years on basis on dates of carbonized vegetation from beneath flows (Taylor, 1968, 1981)

QHb YOUNGER BASALT FLOWS (HOLOCENE)--Fresh, unglaciated basalt flows derived from vents at Belknap Crater, unnamed cinder cones northwest of Belknap Crater, and Sand Mountain cinder cone chain. Younger than the Mazama ash. Flows from Sand Mountain chain of vents are 3,000 - 3,800 ^{14}C years old (Taylor, 1981)

QHc YOUNGER CINDER DEPOSITS (HOLOCENE)--Rudely bedded bombs, blocks, lapilli, and ash of basalt or basaltic andesite composition which form cinder cones and fissure vent deposits

QHg YOUNGER GLACIAL DEPOSITS (HOLOCENE)--Terminal and lateral moraines on Mount Washington. Consists of deposits from both neoglacial and active glaciation

MAZAMA ASH (HOLOCENE)--Unit not shown on map. Pumiceous air-fall ash deposit derived from climactic eruption of Mount Mazama (Crater Lake) about 90 mi south of map area. Thin discontinuous deposit; forms useful time marker with which

	to distinguish relative ages of young deposits. ^{14}C age is about 6,845 years (Bacon, 1983)
Qal	UNCONSOLIDATED ALLUVIUM (HOLOCENE AND PLEISTOCENE)--Glacial outwash, fluvial sand and gravel, and talus deposits
Qg	OLDER GLACIAL DEPOSITS (PLEISTOCENE)--Terminal, lateral, recessional, and ground moraines composed of angular to subrounded cobbles and boulders in a poorly sorted sand- to clay-size matrix. Probably formed during the Cabot Creek glaciation of Scott (1977)
Qba	OLDER BASALTIC ANDESITE FLOWS (PLEISTOCENE)--Nearly aphyric to moderately porphyritic basaltic andesite. Glaciated. Includes flows on the flanks of Mount Washington
Qb	OLDER BASALT FLOWS (PLEISTOCENE)--Nearly aphyric to moderately porphyritic basalt; commonly diktytaxitic. Glaciated.
Qc	OLDER CINDER DEPOSITS (PLEISTOCENE)--Bombs, blocks, lapilli, and ash of basalt or basaltic andesite composition in well preserved to deeply eroded cinder cones. Locally invaded by dikes (unit Qi) of similar composition. Deposits near summit of Mount Washington include palagonite tuff
Qi	INTRUSIVE ROCKS (PLEISTOCENE)--Basalt and basaltic andesite dikes, small plugs, and irregular shaped bodies associated with eroded vents at Mount Washington and southwest corner of map area.

∼	CONTACT-- Approximately located
⬭	VENT DEPOSITS
→	FLOW DIRECTION OF HOLOCENE LAVA FLOWS
x 4	STREAM SEDIMENT SAMPLE SITE (Analyses listed in Table 1)

Table 1. Analyses of stream-sediment samples from the Mount Washington Wilderness, Oregon. Analyses were performed by G. W. Day, U.S. Geological Survey, Denver, Colorado. Sample locations are shown on Figure 2. (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 analyses of non-magnetic heavy-mineral sample)

Field No.	Map No. (fig. 2)	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr
MW1A*	1	7	5	5	1	1500	L	1500	100	500	L	N	700	200	L	1000	200	L	7000
MW1B	1	10	10	20	1	5000	70	700	50	500	150	30	150	30	30	2000	200	50	200
MW2A*	2	5	5	10	0.2	1500	20	300	100	200	15	N	200	20	10	1500	70	L	1500
MW2B	2	10	10	20	1	3000	70	700	50	200	100	30	100	30	30	2000	200	30	200
MW3A*	3	5	2	3	.7	1000	L	700	10	200	L	N	150	N	20	1000	150	L	1000
MW3B	3	10	5	15	1	3000	50	500	30	200	100	30	100	50	15	1000	200	30	200
MW4B	4	10	2	10	1	2000	70	500	30	200	100	30	100	20	15	700	500	30	200
MW5B	5	10	10	10	1	3000	50	500	50	200	100	30	100	20	20	700	200	30	200
MW6B	6	15	10	10	1	2000	70	500	50	300	150	30	100	50	20	700	300	30	200
MW7A*	7	5	5	5	.3	1500	L	1500	50	200	100	N	300	70	L	1500	70	N	700
MW7B	7	10	10	10	1	2000	30	500	50	300	150	20	150	15	15	500	200	30	200
MW8A*	8	1	0.5	5	.2	300	L	500	N	N	10	N	150	L	L	1500	20	N	150
MW8B	8	10	10	10	1	3000	50	700	70	300	150	20	200	30	15	700	200	30	200
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 (ppm indicated in parentheses): antimony (100), arsenic (200), beryllium (2), bismuth (20), cadmium (50), gold (10), molybdenum (10), niobium (50), silver (1), thorium (200), tin (10), tungsten (100), and zinc (200)