



# **Springs on and in the vicinity of Mount Hood volcano, Oregon**

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## Abstract

Chemical and isotopic data are presented for nonthermal, thermal, and slightly thermal springs and drill holes and fumaroles on Mount Hood, Oregon. Temperatures of nonthermal springs on Mount Hood decrease with elevation and are similar to air temperatures from nearby weather stations. Dissolved constituents in nonthermal springs generally increase with spring temperatures and reflect weathering of volcanic rock from the action of dissolved carbon dioxide. Isotopic contents of nonthermal springs follow a local meteoric water line and generally become lighter with elevation. Some nonthermal springs at low-elevation have light values of isotopes indicating a high-elevation source for the water. Three hydrothermal systems have been identified on Mount Hood. Swim Warm Springs is interpreted to have a source water that boiled from 187°C, re-equilibrated at 96°C, and then mixed with nonthermal water to produce the range of compositions found in various springs. The Meadows Spring is interpreted to have a source water that boiled from 223°C, re-equilibrated at 94°C, and then mixed with nonthermal water to produce the range of compositions found in the spring over several years. Both systems contain water that originated as precipitation at higher elevation. The summit fumaroles have gas geothermometer temperatures generally over 300°C, indicating that they are not the steam discharge from the Swim and Meadows hydrothermal systems. Representative values of thermal discharge for the three hydrothermal systems are 10 MW<sub>t</sub> for the fumaroles, 2.2 MW<sub>t</sub> for Swim, and 1.9 MW<sub>t</sub> for the Meadows and Cascade springs.

## Introduction

The Mount Hood edifice occupies a long-lived focus of andesitic volcanism that has been active for the past 1.5 m.y. (Wise, 1969; Scott and others, 1997). The present-day cone is made up of lava flows and volcaniclastic deposits. Most volcanic activity in the past 50 kyr has consisted of the growth and collapse of lava domes and the eruption of lava flows on the summit and upper flanks (Scott and others, 1997). Three eruptive periods have been recognized in late-glacial through Holocene time (Crandell, 1980; Cameron and Pringle, 1986, 1987; Scott and others, 1997): 1) Polallie, 20 -13 ka; 2) Timberline, 1500-1700 yr B.P. (1950 C.E. is present); and 3) Old Maid, 1760-1810 C.E. Minor historical activity has been reported for Mount Hood in 1859, 1865, and 1907 C.E. (Crandell, 1980; Scott and others, 1997). The Polallie eruptive period coincides with and postdates the last major Pleistocene glacial advance in the area, called the Evans Creek advance by Scott and others (1997). Between Polallie and Timberline periods, the Parkdale basaltic andesite flow (7680 yr B.P.) was erupted low on the volcano's north flank, in the upper Hood River valley (Crandell, 1980). The Old Maid eruptive period probably commenced with the emplacement of a near-summit dacite dome, the remnant of which still can be seen as Crater Rock high on the volcano's south flank. One of Mount Hood's thermal features is the fumarolic area near Crater Rock.

Springs on Mount Hood were sampled by Wollenberg and others (1979); however, the reported analyses were incomplete, and inspection of topographic maps indicates that there are more springs than were reported on by Wollenberg and others (1979). This study was initiated to visit additional springs and assess if there were additional sources of thermal

water beyond that identified at Swim Warm Springs and the summit fumaroles. After finding anomalous specific conductance and temperature at the Meadows Spring and finding that there were springs not shown on the topographic maps (but usually located where a stream started on the map), an attempt was made to find springs and to measure specific conductance of streams to locate other anomalies (Table 1 and Figure 1). Although a significant amount of the mountain was visited to look for water with significant conductivity anomalies, it is very likely that there are additional unidentified springs on the mountain.

In studying the characteristics of springs, it is important to be clear on the terminology (Nathenson and others, 2003). A special class of springs known as *thermal springs* are ones "whose water has a temperature appreciably above the mean annual temperature of the atmosphere in the vicinity of the spring (Meinzer, 1923, p. 54.)." Meinzer does not define *appreciable*. Meinzer (p. 55) goes on to state that: "*Nonthermal springs* may be divided into (1) those whose waters have temperatures approximating the mean annual temperatures of the atmosphere in the localities in which they exist, and (2) those whose waters are appreciably colder." The second group of nonthermal springs are *cold springs*. Waring (1965, p. 4) agrees with Meinzer that any spring that "is noticeably above the mean annual temperature of the air at the same locality may be classed as thermal" but uses 15°F (8.3°C) above mean annual temperature of the air to define thermal springs in the United States. Reed (1983, p.2) in the U.S. Geological Survey's assessment of low-temperature geothermal resources of the United States uses a minimum temperature function that is 10°C above the mean annual temperature at the surface and increases with depth by 25°C/km to define low-temperature geothermal resources. In most situations, the question of using a numerical temperature criterion for thermal springs is not important, because measured temperatures are sufficiently anomalous. In the Cascade Range, however, large quantities of cold ground water mix with thermal water making the magnitude of the temperature anomalies very small (e.g. Nathenson, 1990). To cover this situation, the term *slightly thermal springs* is introduced for springs that do not meet the numerical criterion of Reed (1983), but have temperatures greater than nonthermal springs in the area and usually also have dissolved constituents normally found in thermal waters (Nathenson and others, 2003).

Nonthermal springs were sampled to provide temperature, specific conductance, and chemistry data to differentiate nonthermal springs from slightly thermal and thermal springs. An additional topic is the identification of salt applied to the Palmer snow field that was detected in some nonthermal springs. Isotopic data for nonthermal springs make it possible to develop isotope-elevation relationships to estimate recharge elevations for deeply circulating nonthermal springs and thermal springs. Gas analyses from the literature and unpublished data are presented to estimate reservoir temperatures for the summit fumaroles.

## General characteristics of springs

In order to discuss temperature data for springs, data for mean annual air temperatures from weather stations (National Oceanic and Atmospheric Administration, 1997a and b) within a two degree of latitude by two and half degree of longitude block centered on Mount Hood (Figure 2) are plotted versus station elevation (Figure 3). The mean annual air temperatures are the "normal" values for the period 1961 to 1990. (Because normal values are not listed in the tables, they are obtained from the published data

tables by subtracting the listed departure from normal from the mean annual temperature for the year of the table.) Air temperatures are mostly determined by station elevation (Figure 3) with some variability about this relationship. Using least-squares correlation with temperature as the dependent variable, the slope of the correlation line shown in Figure 3 is  $-0.00437 \pm 0.00038$  °C/m and the intercept is  $11.6 \pm 0.2$ °C (standard errors of the mean).

Temperatures of springs in the nonthermal and Palmer springs groups are generally cooler than air temperatures (Figure 3) though close enough to air temperatures to be categorized as nonthermal springs rather than cold springs. Crystal, Lolo Pass, and Rogers springs are cooler than the trend of other nonthermal springs. Crystal, Lolo Pass, and Rogers springs have relatively high flow rates (Table 1), and their lower temperatures could reflect high elevation recharge with flow channeling into discrete channels in the subsurface preventing solar heating as the water flows to lower elevations. Parkdale Cold Spring is in the vicinity of Crystal and Rogers springs and has a relatively high flow rate, but its temperature follows the trend of other nonthermal springs. Temperatures for the Meadows Spring (but not the East Meadows Spring) and the Cascade Spring are higher than the air temperature-elevation line and will be shown below to have a component of thermal water. Temperatures for Swim Warm Springs are too high to plot on the scale of Figure 3.

Specific conductance of the nonthermal springs is linearly related to the measured spring temperature (Figure 4). This behavior reflects weathering of volcanic rock by the action of dissolved carbon dioxide (e.g. Nathenson and Thompson, 1990). Palmer and Still Creek springs and Phlox Point spring box are above the trend, and their behavior is discussed below with their chemistry. Meadows, East Meadows, and Cascade springs are also above the trend and will be shown below to have a component of thermal water.

Data for water chemistry of previously collected samples and those collected in this study are given in Tables 2 and 3, and locations are given in Figure 5. There are some concerns regarding the quality of the early data, and the more modern data will generally be used. However, the older data are included so that unpublished isotopic data can be made available. For the data set in Wollenberg and others (1979), only nonthermal water samples with isotopic data have been included. The data for some of the nonthermal springs are shown in a modified Schoeller diagram in Figure 6. Amounts of chloride and sulfate are about what one would expect in precipitation (e.g. Nathenson and Thompson, 1990). The major anion is bicarbonate from dissolved carbon dioxide reacting with minerals in volcanic rock to produce dissolved silica and cations (Nathenson and Thompson, 1990). Thus the variation of specific conductance with temperature reflects the variation of bicarbonate concentration with temperature.

Data for the rest of the nonthermal springs are given in Figure 7 along with the spring tributary to the Zigzag River for reference and the Salmon River sampled near Palmer Springs. Chloride in these springs range from 3.7 to 17.1 mg/L, well above what would come from precipitation. The Timberline Ski area applies approximately 500,000 kg of sodium chloride to the Palmer snowfield and associated areas between an elevation 1800 and 2600 m primarily during the summer months to condition snow (Mt. Hood National Forest, 1999, 2000, 2001). The data for the Salmon River at the Palmer Springs (just above Timberline Trail) collected in August, 1999 reflect snow melt including applied sodium chloride. During that visit, snow covered additional springs in the area that feed the Salmon River, and only the main Palmer Spring was visible and sampled. The concentrations of sodium and chloride were much lower in the spring sample than in river water. Concentrations of silica and other constituents in the Salmon River samples, except for sodium and chloride, are much lower than in spring samples (Figure 7) as one would expect

from passage of water over a stream bed in contrast to reaction with rock underground. Given the appearance of anomalous chloride and associated sodium in the Palmer Spring, the data for the other springs shown in Figure 7 and comparison with data shown in Figure 6 for other springs indicates that the source of chloride in the Still Creek and Phlox Point springs is probably also snow melt with applied sodium chloride. Figure 8 shows sodium versus chloride for these springs along with the data for the Salmon River and Zigzag River and Cloud Cap Campground springs for reference. One model is that both sodium and chloride found in the samples are produced by dilution. Even though sodium should be added by the reaction of dissolved carbon dioxide with minerals in the subsurface, this model assumes that such reaction does not take place. Another model is that water with dissolved sodium chloride mixes with a normal spring water such as that found in the spring near the Zigzag River. Most of the samples appear to follow the dilution model. The Still Creek spring sample has a lower sodium than predicted by the dilution model and would seem to require sodium exchange for calcium and/or magnesium. Additional features at Palmer Springs found in 2001 were measured for temperature and specific conductance (Table 1), and their behavior is reasonably similar. The Salmon River in 2001 only contained water from these various features with the channel above Palmer Springs completely dry. Thus the spring-fed flow in 2001 of 7 L/s of 81.5  $\mu\text{S}/\text{cm}$  water is a small fraction of the flow in 1999 of around 100 L/s of  $\approx 400$   $\mu\text{S}/\text{cm}$  of snow melt.

Additional information on the characteristics of nonthermal springs and background for discussion of thermal springs is provided by the isotopic data. Figure 9 presents the light-stable isotope data (reported as per mil deviations from VSMOW (Gonfiantini, 1978)). One snow sample is beyond the range of the plot. The intercept of the meteoric water line has been adjusted to best fit the data not including the snow samples or the sample from the Pucci well. The data from Wollenberg and others (1979) are shown as a separate group, and they are consistent with data from this study. The data are plotted versus elevation in Figures 10 and 11. The isotopic composition of precipitation decreases (more negative values) with increasing elevation (Dansgaard, 1964). Assuming that some springs are recharged at elevations only somewhat above their discharge elevations, the samples having the highest deuterium and oxygen-18 values for a given elevation are used to define the lines for local precipitation (fitted by eye) in Figures 10 and 11 (Ingebritsen and others, 1992; Rose and others, 1996). Part of the fitting process involves making the lines consistent with the local meteoric water line of Figure 9. The slope of the oxygen-18 line is -1.7 ‰/km, somewhat less than the value of -2.3 ‰/km found by Rose and others (1996) for the area north of Lassen Peak but close to the slope found for Mount Shasta of -1.4 ‰/km (Nathenson and others, 2003). The snow samples are lighter than the line based on the spring samples, and they may not be a good indicator of recharge-elevation for springs because of their year-to-year and seasonal variability. The snow sample at 2652 m is displaced 9 ‰ in deuterium from the local meteoric water line based on its oxygen-18 content, but its low value compared to the isotope elevation line may indicate that the line has a much more negative slope above some elevation.

Some of the springs are significantly lighter in isotopic composition compared to the isotope-elevation line, indicating that the water fell as precipitation and probably recharged the ground-water system at higher elevations. Crystal and Parkdale springs both have isotope values significantly lighter than the isotope-elevation line, and their indicated recharge elevations are approximately 1600 m and 1400 m. The Robin Hood Quarry Spring sampled by Wollenberg and others (1979) may also have high-elevation recharge, but it drains the mountains east of Mount Hood and could have a somewhat different

isotope-elevation line. Swim Warm Springs has a range of isotopes from the mixing of warm and nonthermal water (see discussion below), and the lightest isotopes are consistent with high elevation recharge. The Meadows springs contain a component of thermal water, and the values are somewhat lighter than the isotope-elevation line but not by a large amount. One of Wollenberg and others (1979) samples was collected from one of the Meadows springs and plots close to them. The spring near the Cascade has very similar isotopes to the Meadows Springs but is at a much lower elevation. It will be shown below that the spring near the Cascade is chemically very similar to the Meadows springs.

The Palmer Spring at 1865 m elevation is on the isotope-elevation line, indicating relatively local recharge. Although the Salmon River sampled in 1999 at the same elevation had much higher sodium and chloride concentrations, concentrations vary throughout the year depending on the schedule of salt application (Mt. Hood National Forest, 1999, 2000, 2001). The lighter isotopes of the Salmon River water compared to the Palmer Spring indicate that the spring is not immediately connected to the surface-water system. The Phlox Point and Still Creek springs that contain smaller amounts of dissolved sodium chloride have slightly heavier isotopes than Palmer Spring indicating that some of the recharge may be from a lower elevation where no salt is applied. The Salmon River isotope values are significantly lighter than all of the springs, but the water is recent snow melt and may not be representative of water that recharges the ground water over the long-term. If it is representative, the snow melt in the Salmon River on that day was dominated by higher elevation melting.

## Swim Warm Springs

Swim Warm Springs is a complex of vents informally named after a ruined swimming pool. The variation of specific conductance with temperature (Figure 12) indicates varying degrees of mixing between a warm water and a nonthermal water. The Schoeller diagram presentation (with a log scale) in Figure 13 has data selected to minimize what appear to be analytical rather than sample differences and shows that the more concentrated samples are a mixture of a concentrated water with a dilute water that contains significant silica and nearly negligible amounts of other constituents. The two dilute samples have a more complex behavior indicating either that there is a somewhat different concentrated water before dilution or additional reaction after dilution. The concentration of magnesium increases along with all other constituents (Figures 13 and 14), indicating that the hot end member has a high concentration of magnesium. All the data are plotted in Figure 14, and some of the scatter is from analytical uncertainty that is removed in the selected data set of Figure 13. But the displacement of the two low-chloride data points (49.5 and 25 mg/L) from the mixing line (Figure 14) appears to be a real difference based on the overall behavior in Figure 13.

Isotopic data show that the Swim Warm Springs samples lie along the local meteoric water line (Figure 9). The mixed nature of the samples from Swim Warm Springs is confirmed by plots of isotopes versus chloride (Figure 15). The recharge elevation for the isotopically lightest sample from Swim Warm Springs is approximately 2400 m based on plots of deuterium and oxygen-18 versus elevation (Figures 10 and 11). Interpretation of chemical geothermometer values (Tables 2 and 3) is somewhat difficult. The chalcedony geothermometer temperature for the most concentrated samples from the East Swimming Pool is about 100°C, the calculated Na-K-Ca temperature is about 80°C, and the sulfate-

oxygen isotope temperature for this spring is 110°C (Nehring and others, 1979). However, the Mg-corrected Na-K-Ca geothermometer and Mg-Li geothermometers agree at about 30°C. The concordance of the Mg-corrected Na-K-Ca and Mg-Li geothermometers indicates that the warm end member for Swim Warm Springs was at about 30°C; the most concentrated sample seems to approximate this warm end member. A hot end-member water at 100°C could exist at some distance from Swim, as indicated by the sulfate-oxygen temperature. This water could lose energy by conductive heat loss, re-equilibrate to around 30°C, and then become the warm end member for mixed waters at Swim. Although the loss of 70°C by conductive heat transfer is possible, it is pretty large.

An alternative interpretation for the data from Swim Warm Springs starts with the silica versus temperature plot shown in Figure 16. The silica versus temperature mixing line can be converted to silica versus enthalpy plot, the intersection of this mixing line with chalcedony or quartz solubility curves would show that there is a parent hot water at some high values of silica and enthalpy (Truesdell and Fournier, 1977). However, the extension of the silica-enthalpy mixing line does not intersect the solubility curves, and thus the warm-springs mixing model does not apply. Another model assumes that a parent hot-water exists at surface boiling (taken as 96°C at the elevation of Swim) that mixes with nonthermal water to obtain the range of mixed compositions shown. This parent hot-water is assumed to boil from the reservoir temperature to surface boiling (Truesdell and Fournier, 1977). Applying this model to the silica-enthalpy mixing line, a reservoir temperatures of 187°C for quartz saturation is obtained. Wollenberg and others (1979) give temperatures of 192-240°C for a similar calculation with somewhat different assumptions. The deuterium and oxygen-18 isotopes in the reservoir fluid calculated using procedures in Truesdell and others (1977) are -134.3‰ and -17.6‰. These values are quite light compared to the projections of the isotope-elevation lines in Figures 10 and 11. It is possible that the isotope-elevation lines change slope at some elevation higher than that sampled by the springs as suggested by the very light values for the snow sample at 2652 m. Also the mixing lines in Figure 15 used to extrapolate to the values in boiled water have slopes that are not well defined. So the very light values of the isotopes calculated for the reservoir may be only approximately correct. In order to explain the high magnesium in the samples from Swim Warm Springs, this model assumes that there was additional chemical reaction after boiling to add magnesium and possibly sulfate.

The discharge of thermal energy from Swim Warm Springs can be calculated a number of ways. The flow and specific conductance of the two streams draining Swim were measured (Table 1). We will use the data from 2001 as the flows were measured more carefully than in 1997. Using the relation between specific conductance and temperature in Figure 12, the measured specific conductance of the streams can be converted to a temperature. Based on the correlation in Figure 12, we use a reference temperature of 7.1°C, and the discharge of thermal energy above that is 0.9 MW<sub>t</sub>. Based on a plot of specific conductance versus chloride (not shown), the measured specific conductance can be used to calculate a chloride flux of 1800 mg/s. From the reservoir chloride of 544 mg/L, calculated from a chloride versus enthalpy plot, and the reservoir enthalpy of 775 J/g above a 5°C reference temperature (based on an estimate of nonthermal water temperature from Figure 3 at Swim's elevation), discharge of thermal energy is 2.2 MW<sub>t</sub>. Mariner and others (1990) measured a thermal-water flow of 6.4 L/s based on a chloride balance on Still Creek. At the spring temperature of 26°C, their flow yields a discharge of thermal energy of 0.6 MW<sub>t</sub> adjusted to a 5°C reference temperature; using the aquifer temperature of 110°C, the

heat discharge is 2.8 MW<sub>t</sub>. The aquifer convective heat flow from Swim Warm Springs is not particularly large for thermal springs in the Cascades (Mariner and others, 1990).

## Meadows Springs

The Meadows Springs are a complex of vents informally named after the Meadows ski area in which they occur. The Schoeller diagram presentation (with a log scale) in Figure 17 shows that the more concentrated samples from the Meadows Spring are mixture of a concentrated water with a dilute water that contains significant silica and nearly negligible amounts of other constituents. The two dilute samples from the East Meadows Spring have a more complex pattern indicating either that there is a somewhat different concentrated water before dilution or additional reaction after dilution. The data for the spring tributary to the Zigzag River are shown for reference as a nonthermal water. The chemistry of the Meadows Spring appears to be significantly different in relative proportions from Swim Warm Springs (compare Figures 13 and 17). The sample from the spring near the Cascade is 6 km from the Meadows (Figure 5) and has very similar (but not identical) chemistry to the Meadows Spring (Figure 17). The appearance of this water at such a distance and at a much lower elevation indicates that this system may be fairly widespread. The concentration of magnesium increases along with all other constituents (Figures 17 and 14), indicating that the hot end member has a high concentration of magnesium. The three samples from the Meadows Spring collected in three different years have temperatures of 4.8, 6.1, and 6.6°C, and the chemistry reflects these increases with increasing concentrations of each constituent (Table 3 and Figure 17). The temperature of 10.5°C measured in a seep below the Meadows Spring (Table 1; C01-05) is thought to have been influenced by solar heating and is assumed to not be representative. The Meadows Spring fits the definition of a slightly thermal spring but not that of a thermal spring. Calculated geothermometer temperatures range from 40°-70°C (Table 3), but they are much above the measured spring temperatures.

As with the data for Swim Warm Springs, an alternative but speculative interpretation for the data from Meadows Spring starts with the silica versus temperature plot shown in Figure 18. The three samples for Meadows Spring form a mixing line consistent with a nonthermal water for this elevation of around 2.5°C and 21 mg/L silica. Surprisingly, the sample from the spring near the Cascade lies on the same silica mixing line as that for the Meadows Spring (Figure 18), although the data for specific conductance versus temperature define a parallel trend (Figure 4). The samples from the East Meadows Spring has higher silica than is consistent with this model, and their chemistry, as already indicated by the data in Figure 17, is more complex. Given the limited range in silica concentrations and temperatures for the three samples from the Meadows Spring, the mixing line defined by them is pretty spectacular. The projection of the mixing line does not intersect either the chalcedony or quartz saturation curves, and the estimate of reservoir temperature once again assumes that a parent hot-water exists at surface boiling (taken as 94°C at the elevation of the Meadows) that mixes with nonthermal water to obtain the range of mixed compositions shown. This parent hot-water is assumed to boil from the reservoir temperature to surface boiling (Truesdell and Fournier, 1977). Applying this model to the silica-enthalpy mixing line, a reservoir temperatures of 233°C for quartz saturation is obtained. The reservoir chloride is calculated to be 563 mg/L, quite similar to the value of 544 mg/L found for Swim Warm Springs with a similar model. The isotopic data are



consistent with both the warm and nonthermal mixing components having the same isotopic values (Figure 15), but the range of chloride concentrations is so small that there could be a nonzero slope that we would not recognize. The estimated elevation for the precipitation is 2700-2900 m based on the isotope-elevation plots (Figures 10 and 11). Thus the Meadows system recharges at a lower elevation than Swim and discharges at a higher elevation about 7 km northeast of Swim, and they appear to be two separate hydrothermal systems.

The discharge of thermal energy can be calculated using the conductance versus temperature relation for the three samples from the Meadows spring. The samples from the East Meadows Spring are a bit off the line for an assumed nonthermal water of 2.5°C and specific conductance of 40  $\mu\text{S}/\text{cm}$ . From the measurement of total flow and specific conductance of the Meadows springs in 2001 (Table 1), the discharge of thermal energy is 0.3 MW<sub>t</sub> above a 2.5°C reference temperature (based on an estimate of nonthermal water temperature from Figure 3 at the Meadows' elevation). Assuming that the Cascade springs are part of the same system, another 0.6 MW<sub>t</sub> is added. Based on a plot of specific conductance versus chloride (not shown), the measured specific conductance can be used to calculate a chloride flux for both the Meadows and Cascade springs of 1300 mg/s. From the reservoir chloride of 563 mg/L, calculated from a chloride versus enthalpy plot, and the reservoir enthalpy of 994 J/g above a 2.5°C reference temperature, discharge of thermal energy is 1.9 MW<sub>t</sub>. Thus, the discharge of thermal energy from the Meadows springs and Cascade springs is approximately the same as from Swim Warm Springs.

## Well Samples

Water chemistry data from a number of drill hole samples are available in the literature, and some have been included in Table 2. Old Maid Flat well samples (Wollenberg and others, 1979) have not been included because their low silica values probably indicate contamination with drill water. Additional data from Priest and Vogt (1982) for samples from Old Maid Flat-7A drill hole also have not been included, because they also have low silica values, indicating contamination with drill water (Priest and others, 1982, p. 16). Figure 19 presents data from the well samples from Table 2 along with data for Swim Warm Springs and the Meadows spring. The data for the Pucci drill hole are from a sample collected on 7/24/81 during the pump test completed on 7/25/81 (U.S. Geological Survey Press Release, August 13, 1981) after the well had been deepened to 1220 m. The chemistry of the sample from the Pucci well is somewhat similar to that for Swim Warm Springs, with sulfate and chloride nearly equal and both greater than bicarbonate. The cations are less similar. The chloride concentration of the Pucci sample is about twice that of the most concentrated sample from Swim Warm Springs, but its silica concentration is only 5 % higher (Tables 2 and 3). The Pucci well sample is shifted from the local meteoric water line (Figure 9) -- surprising considering that maximum temperature in the well is 77°C (Nathenson and Tilling, 1993). From its position on the deuterium versus chloride plot (Figure 15), the sample from the Pucci well could be interpreted as a parent water for Swim Warm Springs. However, the strong relationship between increasing chloride and increasing magnesium for the various samples from Swim Warm Springs (Figure 14) requires the local parent water for Swim Warm Springs to have significantly higher magnesium concentration than that for the Pucci well. The substantially lower chloride concentration and higher magnesium concentration of the East Swimming Pool sample compared to the Pucci sample indicates that the Pucci water is not likely to be the

parent water for Swim Warm Springs. The sample from the Pucci Well contains a significant amount of magnesium, and the Mg-correction to the Na-K-Ca geothermometer lowers the temperature from 170° to 52°C (Table 2). Measured temperature at a depth of 1129 m is 76.6°C, and the maximum temperature is probably somewhat higher as the well is 1220 m deep. The K-Mg geothermometer temperature of 75°C agrees well with the measured temperature; however, the high Na-K-Ca temperature of 170°C may indicate that a higher temperature water is circulating at greater depths and re-equilibrating at a shallower level. The shift of the oxygen-18 isotopes from the meteoric water line (Figure 9) indicates high temperature but should be regarded with caution as it is based on only a single sample.

In addition to surface thermal features, two shallow wells show influence of subsurface thermal water. The samples from the Parkdale well and the Clear Creek Picnic area well have chloride concentrations enough above background to indicate that they are probably thermal waters or they are mixed with a thermal component (Table 2). No obvious relationship exists (Figure 19) between the waters from the Parkdale and Clear Creek Picnic area wells and the East Swimming Pool of Swim Warm Springs and the Pucci drill hole. They all appear to have undergone slightly different water/rock interactions.

The Parkdale drill hole (Figure 5), located east of the Parkdale Spring is close to the Hood River fault zone, has a maximum measured temperature of 24°C at 50 m, and the reversal in the temperature profile clearly indicates movement of thermal water (Steele and others, 1982, Figure 6). The Parkdale well sample is dominantly a sodium bicarbonate water, whereas the other three waters shown on Figure 19 share the atypical characteristic for thermal waters of being relatively high in magnesium concentration. Geothermometer values for the Parkdale well are concordant at a reservoir temperature of 95°C. The sample has a significant Mg-correction to the Na-K-Ca geothermometer, allowing one to speculate about possibly higher temperatures at depth. The Parkdale well is clearly part of a hydrothermal system, in which the water sampled has undergone significant conductive heat loss to cool it from a geothermometer temperature of 95°C to a measured temperature of 24°C. The lack of any appearance of similar chemistry in the Parkdale cold spring, the lack of specific-conductance anomalies in other springs in the Hood River Valley west of the Parkdale drill hole, and the location of the drill hole adjacent to the Hood River fault makes it likely that the chemical and thermal anomaly is related to faulting rather than thermal affects from hydrothermal systems associated with Mount Hood.

The Clear Creek Picnic area well near the Sandy River at the eastern end of Old Maid Flat (Figure 5) is slightly artesian (Wollenberg and others, 1979), but it has a nearly linear thermal gradient of 56°C/km to 90 m and does not appear to be thermally anomalous (Steele and others, 1982, Figure 2). Geothermometer values for the Clear Creek Picnic area well are concordant at a reservoir temperature of 70°C. The sample has a 47°C Mg-corrections to the Na-K-Ca geothermometer, but the general indications seem to be consistent with a reservoir temperature around 70°C. The great distance of the well from the Mount Hood edifice and from other indications of thermal water with sources on Mount Hood make it likely that it is some locally driven system rather than connected to hydrothermal systems associated with Mount Hood.

## Summit Fumaroles

Mount Hood has several fumaroles (Devils Kitchen and other localities) near the summit (Friedman and others, 1982). The near-summit fumaroles occur at elevations of 3020-3230 m encompassing a surface area of 9200 to 9700 m<sup>2</sup> (Friedman and others, 1982; Nehring and others, 1981). Temperatures of summit fumaroles range from 71° to 93°C; boiling temperature at 3100 m elevation is about 89.6°C. Friedman and others (1982) estimate a total heat discharge for the summit fumarole field of about 10 MW<sub>t</sub>, comparable to the fluxes for Mount Rainier of 9.6 MW<sub>t</sub> and Mount Baker in 1972 of 12 MW<sub>t</sub> (before the increase in thermal activity in 1975 to 82 MW<sub>t</sub> [Frank, 1985]). Table 4 presents gas analyses for the summit fumaroles and the D'Amore and Panichi (1980) gas geothermometer to estimate reservoir temperatures. Gas samples are sometimes contaminated with entrained air, and the 1978 sample from the ridge west of Devils Kitchen has nitrogen, oxygen, and argon in the appropriate ratios for air. The carbon dioxide content in this sample is much higher than that for air, but the application of the geothermometer to such a heavily contaminated sample is inappropriate. The 1935 and 1951 samples of Crater Rock also have high oxygen contents and are inappropriate for application of the geothermometer. The 1935 sample from Devils Kitchen lacks data for methane and hydrogen, and a geothermometer temperature has not been calculated for it. Samples with higher amounts of nitrogen tend to have lower amounts of hydrogen sulfide, because the added nitrogen was from air added either in the near surface part of the vent or in sampling, and the associated oxygen reacts with hydrogen sulfide to form sulfur and water until either the oxygen or hydrogen sulfide is gone (Nehring and others, 1981). Geothermometer temperatures for the Base of Steel Cliff are around 290°C for the modern analysis, for Devils Kitchen are around 325°C, and for Crater Rock are the highest at 360°C. These high temperatures are somewhat surprising because the last significant eruption from Mount Hood was about 200 years ago. The calculated reservoir temperatures for Swim Warm Springs and the Meadows Spring are quite a bit lower than the temperatures calculated for the fumaroles indicating that the fumaroles are not just the vents for the boiling hydrothermal systems.

A sample from a summit fumarole collected in 1978 has a <sup>3</sup>He/<sup>4</sup>He ratio of 7.2 times that for air (Welhan and others, 1988; Poreda and Craig, 1989), one collected in 1997 had a value of 7.6 (Symonds and others, 2003), and samples collected in August, 2002 had values of 6.35 and 6.68 times that for air (M. C. van Soest, analyst). These values are similar to those found in other Cascade volcanoes and about what would be expected for degassing of andesitic magma that has a source in the mantle. Thus, the summit fumaroles involve input of magmatic volatiles that have been modified by scrubbing (Symonds and others, 2003). Whether the difference in helium-ratio values over time is significant is unclear.

## Conclusions

Temperatures of nonthermal springs on Mount Hood decrease with elevation and are similar to air temperatures from nearby weather stations. Dissolved constituents in nonthermal springs generally increase with spring temperature and reflect weathering of volcanic rock from the action of dissolved carbon dioxide. Salt that is applied to the Palmer

snow field is found in several nonthermal springs. Isotopic contents of nonthermal springs follow a local meteoric water line and generally decrease in deuterium and oxygen-18 with elevation. Some nonthermal springs at low-elevation have light values of isotopes indicating a high-elevation source for the water.

Three hydrothermal systems have been identified on Mount Hood. Swim Warm Springs is a complex of springs with temperatures ranging to 26°C. Chemistry and isotopic variations generally reflect mixing a warm water with a dilute water that contains significant silica. Magnesium content increases with chloride and temperature indicating that the warm end member must have undergone some low-temperature reaction as magnesium is normally very low in thermal water. One model for Swim Warm Springs is that the hot end member is 110°C and has undergone significant conductive heat loss to reduce its temperature to the 25°C vent temperature. A second model involves boiling of a reservoir water from 187°C to the local boiling temperature of 96°C. Additional low-temperature equilibration added magnesium and subsequent mixing with nonthermal water produced the range of compositions found in the various vents. Isotopic contents calculated for the 187°C reservoir water are very light compared to the extrapolation of the isotope elevation line, but the extrapolation is somewhat uncertain, and there is an indication that the slope of the isotope-elevation line may become more negative at higher elevations.

The Meadows Spring only ranges in temperature to 6.6°C. Similar to Swim, a model involving boiling, 223°C in this case, and subsequent low-temperature equilibration with added magnesium and subsequent mixing with nonthermal water produce the range of compositions found. The mixing line for isotopes versus chloride is poorly constrained in this case because of the limited range of chloride contents, and the available data are consistent with the isotopes being constant with increasing chloride concentration. The elevation for the projected isotopic contents is 2700-2900 m, lower than the summit elevation of 3426 m.

The fumaroles near the summit have somewhat variable compositions between the various vents. The older analyses should be regarded with some caution, but the vent at the base of Steel Cliff does seem to have a lower hydrogen content than the other vents. The calculated temperatures for this vent may not be reliable, because the analyses are so old. The other vents discharge gases that consistently indicate system temperatures over 300°C, providing an ample fluid and heat source to develop hydrothermal systems. The calculated reservoir temperatures for Swim Warm Springs and the Meadows Spring are lower than the temperatures calculated for the fumaroles indicating that the fumaroles are not just the vents for the boiling hydrothermal systems.

Representative values for the various measurements of thermal discharge for the three hydrothermal systems are 10 MW<sub>t</sub> for the fumaroles, 2.2 MW<sub>t</sub> for Swim, and 1.9 MW<sub>t</sub> for the Meadows and Cascade Springs. There are quite possibly more areas of discharge of slightly thermal water that could add to the totals for the springs, but the amounts of heat discharge are not very large. Based on a comparison of heat flows measured in drill holes to a model for heat loss from an isothermal magma chamber, Nathenson and Tilling (1993) estimated that the conductive heat loss from Mount Hood is between 28 and 55 MW<sub>t</sub>. This conductive heat loss is larger than the total of all convective heat discharges found at the surface. The small magnitudes of the convective heat discharge for Swim and the Meadows springs are surprising given the high temperatures estimated for the source water and may indicate that these systems are not large in volume. This supposition is consistent with conductive heat flows found in the deep (>300 m) drillholes at Mount Hood (Steele and others, 1982; Nathenson and Tilling, 1993).

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**Table 1.** Mount Hood physical measurements. For one location, measurement point is at feature. For two locations, measurement point is given, and location of feature is also given. Measurements on springs at the orifice are identified by an \* after the name.

	Sample or ID No.	Measurement point Lat.      Lon.		Elev. m	Date	Feature Lat.      Lon.		Flow L/s	T °C	Cond. µS/cm
<u>Swim Warm Springs</u>										
Below swimming pool		45°17.78'	121°44.26'	1158	8/1/97	45°17.80'	121°44.24'	6.3	16.3	655
Still Creek		45°17.77'	121°44.21'	1158	8/1/97			19	9.2	204
Spring nr. Screen Spring*	2	45°17.83'	121°44.19'	1164	8/1/97			0.3	22.8	939
Spring nr. Screen Spring*	3	45°17.83'	121°44.17'	1164	8/1/97			1.2	13.4	465
Spring nr. Screen Spring*	4	45°17.82'	121°44.17'	1164	8/1/97			0.3	9.0	280
Pipeline by swimming pool*	5	45°17.81'	121°44.24'	1158	8/1/97			2	17.6	576
Sp. nr. Pipeline Sp. *	6	45°17.80'	121°44.26'	1158	8/1/97			0.2	21.7	1227
E. side of pool*	MNH-97-1	45°17.80'	121°44.24'	1158	8/1/97			0.3	25.0	1263
Sp. nr. Phlox Point*	MNH-97-2	45°19.05'	121°42.96'	1548	8/2/97			83	2.4	45.2
Sp. trib. of Zigzag R.*	MNH-97-3	45°20.50'	121°44.23'	1628	8/2/97			26	2.3	17.5
<u>Upper Hood River Valley</u>										
Crystal Spring*	MNH-97-4	45°27.55'	121°35.11'	744	8/3/97			210	5.1	70.1
Rogers Spring*		45°31.14'	121°37.20'	524	8/3/97			57	4.8	58.1
Spgs. NE1/4 1N10E32		45°32.07'	121°35.57'	463	8/3/97	45°31.75'	121°35.60'	19	13.9	60.4
Parkdale Cold Spring*	MNH-97-5	45°29.97'	121°36.26'	585	8/3/97			66	7.9	102.0
Spgs? NW 1/4 1S9E12		45°30.06'	121°36.77'	585	8/3/97	45°29.94'	121°36.97'	5	10.2	63.0
Spgs. SE 1/2 1S9E01		45°31.18'	121°36.45'	512	8/3/97	45°30.66'	121°36.85'	2.4	11.7	60.3
Sp. on Lolo Pass Rd.*	MNH-97-6	45°29.44'	121°45.20'	695	8/4/97			94	4.7	40.8
Sp. on Coe Branch*	MNH-97-7	45°26.70'	121°39.41'	1000	8/4/97			2	6.0	60.9
<u>Meadows area</u>										
E. Meadows Sp.*	MNH-97-8	45°20.34'	121°39.91'	1792	8/5/97			12	2.8	111.5
Stream from Meadows Spring		45°20.31'	121°40.05'	1743	8/5/97	45°20.37'	121°40.05'	28	5.9	246
East Fork Hood River	Cond. 1	45°20.24'	121°40.25'	1768	8/5/97			250		10
Stream	Cond. 2	45°20.11'	121°40.34'	1780	8/5/97			28		3.4
Stream	Cond. 3	45°19.98'	121°40.43'	1780	8/5/97			230		10.1
Mitchell Creek	Cond. 4	45°19.92'	121°40.51'	1768	8/5/97			19		10.0
Meadows Spring*	MNH-97-10	45°20.37'	121°40.05'	1798	8/7/97			49	4.8	233



**Table 1** (continued).

	Sample or ID No.	Measurement point		Elev. m	Date	Feature		Flow L/s	T °C	Cond. µS/cm
		Lat.	Lon.			Lat.	Lon.			
<u>Cloud Cap area</u>										
Tilly Jane Creek	CC-1	45°23.95'	121°38.82'	1743	8/6/97			85		20.0
Stream	CC-2	45°24.00'	121°39.10'	1792	8/6/97			2.4		26.4
Stream from Cloud Cap Cmpgrnd Sp.	CC-3	45°24.05'	121°39.20'	1792	8/6/97	45°23.96'	121°39.25'	4.7		30.8
Eliot Branch	CC-4	45°24.03'	121°39.48'	1768	8/6/97			3400		18.7
Stream	CC-5	45°24.03'	121°39.66'	1829	8/6/97			1.2		19.1
Stream	CC-6	45°24.09'	121°39.72'	1780	8/6/97			400		6.6
Compass Creek	CC-7	45°24.03'	121°40.45'	1756	8/6/97			400		4.9
Stream	CC-8	45°23.96'	121°40.70'	1792	8/6/97			0.6		7.3
Cloud Cap Cmpgrnd Sp.*	MNH-97-9	45°23.96'	121°39.25'	1823	8/6/97			3.1	1.7	33.4
Stream	C99-1	45°19.38'	121°41.05'	1530	8/18/99			6.4	9.4	47.2
East fork White River	C99-2	45°19.34'	121°41.15'	1487	8/18/99			61	10.1	41.8
West fork White River	C99-3	45°19.31'	121°41.20'	1494	8/18/99			1200	9.5	6.6
Mitchell Creek	C99-5	45°19.98'	121°40.63'	1817	8/18/99			1.0	1.0	13.0
Stream with snow	C99-7	45°20.24'	121°39.44'	1786	8/19/99			7.0	5.2	1.2
Clark Creek	C99-8	45°20.53'	121°39.45'	1762	8/19/99			36	2.0	13.0
Stream	C99-10	45°20.82'	121°39.52'	1731	8/19/99			11.4	4.2	11.1
Stream below snow	C99-11	45°20.89'	121°39.55'	1731	8/19/99			400	2.1	36.5
E. Meadows Sp.*	MNH-99-1	45°20.34'	121°39.91'	1792	8/19/99			3.6	2.6	107.6
Meadows Spring*	MNH-99-2	45°20.37'	121°40.05'	1798	8/19/99			20	6.1	270
Little Zigzag Canyon	CC99-14	45°20.28'	121°43.58'	1780	8/20/99			120	1.1	1.5
Stream	C99-15	45°20.53'	121°44.01'	1731	8/20/99			0.7	4.0	18.5
Stream	C99-16	45°20.61'	121°44.30'	1640	8/20/99			0.5	2.7	27.4
Zigzag Canyon	C99-17	45°20.64'	121°44.57'	1500	8/20/99			1100	7.1	60.6
Salmon River	C99-18	45°20.70'	121°42.37'	1829	8/20/99			110	3.5	298
Palmer Spring*	MNH-99-3	45°20.13'	121°42.35'	1865	8/21/99			1.4	2.4	82.8
Salmon River 11:10 AM	MNH-99-4	45°20.12'	121°42.31'	1853	8/21/99			140	0.9	479
Salmon River 5:30 PM	MNH-99-5	45°20.12'	121°42.31'	1853	8/23/99			100	0.9	394

**Table 1** (continued).

	Sample or ID No.	Measurement point		Elev. m	Date	Feature		Flow L/s	T °C	Cond. µS/cm
		Lat.	Lon.			Lat.	Lon.			
Newton Creek	C99-21	45°20.21'	121°37.54'	1414	8/22/99			1800	5.8	14.3
Stream	C99-22	45°19.96'	121°37.66'	1396	8/22/99			140	4.6	19.6
Stream	C99-23	45°19.86'	121°37.78'	1390	8/22/99			9.6	5.4	35.0
Clark Creek	C99-24	45°19.77'	121°37.84'	1390	8/22/99			1800	7.5	41.2
South Fork Iron Creek	C99-25	45°18.35'	121°40.06'	1286	8/22/99			54	4.4	99.3
South Fork Mineral Creek	C99-26	45°18.86'	121°41.15'	1426	8/22/99			5.0	8.2	25.4
Rushing Water Creek	C99-27	45°22.51'	121°46.72'	1030	8/23/99			350	5.3	94.0
Stream	C99-28	45°22.54'	121°46.70'	1024	8/23/99			34	5.4	39.6
Sandy River	C99-29	45°22.62'	121°46.74'	1012	8/23/99			1700	9.7	16.8
Ramona Falls	C99-30	45°22.81'	121°46.51'	1073	8/23/99			62	10.8	22.8
Muddy Fork	C99-31	45°23.76'	121°47.89'	860	8/23/99			3600	10.6	87.0
Middle Fork Cold Springs Creek	C01-01	45°21.80'	121°38.47'	1817	7/25/01			14.4	13.3	12.8
<u>Meadows area</u>										
Stream from Meadows Spring	C01-02	45°20.31'	121°40.05'	1743	7/26/01	45°20.37'	121°40.05'	18	7.9	354
Stream from E. Meadows Spring	C01-03	45°20.27'	121°39.92'	1743	7/26/01	45°20.34'	121°39.91'	4.5	3.4	157
Meadows Spring*	MNH-01-1	45°20.37'	121°40.05'	1798	7/26/01			8.8	6.6	364
Spring in Meadows*	C01-05	45°20.23'	121°40.05'	1719	7/26/01			0.2	10.5	270
Main Meadows stream	C01-06	45°20.23'	121°40.05'	1719	7/26/01			16.5		343
Main Meadows stream - lower	C01-07	45°20.16'	121°40.01'	1695	7/26/01			18.0		338
Tilly Jane Creek Spring*	C01-08	45°23.67'	121°39.38'	1890	7/27/01			0.3	2.6	25.2
Stream from snow	C01-09	45°23.08'	121°39.64'	2134	7/27/01			2.8	4.8	1.4
Elk Creek	C01-10	45°25.08'	121°46.72'	1055	7/29/01			10.5	8.8	21.0
McGee Creek	C01-11	45°25.07'	121°46.05'	908	7/29/01			405	7.8	31.6
McGee Creek tributary	C01-12	45°26.00'	121°46.35'	835	7/29/01			68	6.4	36.5
Ladd Creek	C01-13	45°28.31'	121°46.39'	701	7/29/01			1620	6.4	25.6
Red Hill Creek	C01-14	45°28.33'	121°46.17'	719	7/29/01			54	7.4	46.0
Clear Branch	C01-15	45°27.43'	121°40.67'	914	7/29/01			127	7.7	55.0
Pinnacle Creek	C01-16	45°27.40'	121°39.64'	914	7/29/01			120	7.1	49.0

**Table 1** (continued).

	Sample or ID No.	Measurement point Lat. Lon.		Elev. m	Date	Feature Lat. Lon.		Flow L/s	T °C	Cond. µS/cm
<u>Swim Warm Springs</u>										
Pipeline by swimming pool*	MNH-01-2	45°17.81'	121°44.24'	1158	7/30/01			0.67	15.9	575
E. side of pool*	MNH-01-3	45°17.80'	121°44.24'	1158	7/30/01			0.05	24.7	1248
Still Creek	C01-19	45°17.77'	121°44.21'	1158	7/30/01			59	9.7	231
Below swimming pool	C01-20	45°17.78'	121°44.26'	1158	7/30/01	45°17.80'	121°44.24'	6.3	15.6	655
Still Creek above Swim	C01-21	45°17.87'	121°44.17'	1167	7/30/01				5.9	132
Still Creek @ Hwy 26	MNH-01-4	45°18.05'	121°44.10'	1195	7/30/01			150	5.5	134.0
Palmer Spring*	MNH-01-5	45°20.13'	121°42.35'	1865	7/31/01			0.68	2.3	69.5
Palmer Spring Box*	C01-24	45°20.18'	121°42.32'	1884	7/31/01			1.2	2.1	88.0
Palmer Spring in snow	C01-25	45°20.21'	121°42.30'	1890	7/31/01			0.4	1.3	84.0
Palmer Spring in river	C01-26	45°20.21'	121°42.30'	1890	7/31/01			1.5	1.7	81
Salmon River	C01-27	45°20.12'	121°42.31'	1853	7/31/01			6.8	6.5	81.5
Spring Box nr. Phlox Pt.*	MNH-01-6	45°19.03'	121°42.95'	1542	7/31/01			18.0	2.6	55.4
Still Creek Spring*	MNH-01-7	45°18.95'	121°43.14'	1512	8/01/01			1.2	2.7	76.3
Still Creek at road	C01-38	45°19.00'	121°43.38'	1475	8/01/01			60	3.6	67.6
	C01-39							7.2	5.3	71.6
	C01-40							6.1	5.3	65.8
Still Creek at road	C01-41	45°18.67'	121°43.62'	1402	8/01/01			29.4	5.8	66.4
Still Creek tributary	C01-42	45°18.39'	121°43.96'	1274	8/01/01			57.8	4.6	76.4
Still Creek cascade	MNH-01-8	45°18.37'	121°43.83'	1283	8/01/01			27.0	7.4	256

**Table 1** (continued).

	Sample or ID No.	Measurement point Lat.      Lon.		Elev. m	Date	Feature Lat.      Lon.		Flow L/s	T °C	Cond. µS/cm
<u>Swim Warm Springs</u>										
E. side of pool*	C02-01	45°17.80'	121°44.24'	1158	7/24/02			0.1	25.7	1222
Still Creek	C02-02	45°17.77'	121°44.21'	1158	7/24/02			74	10.5	194.2
Below swimming pool	C02-03	45°17.78'	121°44.26'	1158	7/24/02	45°17.80'	121°44.24'	6.0	18.4	618
Pipeline by swimming pool*	C02-04	45°17.81'	121°44.24'	1158	7/24/02			5	18.4	563
Still Creek above Swim	C02-05	45°17.87'	121°44.17'	1167	7/24/02			225	7.6	116.3
<u>Meadows area</u>										
Meadows Spring*	C02-06	45°20.37'	121°40.05'	1798	7/25/02			5.0	6.3	305
Stream from Meadows Spring	C02-07	45°20.31'	121°40.05'	1743	7/25/02	45°20.37'	121°40.05'	40	7.6	300
Stream from E. Meadows Spring	C02-08	45°20.27'	121°39.92'	1743	7/25/02	45°20.34'	121°39.91'	3.6	3.2	120.0
Main Meadows stream - lower	C02-09	45°20.16'	121°40.01'	1695	7/25/02			24.0	8.1	281
Umbrella Falls	C02-10	45°19.75'	121°39.53'	1597	7/25/02			216	11.5	105.3
Stream	C02-11	45°19.75'	121°39.40'	1603	7/25/02			21.6	16.8	15.0
Stream	C02-12	45°19.76'	121°38.75'	1524	7/25/02			3.2	5.9	38.2
<u>Swim Warm Springs</u>										
E. side of pool*	C02-13	45°17.80'	121°44.24'	1158	7/26/02				25.2	1256
Pipeline by swimming pool*	C02-14	45°17.81'	121°44.24'	1158	7/26/02				17.2	569
Spring nr. Cascade*	MNH-02-1	45°18.32'	121°43.75'	1311	7/26/02			2.0	6.8	234
Salmon River	C02-17	45°20.21'	121°42.30'	1853	7/26/02			45	2.2	360
Palmer Spring Box*	C02-18	45°20.18'	121°42.32'	1884	7/26/02			2.4	2.1	52.6
Palmer Spring*	C02-19	45°20.13'	121°42.35'	1865	7/26/02			0.9	2.4	55.8

**Table 1** (continued) Locations in 2003 from GPS unit and differ from earlier estimated locations.

	Sample or ID No.	Measurement point		Elev. m	Date	Feature		Flow L/s	T °C	Cond. μS/cm
		Lat.	Lon.			Lat.	Lon.			
<u>Meadows area</u>										
Meadows Spring*	C03-11	45°20.26'	121°40.21'	1761	8/22/03				6.5	343
Main Meadows stream - lower	C03-12	45°20.15'	121°40.12'	1745	8/22/03			50	7.2	328
Spring nr. Cascade*	C03-13	45°18.25'	121°43.73'	1279	8/22/03				7.0	262
<u>Swim Warm Springs</u>										
E. side of pool*	C03-14	45°17.74'	121°44.27'	1176	8/22/03				25.4	1225
Below swimming pool	C03-15				8/22/03				17.5	679
Pipeline by swimming pool*	C03-16				8/22/03				17.5	601

**Table 2.** Concentrations of dissolved constituents, isotopic contents, and geothermometer temperatures for samples from Mount Hood and vicinity. Data from Wollenberg and others (1979) except for Pucci Drill Hole (R. H. Mariner, unpublished data, 1981) and Parkdale Well (Oregon Department of Geology and Mineral Industries, unpublished data, 1978; Bliss, 1983). Isotopic data by N. L. Nehring, L. Merlivat, and J. Borthwick. Geothermometers are from Fournier (1981), Giggenbach (1986), and Kharaka and Mariner (1989).

	Lat. <sup>e</sup>	Lon. <sup>e</sup>	Elev. m	Samp. No.	Date	T °C	pH	Concentrations (mg/L)										Geothermometers							
								SiO <sub>2</sub>	Ca	Mg	Na	K	HCO <sub>3</sub>	SO <sub>4</sub>	Cl	B	Li	δD o/oo	δ <sup>18</sup> O o/oo	Chal- ced.	K-Mg	Mg-Li	Na-K -Ca	R- value	Na-K -Ca-Mg
<u>Swim Warm Springs</u>																									
Pipeline	45°17.89'	121°44.10'	1170	MH-4 MH-39	12/2/76	20	7.3	55.4	42	29	79	6	141	149	103	0.3	0.08			77 <sup>a</sup>	45	28	64	51.5	39 <sup>b</sup>
					6/2/77	22	7.5	75	50	34	92	7.5	184 <sup>d</sup>	162	110	2.0		-95.6	-13.55						
					2/22/78	21.6	7.5	75	53	38	92	7	211 <sup>d</sup>	174	102	0.5		-95.0	-13.33						
Screen	45°17.83'	121°44.17'	1164	MH-5 MH-38	12/2/76	25	7.3	71.6	57	44	114	10	191	193	139	0.4	0.12			91 <sup>a</sup>	51	32	77	53.9	30 <sup>b</sup>
					6/2/77	25	7.5	75	55	36	95	8	170 <sup>d</sup>	186	120	1.0		-98.1	-13.90						
					2/22/78	25.5	7.5	78	60	43	105	8	183 <sup>d</sup>	216	135	0.5		-97.4	-13.66						
E. Swim Pool	45°17.80'	121°44.24'	1158	MH-6 MH-37	12/2/76	25.6	7.5	72.3	60	48	136	11.7	218	205	161	0.3	0.13			91 <sup>a,c</sup>	54	33	83	54.5	27 <sup>b</sup>
					6/2/77	26	7.5	80	60	40	120	9.2	235 <sup>d</sup>	189	140	3.0		-99.2	-13.85						
					2/22/78	26.2	7.3	88	64	50	126	9	247 <sup>d</sup>	222	154	0.5		-99.4	-13.74						
Cistern Box	45°17.81'	121°44.24'	1158	MH-7	6/2/77	20	7.5	70	42	30	86	7.2	156 <sup>d</sup>	156	95	1		-93.0	-13.15						
Nr. Cistern Box	45°17.83'	121°44.24'	1164	MH-8	6/2/77	21	7.4	80	41	20	62	6.4	79 <sup>d</sup>	144	80	2		-97.3	-13.80						
Sp. on West Branch Ck.	45°17.87'	121°44.24'	1170	MH-9	6/2/77	19	7.5	60	19	13	36	3.6	82 <sup>d</sup>	78	25	0.2		-89.7	-13.05						
<u>Wells</u>																									
Pucci Well (1220 m)	45°19.3'	121°42.8'	1628	CQ81JR	7/24/81	40.8	9.2	95	110	33	270	25	200	410	295	<1	--	-104.5	-13.46	107	75	--	170	30.7	52
Parkdale Well (150 m)	45°29.8'	121°33.8'	560	WS78-314	11/29/78	24	8.4	80	11	2.9	94	17	242	10	37	3	0.05			97	96	41	209	19.5	97
Clear Ck. Picnic well	45°21.5'	121°56.1'	442	MH-22	8/2/77	10	8.5	54	51	20	125	16	--	--	25	3	--			76	70	--	97	35.8	50
<u>Springs</u>																									
Sp. nr. White River	45°18.2'	121°40.4'	1305	MH-2	6/1/77	3.5	6.2	--	2	<1	2.2	1	--	--	1	0.5	--	-84.4	-12.20						
Ski Bowl, artesian well	45°18.1'	121°46.5'	1107	MH-3	6/2/77	7	8.5	--	17	4	16	2	--	--	2	0.2	--	-84.9	-12.35						
Robin Hood Quarry Sp.	45°20.2'	121°34.1'	1097	MH-10	6/3/77	7	7.5	--	50	5	6	<0.2	--	--	<0.2	0.5	--	-94.3	-13.15						
Robin Hood Quarry Sp.				MH-36	2/22/78	4	7.8	10	43	2	4	0.1	91 <sup>d</sup>	45	2	0.5		-90.8	-12.57						
HWY 35 Sp.	45°18.6'	121°39.7'	1317	MH-11	6/4/77	3	6.7	--	<0.01	1	1.2	0.4	--	--	<0.1	0.3		-82.8	-12.15						
HWY 26 Sp.	45°17.4'	121°44.0'	1182	MH-12	6/4/77	5	6.9	30	0.11	2	7	1	11 <sup>d</sup>	9	5	0.2		-87.2	-12.70						
Laurel Hill Sp.	45°18.4'	121°49.6'	853	MH-13	6/4/77	10	6.5	--	0.15	<0.6	2	<0.4	--	--	<0.2	0.5		-78.4	-11.15						
Meadows Sp.	45°20.3'	121°40.1'	1768	MH-14	6/5/77	8	7.5	42	19	6	6.5	3.5	--	--	6	0.5		-97.2	-13.75						
Mt. Hood Snow melt			1829		2/2/79													-100.5	-14.00						
Mt. Hood Snow melt			2134		2/2/79													-100.4	-14.50						
Mt. Hood Snow melt			2652															-139.1	-17.81						

<sup>a</sup> Chalcedony temperature is a minimum, because water is a mixture of cold and warm waters.

<sup>b</sup> Magnesium correction is normally not applied when R>50; geothermometer temperature is usually the same as the spring temperature in that case.

<sup>c</sup> Sulfate oxygen temperature is 110°C on sample MH-6 of same spring (Nehring and others, 1979).

<sup>d</sup> Bicarbonate concentration determined by charge balance.

<sup>e</sup> Minutes of latitude and longitude for Swim Warm Springs reported to four significant figures to preserve relative locations in Wollenberg and others' (1979) Figure 5 but are not accurate to that level. Locations of other features corrected based on feature descriptions.

**Table 3.** Concentrations of dissolved constituents (Dale Counce analyst), isotopic contents (Mark Huebner and L. Douglass White analysts), and geothermometer temperatures for samples from Mount Hood and vicinity collected for this study. Geothermometers are from Fournier (1981), Giggenbach (1986), and Kharaka and Mariner (1989).

	Lat.	Lon.	Elev. m	Samp. No.	Date	T °C	Spec.		Concentrations (mg/L)											Geothermometers							
							F	pH	Cond. µS/cm	Flow L/s	SiO <sub>2</sub>	Ca	Mg	Na	K	HCO <sub>3</sub>	SO <sub>4</sub>	Cl	B	Li	δD o/oo	δ <sup>18</sup> O o/oo	Chal- ced.	K-Mg	Mg-Li	Na-K R- -Ca	Na-K value
<u>Swim Warm Springs</u>																											
E. side of pool	45°17.80'	121°44.24'	1158	MNH-97-1	8/1/97	25	--	1263	0.3	89.6	64.4	48.7	119	11.8	213 <sup>a</sup>	239	156	0.14	0.13	-97.5	-14.0	104 <sup>b</sup>	54	32	80	53.3	30 <sup>c</sup>
E. side of pool	45°17.80'	121°44.24'	1158	MNH-01-3	7/30/01	24.7	7	1248	0.05	82.4	64.5	51.6	129	9.86	209 <sup>a</sup>	233	147	0.10	0.13	-100.2	-13.90	99 <sup>b</sup>	49	32	75	55.0	30 <sup>c</sup>
Pipeline near pool	45°17.81'	121°44.24'	1158	MNH-01-2	7/30/01	15.9	6.5	575	0.67	65.7	28.3	21.8	50.6	5.52	107	118	49.5	0.064	0.044	-94.5	-13.44	86 <sup>b</sup>	46	20	65	53.6	36 <sup>c</sup>
<u>Meadows Springs</u>																											
E. Meadows Sp.	45°20.34'	121°39.91'	1792	MNH-97-8	8/5/97	2.8	6	111.5	12	35.1	10.6	3.48	5.31	2.00	57.1	2.20	3.55	0.007	<0.01	-93.1	-13.4						
E. Meadows Sp.	45°20.34'	121°39.91'	1792	MNH-99-1	8/19/99	2.6	6	107.6	3.6	35.5	10.5	3.94	5.39	2.03	58.0	2.64	2.83	0.009	<0.01	-96.7	-13.5						
Meadows Spring	45°20.37'	121°40.05'	1798	MNH-97-10	8/7/97	4.8	6	233	49	35.3	17.5	7.55	14.5	2.82	77.6	16.2	21.6	0.040	0.01	-94.4	-13.4	55 <sup>b</sup>	43	5	43		
Meadows Spring	45°20.37'	121°40.05'	1798	MNH-99-2	8/19/99	6.1	6	270	20	40.9	20.2	11.1	18.9	3.20	93.5	22.0	29.3	0.053	0.02	-96.9	-13.2	62 <sup>b</sup>	42	13	46		
Meadows Spring	45°20.37'	121°40.05'	1798	MNH-01-1	7/26/01	6.6	6.5	364	8.8	45.8	24.5	13.5	22.6	3.63	119	28.4	36.7	0.060	0.025	-96.6	-13.50	68 <sup>b</sup>	43	15	48		
Spring nr. Cascade	45°18.32'	121°43.75'	1311	MNH-02-1	7/26/02	6.8	6	234	2	45.8	14.0	7.29	18.6	4.03	65.6	24.7	21.9	0.049	0.021	-90.0	-12.8						
<u>Nonthermal springs</u>																											
Sp. nr. Phlox Point	45°19.05'	121°42.96'	1548	MNH-97-2	8/2/97	2.4	5.5	45.2	83	24.8	3.78	0.89	4.31	1.06	16.6	1.00	3.71	0.008	<0.01	-85.6	-12.7						
Sp. trib. of Zigzag R.	45°20.50'	121°44.23'	1628	MNH-97-3	8/2/97	2.3	5.5	17.5	26	21.6	1.12	0.27	2.36	0.64	7.5	1.03	0.36	0.004	<0.01	-85.8	-12.8						
Crystal Spring	45°27.55'	121°35.11'	744	MNH-97-4	8/3/97	5.1	6	70.1	210	32.7	6.05	1.98	4.45	1.27	37.9	1.57	0.76	0.003	<0.01	-89.8	-12.7						
Parkdale Cold Spring	45°29.97'	121°36.26'	585	MNH-97-5	8/3/97	7.9	6	102	66	40.0	7.84	3.81	6.10	1.37	50.8	1.15	1.11	0.005	<0.01	-87.3	-12.3						
Sp. on Lolo Pass Rd.	45°29.44'	121°45.20'	695	MNH-97-6	8/4/97	4.7	6	40.8	94	22.0	3.84	1.12	2.94	0.91	22.9	0.26	0.65	<0.002	<0.01	-78.3	-11.7						
Sp. on Coe Branch	45°26.70'	121°39.41'	1000	MNH-97-7	8/4/97	6	6	60.9	2	43.9	5.83	0.97	4.11	1.96	34.3	0.13	0.66	<0.002	<0.01	-82.7	-11.9						
Cloud Cap Cmpgrnd Sp.	45°23.96'	121°39.25'	1823	MNH-97-9	8/6/97	1.7	5.7	33.4	3.1	25.7	2.91	0.66	2.62	1.13	17.8	0.93	0.31	<0.002	<0.01	-99.8	-13.7						
Palmer Spring	45°20.13'	121°42.35'	1865	MNH-99-3	8/21/99	2.4	6	82.8	1.4	15.9	3.58	0.74	9.49	1.26	10.2	1.69	17.1	<0.002	<0.01	-93.1	-13.1						
Palmer Spring	45°20.13'	121°42.35'	1865	MNH-01-5	7/31/01	2.3	6	69.5	0.68	16.3	3.05	0.55	8.49	1.12	10.9	1.49	13.3	0.002	0.002	-91.3	-12.92						
Spring Box nr. Phlox Pt.	45°19.03'	121°42.95'	1542	MNH-01-6	7/31/01	2.6	6	55.4	18	24.6	4.33	0.94	4.31	1.21	18.2	1.81	5.77	0.003	0.003	-89.4	-12.72						
Still Creek Spring	45°18.95'	121°43.14'	1512	MNH-01-7	8/1/01	2.7	6	76.3	1.2	27.6	6.32	1.34	4.64	1.62	17.9	2.49	11.2	0.003	0.003	-87.8	-12.74						
<u>Streams</u>																											
Salmon River 11:10 AM	45°20.12'	121°42.31'	1853	MNH-99-4	8/21/99	0.9	6	479	140	2.2	0.55	0.13	92.4	0.22	<0.8	0.68	145	<0.002	<0.01	-101.4	-14.0						
Salmon River 5:30 PM	45°20.12'	121°42.31'	1853	MNH-99-5	8/23/99	0.9	6	394	100	2.2	0.55	0.12	78.2	0.25	3.7	0.56	123	<0.002	<0.01	-98.7	-13.7						
Still Creek cascade	45°18.37'	121°43.83'	1283	MNH-01-8	8/1/01	7.4	6.5	256	27	47.1	17.1	9.13	19.1	3.86	69.3	27.7	27.1	0.048	0.023	-91.5	-13.02						
Still Creek @ Hwy 26	45°18.05'	121°44.10'	1195	MNH-01-4	7/30/01	5.5	6	134	150	35.5	8.68	4.02	9.95	2.19	37.0	11.6	13.2	0.07	0.008	--	--						

<sup>a</sup> Carbonate reported as bicarbonate for MNH-97-1 14.9 mg/L and MNH-01-3 11.0 mg/L

<sup>b</sup> Chalcedony temperature is a minimum, because water is a mixture of cold and warm waters.

<sup>c</sup> Magnesium correction is normally not applied when R>50; geothermometer temperature is usually assumed to be the same as the spring temperature in that case. For sample MNH-01-2, magnesium correction applied even though Na-K-Ca temperature < 70°C

**Table 3** (continued). Concentrations of dissolved constituents (Dale Counce analyst).

	Samp. No.	Date	L pH	Concentrations (mg/L)												
				Al	As	Ba	Br	Cs	F	Hg	NO <sub>3</sub>	Rb	Sr	U	V	Zn
<u>Swim Warm Springs</u>																
E. side of pool	MNH-97-1	8/1/97	8.18	0.03	0.0012	0.048	0.30		0.34		<0.02		0.47		0.002	<0.01
E. side of pool	MNH-01-3	7/30/01	8.02	0.002	0.0022	0.048	0.28	<0.001	0.35	0.00008	<0.02	0.024	0.40	0.0015	0.002	0.003
Pipeline Sp.	MNH-01-2	7/30/01	7.84	0.006	0.0012	0.014	0.04	<0.001	0.18	0.00007	0.05	0.011	0.18	<0.001	0.004	0.003
<u>Meadows Springs</u>																
E. Meadows Sp.	MNH-97-8	8/5/97	7.58	<0.01	0.0012	0.006	<0.02		0.02		<0.02		0.082		<0.002	<0.01
E. Meadows Sp.	MNH-99-1	8/19/99	6.18	<0.02	<0.0001	0.005	<0.02		0.02		<0.02		0.071		<0.002	<0.01
Meadows Spring	MNH-97-10	8/7/97	7.77	<0.01	<0.0002	0.006	<0.02		0.04		0.10		0.12		0.002	<0.01
Meadows Spring	MNH-99-2	8/19/99	6.32	<0.02	<0.0001	0.007	<0.02		0.04		<0.02		0.12		<0.002	<0.01
Meadows Spring	MNH-01-1	7/26/01	7.83	0.004	0.0002	0.009	<0.02	<0.001	0.03	0.00006	0.03	0.010	0.16	<0.001	0.002	0.004
Spring nr. Cascade*	MNH-02-1	7/26/02	7.67	0.001	<0.0002	0.004	<0.02	<0.001	0.03	<0.00005	<0.02	0.009	0.089	0.0001	0.003	0.001
<u>Nonthermal springs</u>																
Sp. nr. Phlox Point	MNH-97-2	8/2/97	7.03	0.02	0.0022	0.011	<0.02		0.03		0.16		0.04		0.002	0.07
Crystal Spring	MNH-97-4	8/3/97	7.52	<0.01	<0.0002	0.004	<0.02		0.03		<0.02		0.054		<0.002	0.03
Parkdale Cold Spring	MNH-97-5	8/3/97	7.75	0.02	0.0023	0.004	<0.02		0.05		6.76		0.13		0.004	<0.01
Sp. on Lolo Pass Rd.	MNH-97-6	8/4/97	7.23	0.01	0.0010	<0.002	<0.02		0.02		<0.02		0.028		0.002	0.01
Sp. on Coe Branch	MNH-97-7	8/4/97	7.60	<0.01	0.0032	0.003	<0.02		0.05		<0.02		0.068		<0.002	<0.01
Cloud Cap Cmpgrnd Sp.	MNH-97-9	8/6/97	7.10	0.01	0.0005	0.002	<0.02		0.05		<0.02		0.027		<0.002	<0.01
Palmer Spring	MNH-99-3	8/21/99	5.57	<0.02	<0.0001	0.004	<0.02		0.01		<0.02		0.026		<0.002	<0.01
Palmer Spring	MNH-01-5	7/31/01	6.45	0.005	<0.0001	0.002	<0.02	<0.001	<0.02	<0.00005	<0.02	0.003	0.020	<0.001	<0.001	0.002
Spring Box nr. Phlox Pt.	MNH-01-6	7/31/01	6.60	0.004	<0.0001	<0.001	<0.02	<0.001	<0.02	<0.00005	<0.02	0.003	0.030	<0.001	0.002	0.002
Still Creek Spring	MNH-01-7	8/1/01	6.64	0.017	<0.0001	0.0012	<0.02	<0.001	0.02	<0.00005	<0.02	0.004	0.041	<0.001	0.002	0.002
<u>Streams</u>																
Salmon River 11:10 AM	MNH-99-4	8/21/99	5.36	<0.02	<0.0001	<0.002	<0.02		<0.01		0.10		0.003		<0.002	<0.01
Salmon River 5:30 PM	MNH-99-5	8/23/99	5.45	<0.02	<0.0001	<0.002	<0.02		<0.01		<0.02		0.003		<0.002	<0.01
Still Creek cascade	MNH-01-8	8/1/01	7.66	0.003	0.0002	0.005	<0.02	<0.001	0.09	<0.00005	<0.02	0.010	0.11	<0.001	0.004	0.003
Still Creek @ Hwy 26	MNH-01-4	7/30/01	7.26	0.006	0.0001	0.002	<0.02	<0.001	0.03	<0.00005	<0.02	0.006	0.060	<0.001	0.003	0.002



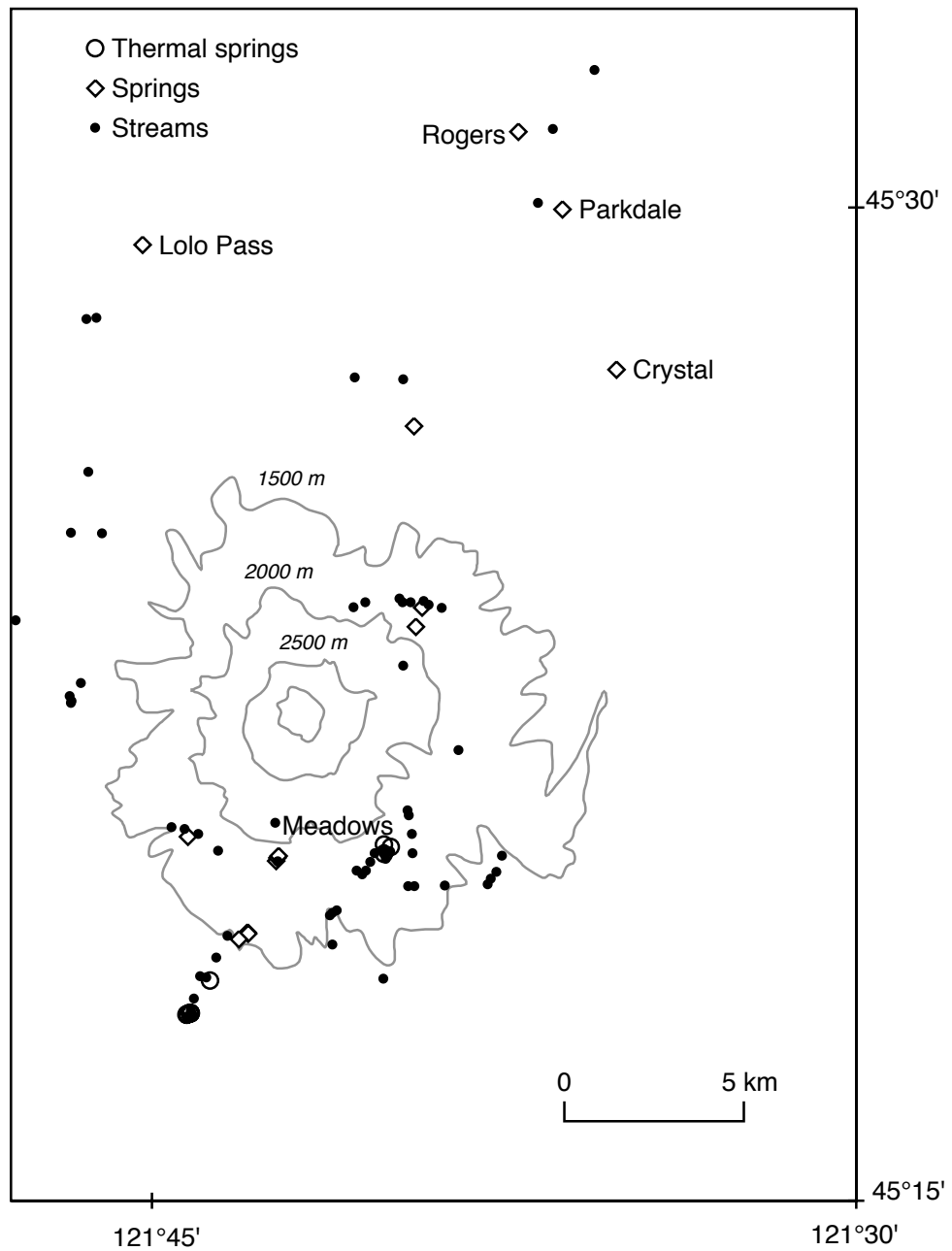
**Table 4.** Gas concentrations without water in mole % for samples from Mount Hood fumaroles. Samples for 1935 from Phillips (1936), for 1951 from Ayers and Creswell (1951), for 1977 and 1978 from Nehring and others (1981), for 1983 from D. S. Sheppard (unpublished data, 1983), for 1980 and 1995 from Mariner and others (2003), for 1996 from unpublished data from R. Symonds and C. J. Janik (1998), for 1997 from Symonds and others (2003), and for 2002 W. C. Evans, analyst. Geothermometer temperatures  $T_{DP}$  from D'Amore and Panichi (1980). Geothermometer uses concentrations of  $CO_2$ ,  $H_2S$ ,  $H_2$ , and  $CH_4$ . Where concentration is listed as 0 or less than, a value of 0.001 % is used in the calculation.

Date	Sample No.	Temp °C	$CO_2$	$H_2S$	$H_2$	$CH_4$	$N_2$	$O_2$	He	Ar	He+Ar	$T_{DP}$ °C
<u>Base of Steel Cliff</u>												
10/6/35	D-1	89	86.9	2.92	0.25	0.085	8.99	0.85			0.11	225
5/15/51	D-3	89	86.8	10.7	0.27	0.038	1.94	0.22			0.01 <sup>a</sup>	253
5/15/51	D-6	89	86.9	10.5	0.24	0.033	2.04	0.25			0.02 <sup>a</sup>	250
7/21/77	MH77-16	91	91.5	4.02	0.51	0	3.87	0	0.00081	0.021	0.0218	294
<u>Devils Kitchen</u>												
10/6/35	A-2	89	93.8	1.77	trace	--	4.21	0.13			0.05	
5/15/51	A-1	89	89.9	4.11	3.87	0.040	1.65 <sup>a</sup>	0.16			0.3	323
5/15/51	A-5	89	89.3	4.30	4.09	0.059	1.85	0.16			0.3	321
7/21/77	MH77-15	88	91.9	0.16	0.0062	0	5.61	1.26	0	0.081	0.081	144
10/4/78	78H-2g	92	94.4	3.90	1.22	0	0.46	0	0	0.0018	0.0018	323
10/4/78	78H-2g Dup.	92	93.2	3.67	2.22	0.0055	0.87	0	0	0.0027	0.0027	323
7/21/83		91	87.9	2.45	1.64	<0.001	7.94	0	<0.0013	0.118	0.118	328
5/8/97	970508-1	90.3	77.9	16.1	2.62	<0.0005	2.19	0.0039	0.00291	0.0155	0.0184	
<u>Hot Rocks</u>												
5/15/51	2	91	90.9	2.26	4.02	0.055	2.46	0.34				309
<u>Crater Rock</u>												
10/6/35	B-3	71	0.69	--	0.58	--	79.1	19.7				
5/15/51	B-4	86	58.4	0.000	trace?	0.0000	32.9	8.32			0.44	51
7/21/77	MH77-17	90	96.7	1.23	1.22	0	0.95	0.0082	0.025	0.0077	0.0327	301
10/4/78	78H-4g Dup.	91	92.7	3.69	2.76	0	0.89	0	0	0	0	354
10/4/78	78H-4g	91	93.3	2.63	3.21	0.0003	1.02	0	0	0	0	370
8/9/80			93.28	3.10	2.81	<0.002	0.87	<0.02	<0.005	<0.02		351
7/21/83		90	91.1	0.985	2.93	<0.0002	4.92	0.0018	<0.0006	0.066	0.066	331
9/12/95			93.15	3.50	3.23 <sup>c</sup>	<0.0002	0.92	0.042	--	0.0028	0.0028	360
10/8/96	961008-1	89.2	90.9	4.96	2.49	<0.00077	1.61	0.0018	0.00072	0.0203	0.0210	357
10/8/96	961008-2	89.2	91.3	5.07	2.22	<0.00068	1.38	0	0.00057	0.0168	0.0174	353
10/8/96	961008-8	90.0	91.4	3.69	3.11	<0.00093	1.84	0	0.00074	0.0237	0.0244	360
9/9/97	970909-2	91	91.69	4.55	2.13	<0.0004	1.21	0.0017	0.00101	0.0101	0.0111	349
8/29/02		89	90.2	5.12	2.88	<0.0002	1.62	0.19	0.002	0.012	0.014	365
<u>Ridge west of Devils Kitchen</u>												
10/4/78	78H-1g	--	6.3	0	0	0	70.5	17.0	0	0.84 <sup>b</sup>	0.84	

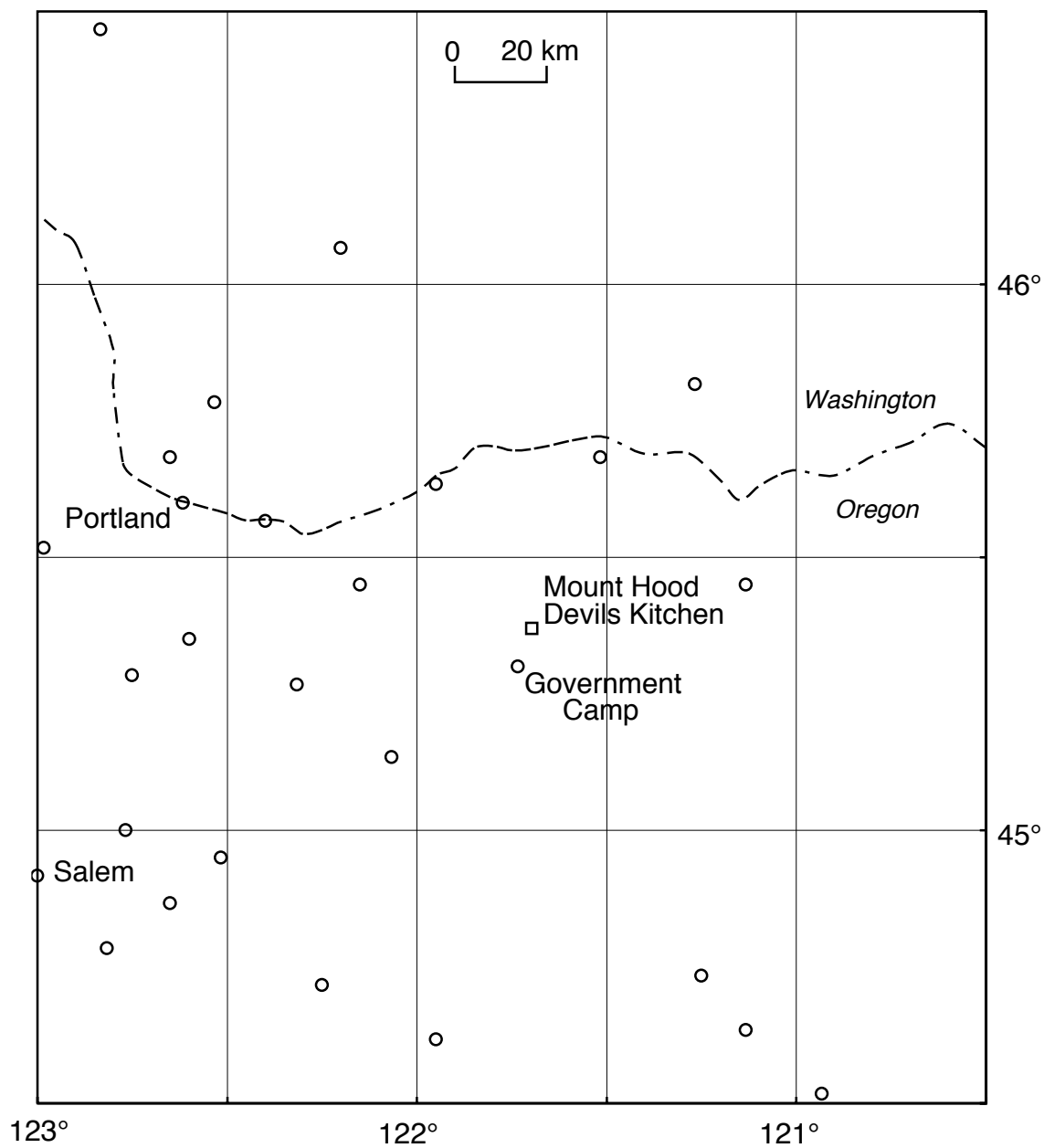
<sup>a</sup> Value in Nehring and others (1981) does not agree with recalculation of analysis in Ayers and Creswell (1951).

<sup>b</sup> Value in Nehring and others (1981) corrected based on original laboratory notes.

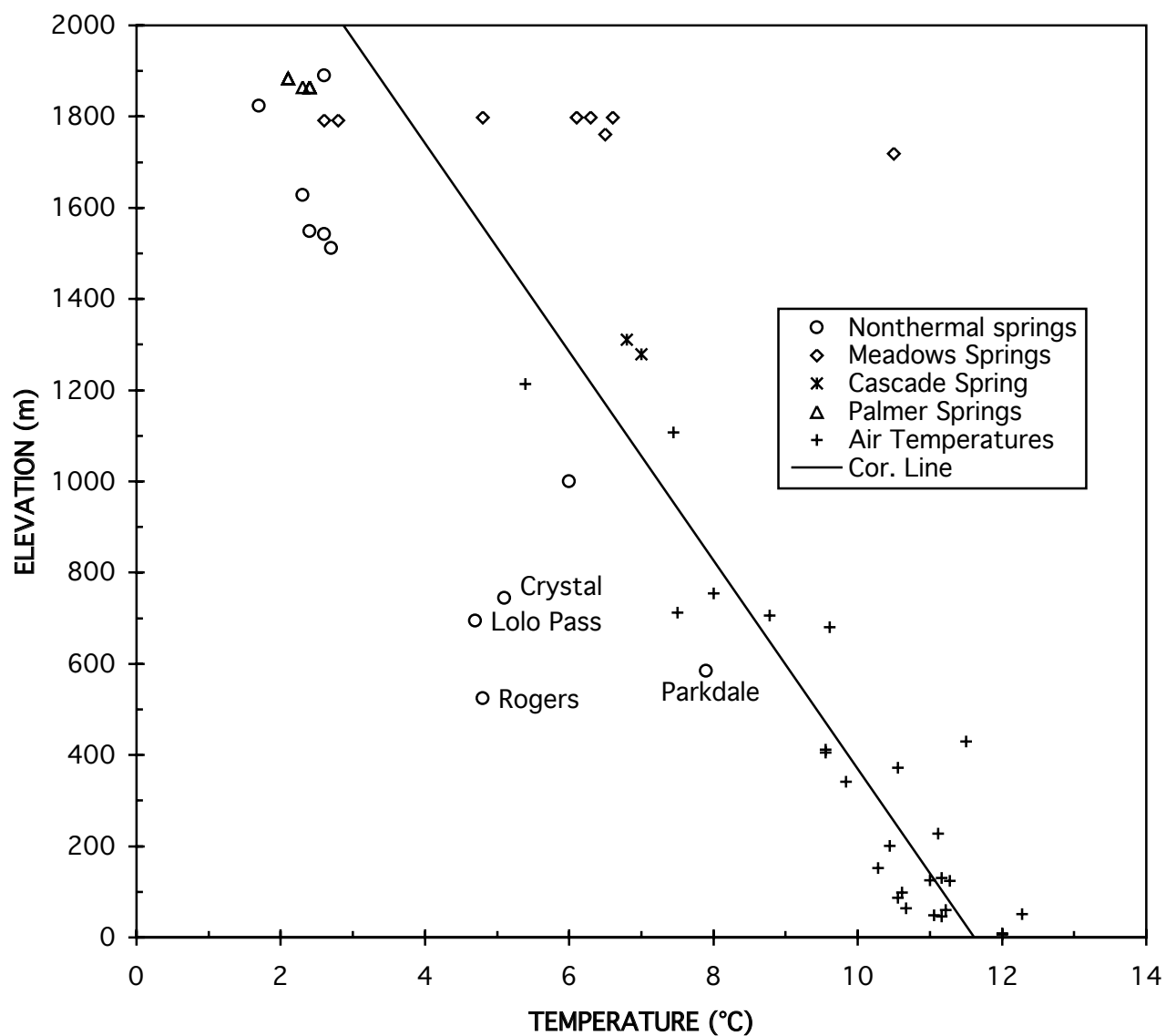
<sup>c</sup> Estimated value based on air corrected ratio of  $H_2/CO_2$  from a sample from the same site that was contaminated with air.



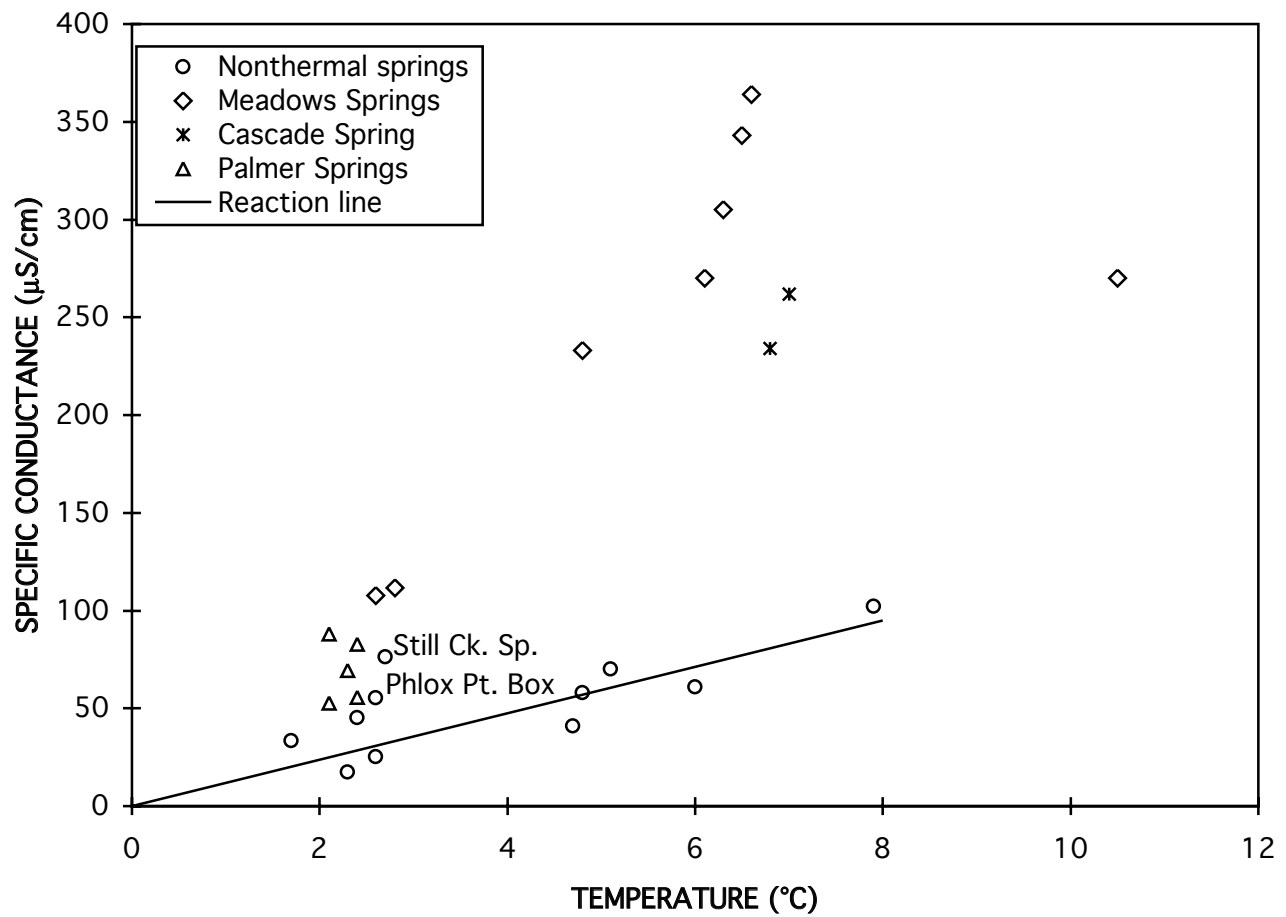
**Figure 1.** Map of locations of sites visited in this study. Topography of cone is shown above 1500 m.



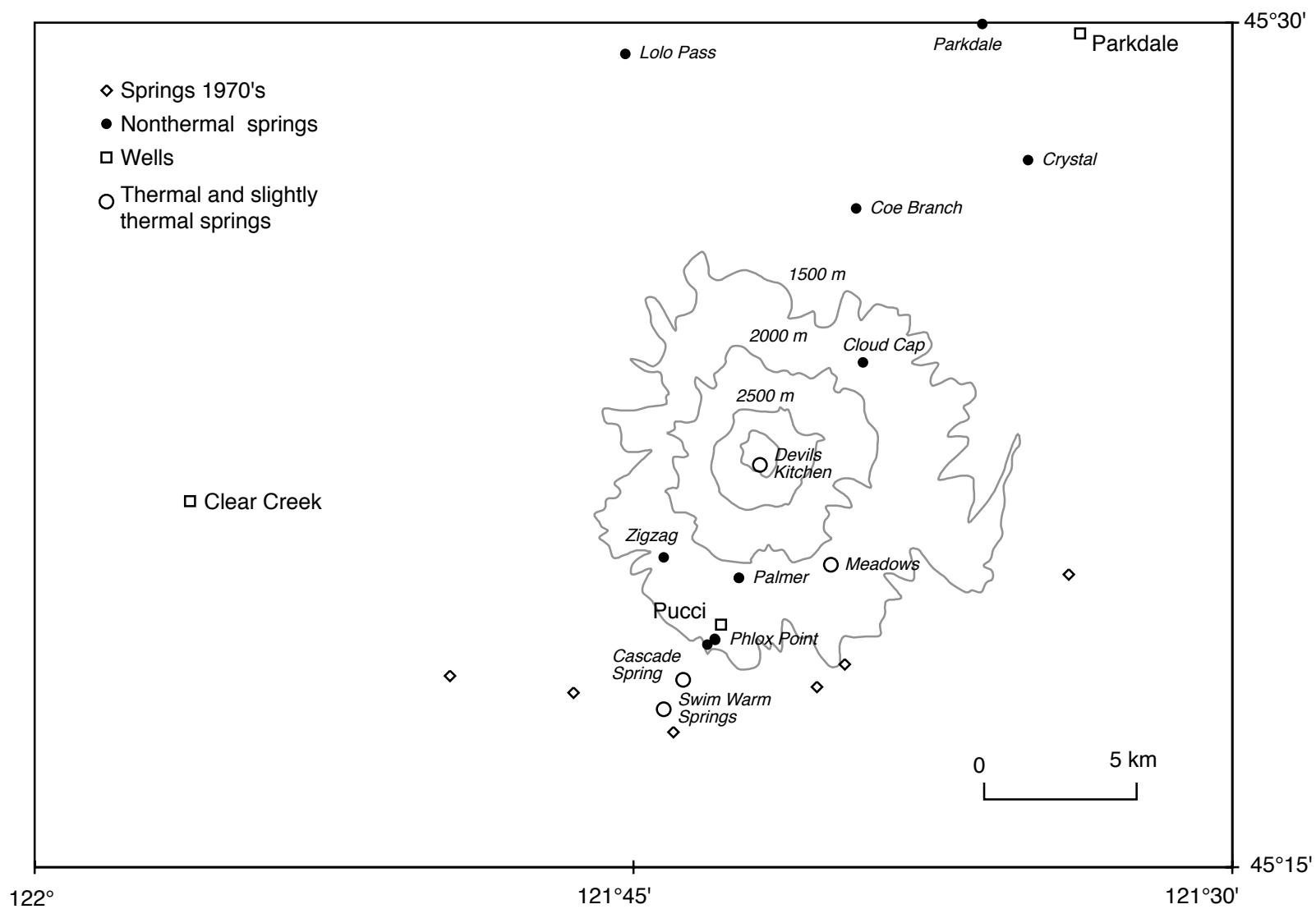
**Figure 2.** Map of weather stations in the vicinity of Mount Hood with 30-year records for calculation of normal air temperatures.



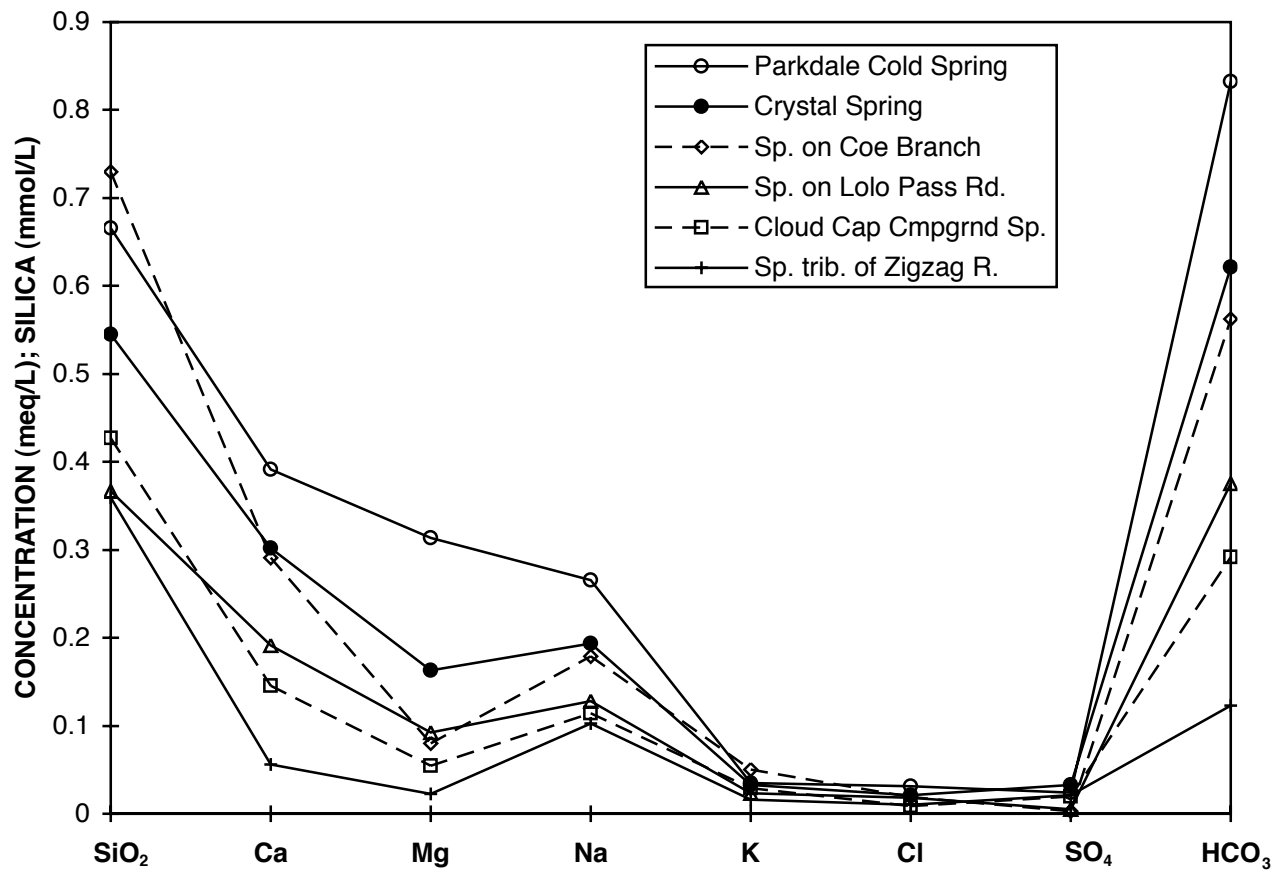
**Figure 3.** Temperature versus elevation for air temperatures from weather stations shown in Figure 2 and data for temperatures of springs from sites in Figure 1 except for Swim Warm Springs whose values plot beyond the scale of this figure.



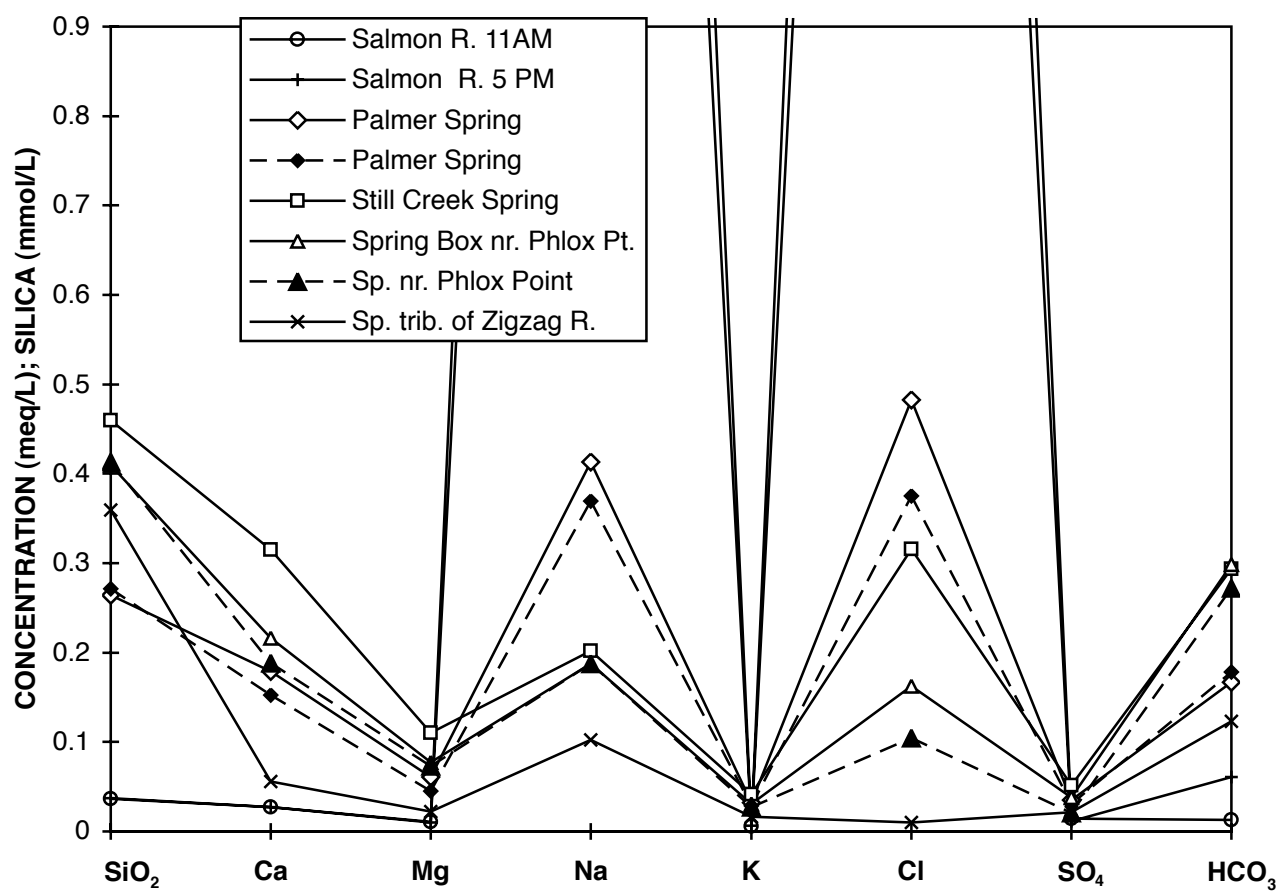
**Figure 4.** Specific conductance versus temperature of springs from sites in Figure 1 except for Swim Warm Springs whose values plot beyond the scale of this figure.



**Figure 5.** Map of locations of springs and wells with data published earlier (Table 2), nonthermal, thermal, and slightly thermal springs from this study (Table 3). Topography of cone shown above 1500 m.

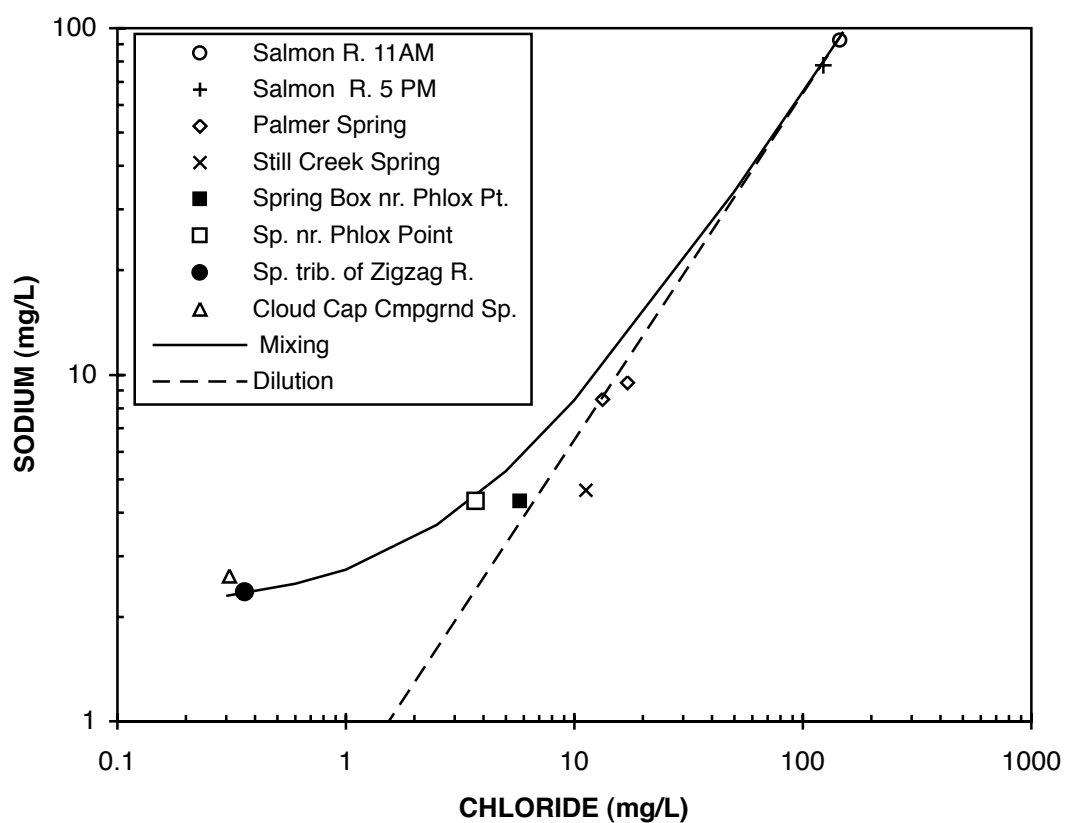


**Figure 6.** Modified Schoeller diagram for some of the nonthermal springs sampled in this study.

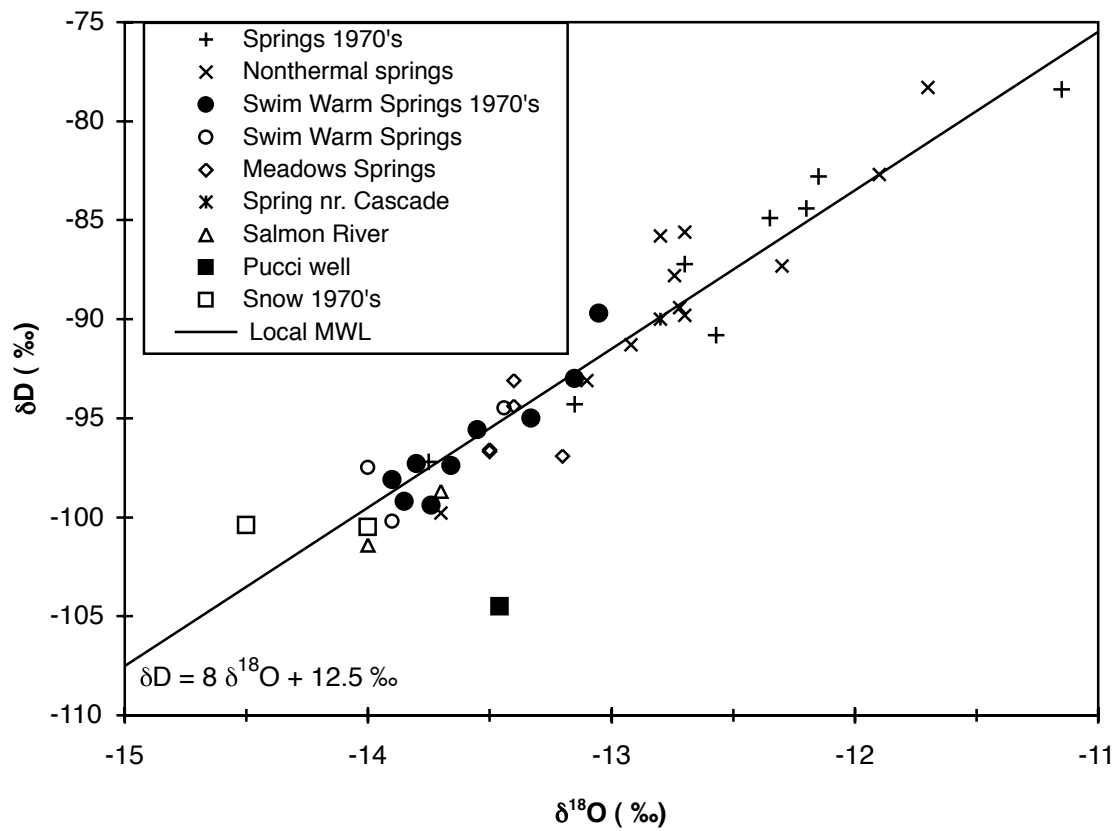


**Figure 7.** Modified Schoeller diagram for nonthermal springs sampled in this study showing anomalous chloride from salt added to snow, Salmon River samples, and the spring tributary to the Zigzag River for comparison.

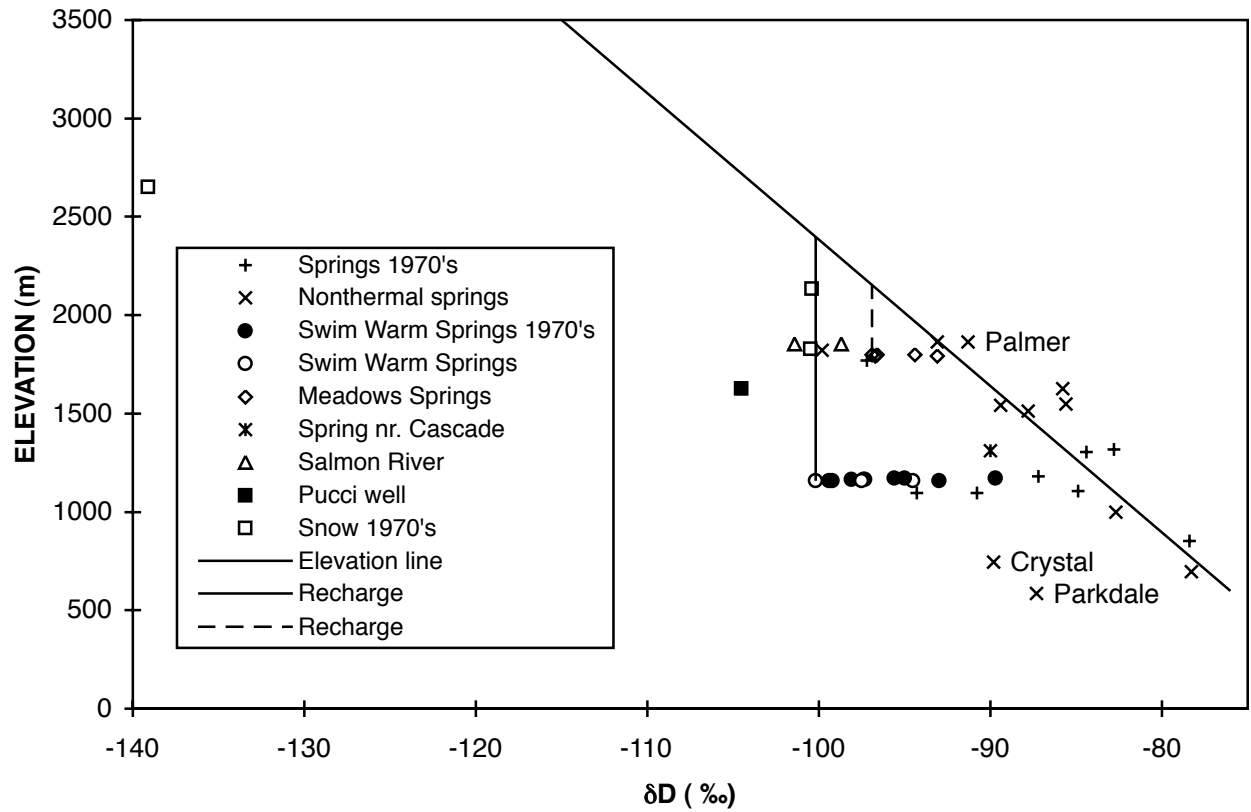




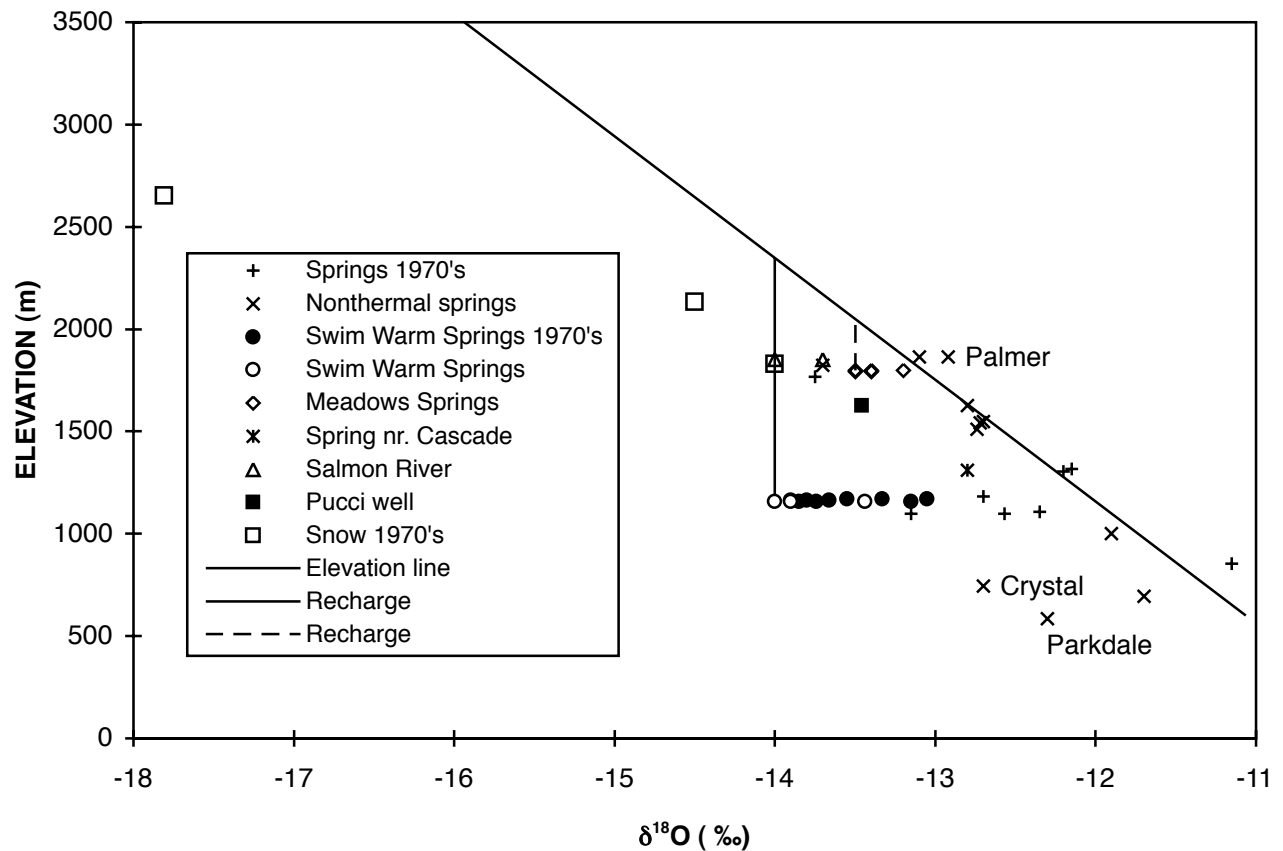
**Figure 8.** Sodium versus chloride for nonthermal springs sampled in this study showing anomalous chloride from salt added to snow, Salmon River samples, and the spring tributary to the Zigzag River and Cloud Cap Campground Spring for comparison.



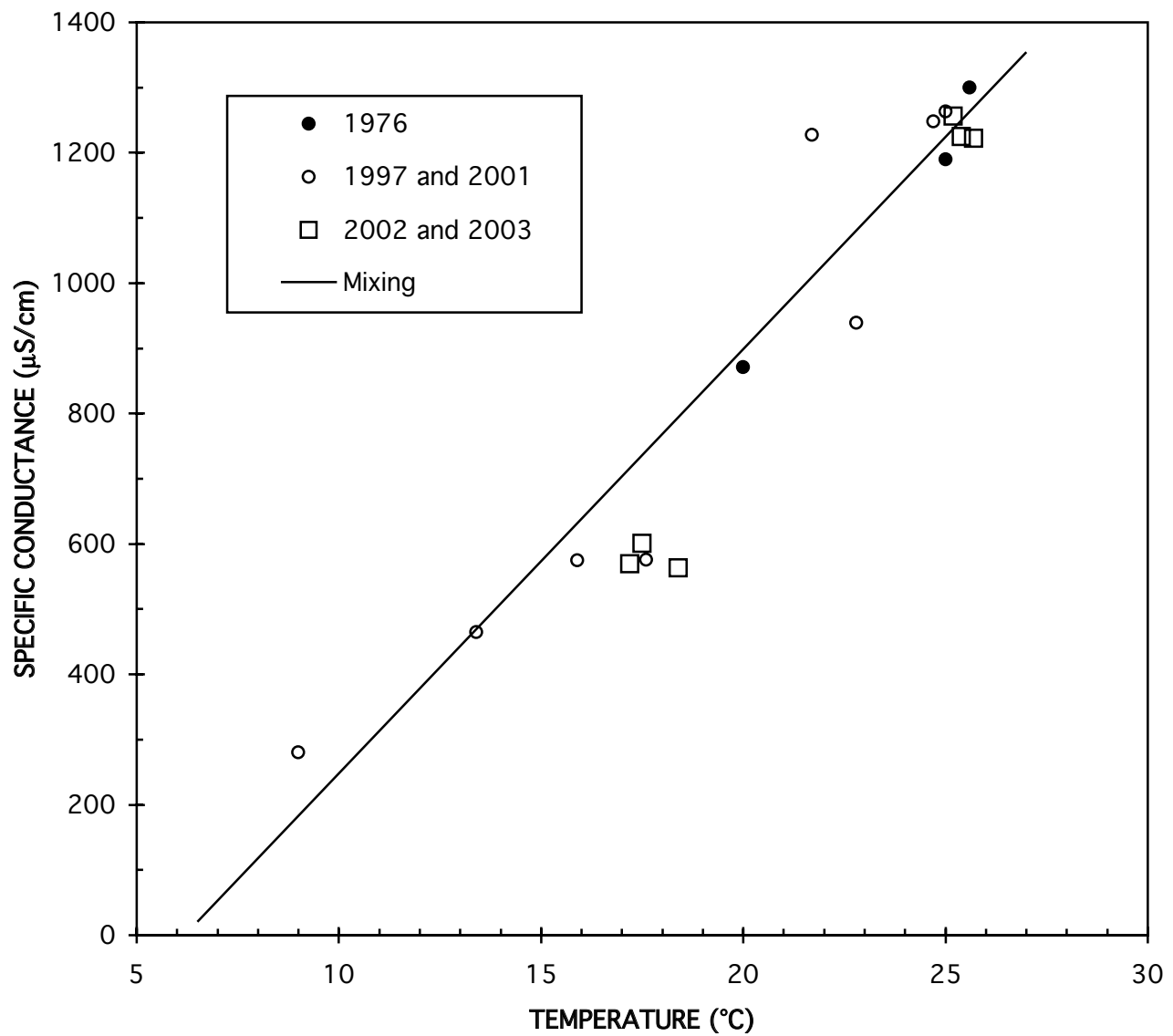
**Figure 9.** Deuterium versus oxygen-18 for samples from Tables 2 and 3. Local meteoric water line determined by fixing slope at a value of 8 and adjusting the intercept to minimize  $\delta D - 8 \delta^{18}O - \text{intercept}$ .



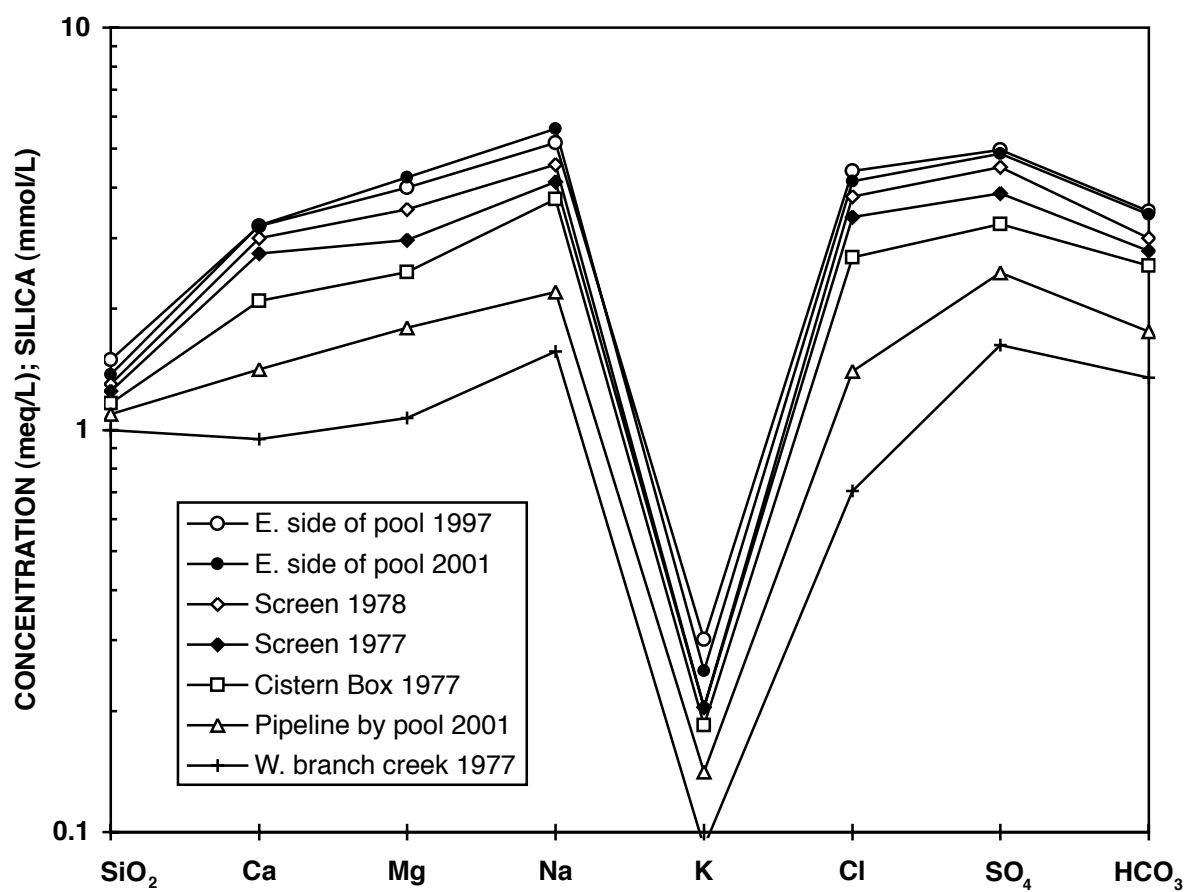
**Figure 10.** Deuterium versus elevation for samples from Tables 2 and 3.



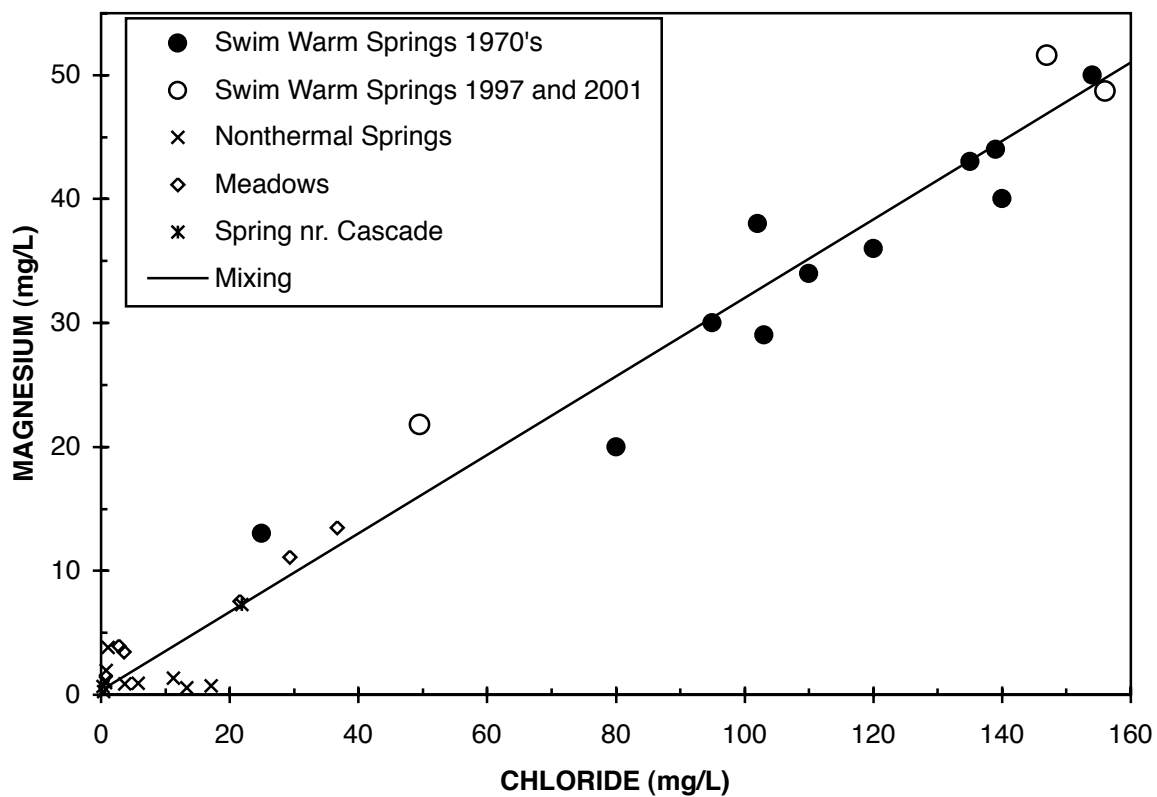
**Figure 11.** Oxygen-18 versus elevation for samples from Tables 2 and 3.



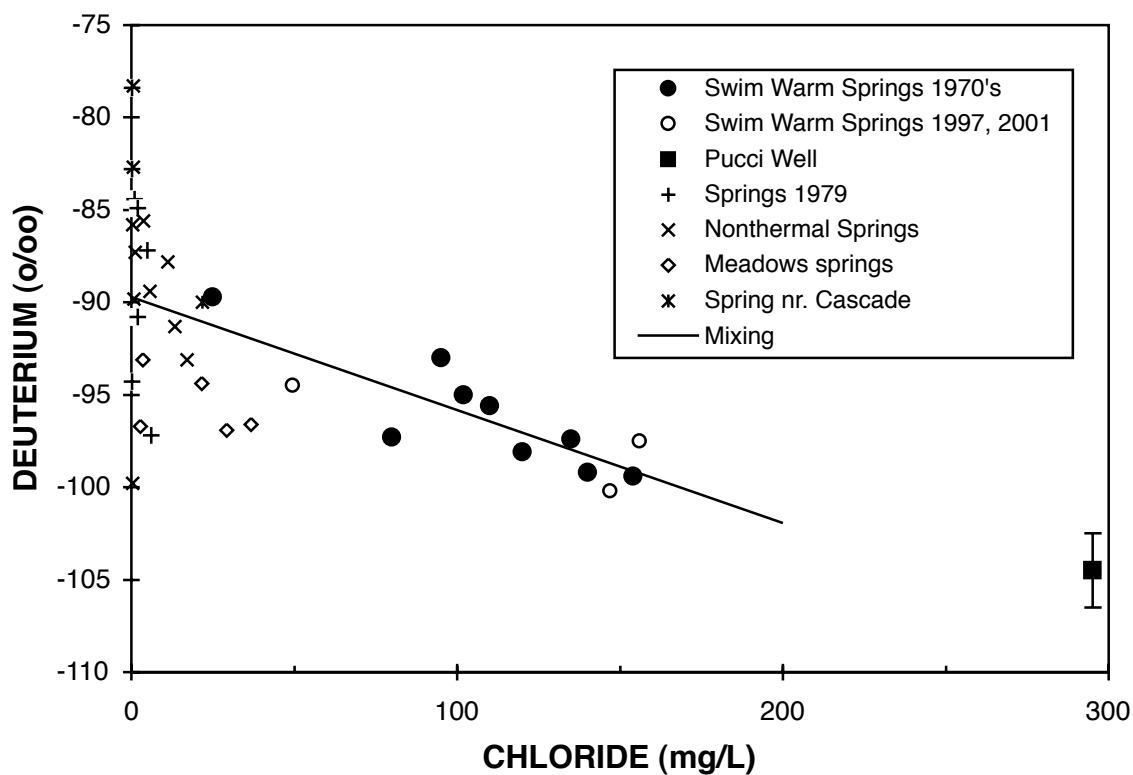
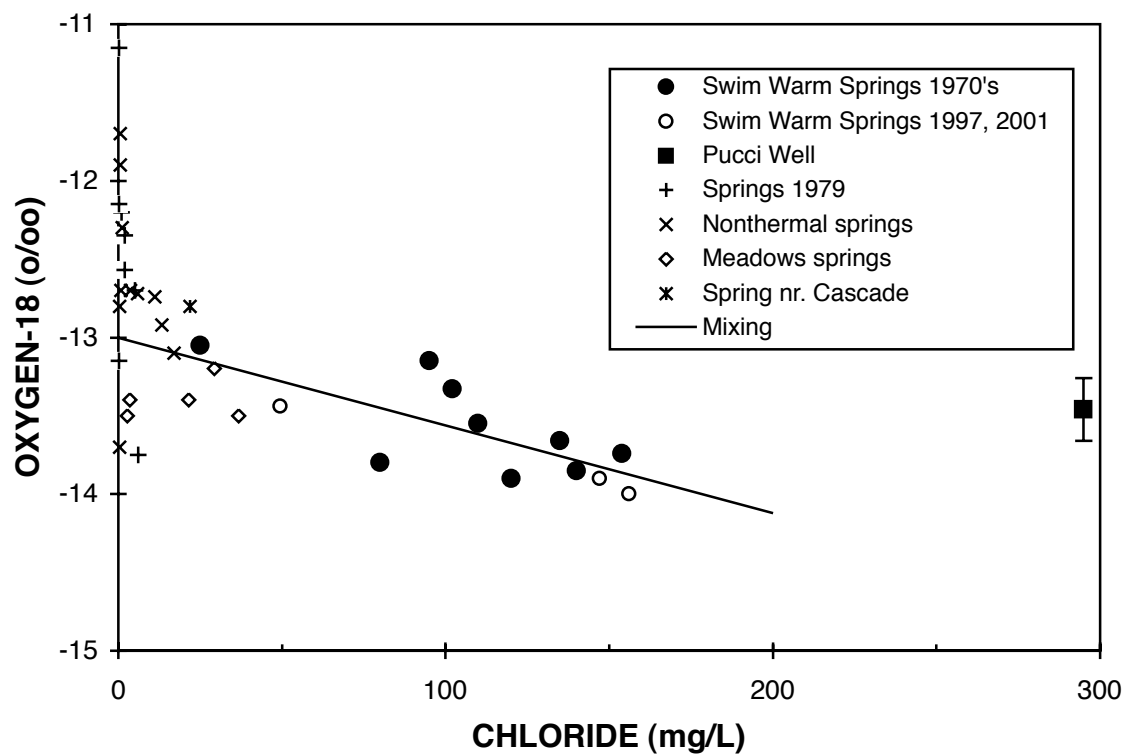
**Figure 12.** Specific conductance versus spring temperature for various vents of Swim Warm Springs. Data from 2002 and 2003 not included in least-squares line to keep from biasing result from repeated sampling of same two features.



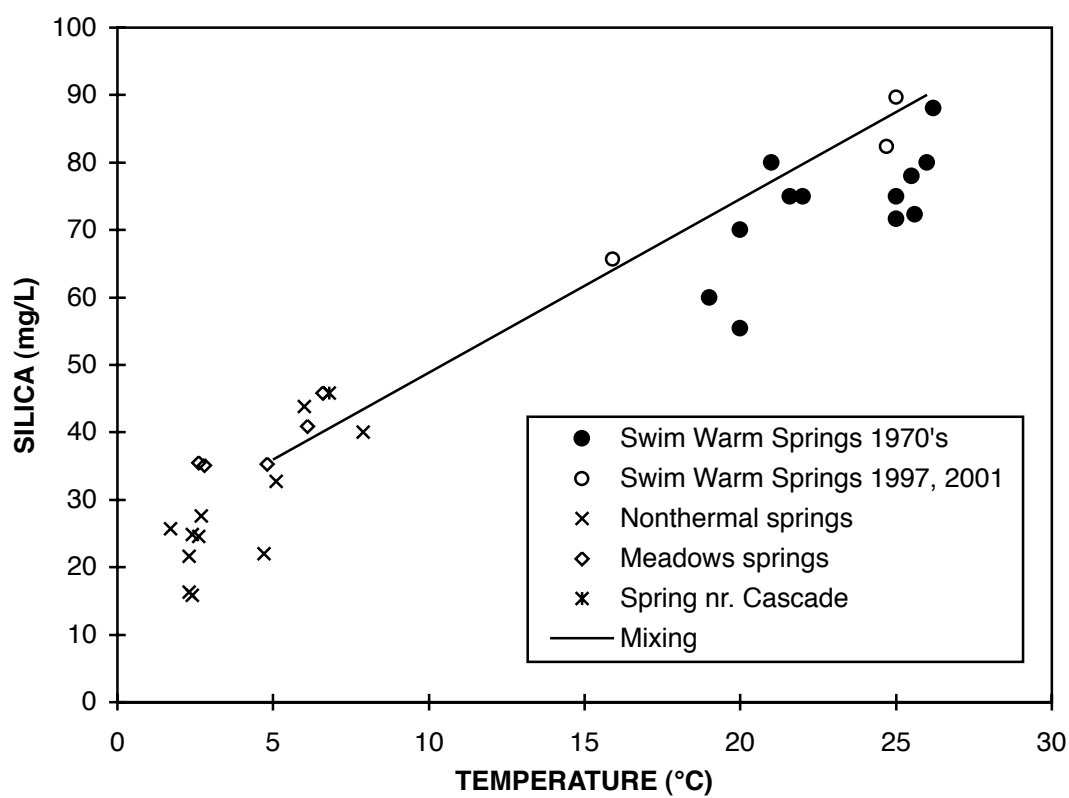
**Figure 13.** Modified Schoeller diagram (note log scale) for various vents of Swim Warm Springs.



**Figure 14.** Magnesium versus chloride for springs. Mixing line is for Swim Warm Springs samples.

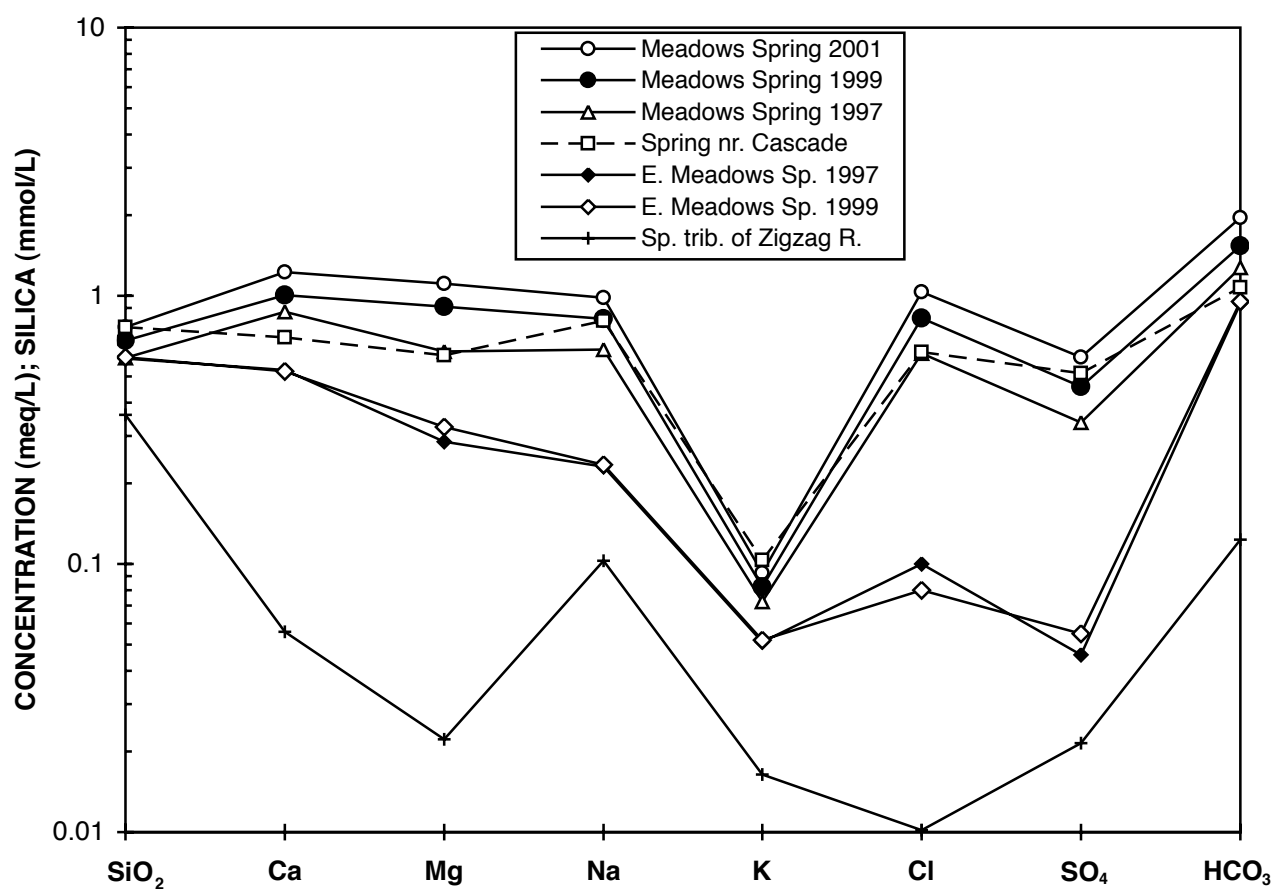


**Figure 15.** Isotopes versus chloride for springs and other samples. Mixing lines are for Swim Warm Springs samples. Some analyses from 1970's with chloride values given as less than some value have been plotted using the reported value.

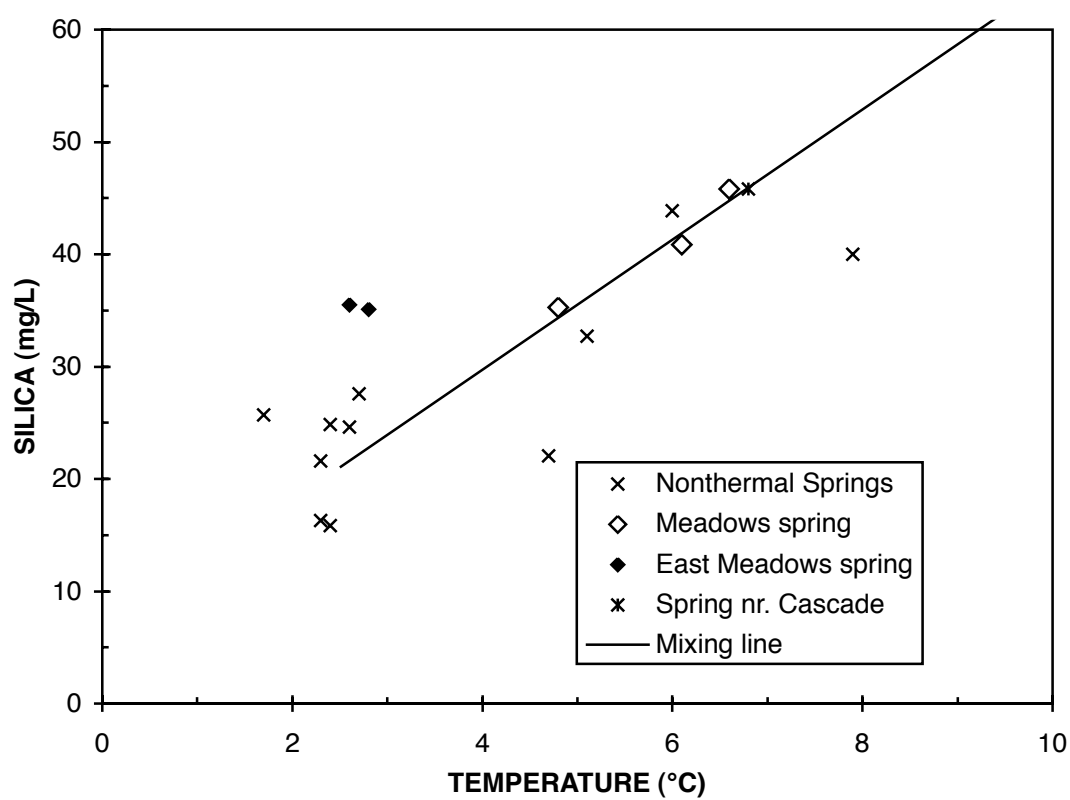


**Figure 16.** Silica versus spring temperature for springs. Mixing line is for Swim Warm Springs samples.

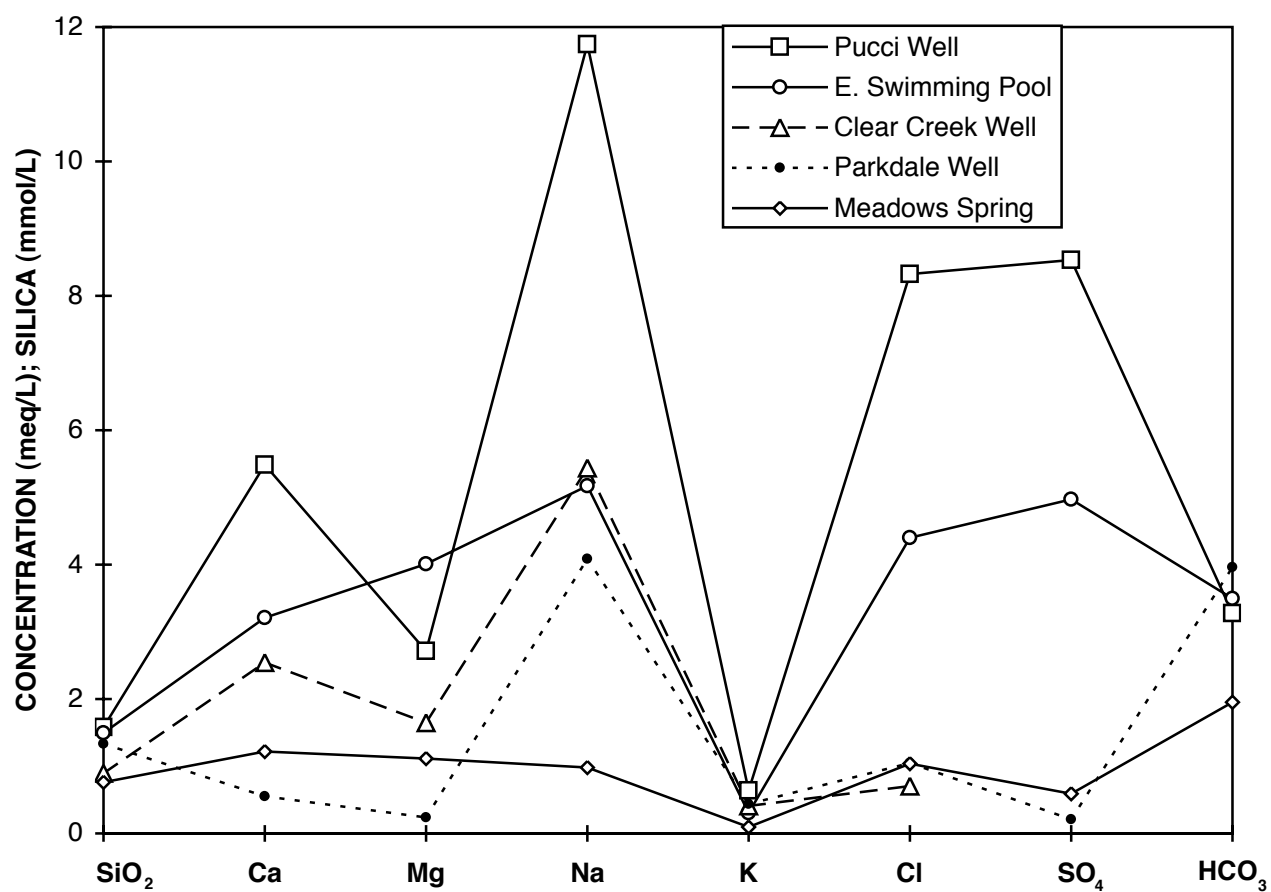




**Figure 17.** Modified Schoeller diagram (note log scale) for Meadows springs, spring near the Cascade, and spring tributary to the Zigzag River for reference.



**Figure 18.** Silica versus spring temperature for Meadows springs, spring near the Cascade, and nonthermal springs. Mixing line is for Meadows Spring samples.



**Figure 19.** Modified Schoeller diagram for well samples and Swim Warm Springs (East Swimming Pool) and Meadows Spring.