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Temperatures of springs in the vicinity of Crater Lake, Oregon, in relation to air and ground temperatures

by

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ABSTRACT

Orifice temperatures, specific conductance, and flow have been measured for springs in the vicinity of Crater Lake ranging in elevation from 1266 to 2182 m. Spring temperatures generally decrease with increasing elevation. Air temperatures from weather stations in an area surrounding Crater Lake decrease by 4.6°C/km of elevation with an intercept of 13.2°C at sea level. Ground temperatures obtained by extrapolating temperature/depth data for seven drill holes back to the surface show a variation with elevation generally similar to that found for air temperatures. Comparison of spring and air temperatures versus elevation shows that spring temperatures are generally cooler (1.9°±1°C) than air temperatures except for a group of springs in the eastern Wood River Valley. Some of the springs in the eastern Wood River Valley are as much as 4°C higher in temperature than other springs at the same elevation. A chloride inventory of the springs in the eastern Wood River Valley shows an anomalous discharge larger than the inflow to Crater Lake. Though not warm enough to qualify as thermal springs, the springs in the eastern part of the Wood River Valley represent a significant thermal and chemical anomaly.

INTRODUCTION

The chemistry of springs in the vicinity of Crater Lake, Oregon, has been discussed by Thompson and others (1990) and by Nathenson and Thompson (1990). The purpose of this study is to extend those works by using careful measurements of spring temperatures to relate spring temperature to air and ground temperatures and by using these data to explore the notions of thermal, nonthermal, and cold springs.

The temperatures of springs involve a complex relationship between circulation path, flow rate, average annual air temperature, and local climate effects. 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. Muffler (1987) in a letter to the Director of the National Park Service concerning "Significant Thermal Features" proposes that 10°C above mean annual air temperature be used to define thermal. 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 can mix with thermal water making the magnitude of the temperature anomaly very small.

The definitions for thermal spring use mean annual air temperature, because there are abundant data available from weather stations. Conceptually, a more appropriate quantity for comparison to spring temperatures would be the average ground temperature at the surface. Although a small number of weather stations do measure ground temperatures, many more ground-temperature values can be calculated by projecting temperature versus depth data obtained in drill holes back to the surface. An advantage of this method is that it provides an integrated measure that is less sensitive to small-scale variations in soil properties. Bodell and Chapman (1982) used this method to study part of the Colorado Plateau. They found that ground temperatures had a lapse rate of -6.9°C/km over an elevation interval of 1100 to 2900 m. The U.S. Standard Atmosphere (U.S. Committee on Extension to the Standard Atmosphere, 1976) assumes a lapse rate for air temperatures of -6.5°C/km from 0 to 11 km altitude, agreeing with the slope found by Bodell and Chapman (1982). Powell and others (1988) added mean annual air temperatures from weather stations to the data set of Bodell and Chapman and found that both had a lapse rate of about -7°C/km. Ground temperatures averaged approximately 3°C warmer than air temperatures. Delisle (1988) gives a general rule that ground temperatures have a lapse rate of -7 °C/km in dry climates and -4 °C/km in wet climates, and values cited in Birch (1950, Table 5) generally agree. Thus ground temperatures are not necessarily the same as air temperatures.

AIR AND GROUND TEMPERATURES

Air temperatures for weather stations in an area of 3° longitude by 2° latitude are given in Table 1. Locations of the weather stations are shown on Figure 1, and temperatures are plotted versus elevation in Figure 2. These values are for a 30 year period and should be relatively stable. The area covered by these stations is relatively large, ranging from the Coast Range through the Cascade Range and into the Basin and Range. Stations from a large area are necessary to get an adequate range of elevations. Figure 2 shows that at each elevation there is a significant range of average annual temperatures, but it appears reasonable to fit a best straight line to the data. Using temperature as the dependent coordinate, the line has a slope of -4.6±0.4°C/km and an intercept of 13.2±0.5°C at sea level elevation (± values are standard error). The value for lapse rate is smaller in absolute value than that found by Bodell and Chapman (1982) for the Colorado Plateau but is similar to the ground temperature lapse rate given by Delisle (1988) for wet climates.

A search was made to find drill hole data for calculating average ground temperatures for the same area. Data from many drill holes indicate either hydrologic disturbances or near-surface disturbances that are not easily understood. Data from seven drill holes were found to be used easily for extrapolation, and the results are given in Table 2 and plotted on Figures 1 and 2. The ground temperature data are more restricted areally and in elevation range because of the significant influence of hydrology on near-surface temperatures in the higher elevations of the Cascades (e.g. Black and others, 1983a). Unlike the results for the Colorado Plateau, the distribution of ground temperatures is generally similar to that for air temperatures (Figure 2). More data might show that this is somehow a biased sample; however, the larger data set of Powell and others (1988) has no ground temperatures cooler than mean annual air temperatures whereas 3 out of 7 in Figure 2 are cooler than the air temperature best fit line. It seems likely that the difference reflects a difference in climate between the Cascade Range and the Colorado Plateau and is not an artifact of the data set.

SPRING TEMPERATURES AND OTHER CHARACTERISTICS

Measurements of temperature, specific conductance, and flow have been made for many of the springs in the vicinity of Crater Lake (Figure 3 and Table 3). Temperatures were measured using a thermocouple thermometer (Omega Engineering Model 871) with 0.1°C electronic digital readout. Temperatures from the thermocouple and readout device were compared to a 0.1°C mercury-in-glass thermometer in a well-stirred beaker of water and found to be within 0.2°C over the range 1° to 15°C, both before and after the field trip. Spring temperatures were measured by placing the thermocouple in the orifice. Specific conductance was measured using a digital conductivity meter (Whatman CDM 300) with automatic temperature compensation of 2% per °C. Comparison to standard solutions at 74 and 718 µS/cm showed the meter and cell to agree to the standard solutions to within 3 %. Specific conductance was measured either in the spring orifice or slightly downstream. Elevations were obtained from 1:24,000 topographic maps to the nearest contour (40, 20, 5, or 1 foot depending on the map). Spring flows were obtained by measuring a representative depth (in a few cases several depths were measured) and a representative width to obtain a cross-sectional area and measuring speeds by timing the passage of a floating object over a measured distance. This method of measuring flows is inherently limited in accuracy and precision, and flows are probably only known within ±50 %.

Figure 4 shows the measured temperatures plotted versus elevation. It has previously been established that the source of the Wood River and other springs in the eastern Wood River Valley are anomalous in chemical constituents compared to the water in other springs (Nathenson and Thompson, 1990). Data for these springs are shown using special symbols in Figures 3 and 4 and will be discussed as the Wood River group. Springs in the western Wood River Valley along with Cedar Spring provide a useful comparison to the Wood River group and are combined as the Cedar Springs group. Except for about half the data for the Wood River group, nearly all of the spring temperatures in Figure 4 plot below the best-fit air line and even below the lowest air temperature measured. Spring temperatures, like air temperatures, increase with decreasing elevation. Most of these springs probably fit Meinzer's definition of a cold spring. Excluding the Wood River group, spring temperatures average 1.9±1.0°C cooler than the air temperature line.

Some of the temperatures that have been obtained in this study are significantly cooler than those published by Thompson and others (1990). Many of the temperatures in that study were collection temperatures rather than orifice temperatures. This is especially true for samples from within the crater walls, where the orifice was physically difficult to get to.

Also shown on Figure 4 is a temperature profile for Crater Lake obtained in June 1971 (Neal and others, 1972). The upper 300 m of Crater Lake has large variations in temperature in response to winter cooling and summer heating, but the profile was measured at a time of year when these effects are minimal. The important temperatures are those in the bottom half of Crater Lake, which do not vary seasonally and represent an annual average. These temperatures are similar to those for nearby cold springs and indicate that the lake is neither particularly cold nor hot compared to its surroundings.

On Figure 4, the springs of the Wood River group are shown separated into the source of the Wood River and the remainder of the group. The source of the Wood River is a large pool with numerous vents aligned along an ≈800-m linear, and data obtained at several of these vents cover a significant range in temperature (Figure 4). Orifice temperatures for about half of the Wood River group are significantly warmer than the best-fit air line and appear to be significantly warmer than the trend of other springs on Mount Mazama and springs at the same elevation in the Cedar Springs group.

To gain perspective on the anomalous temperatures for springs in the Wood River group, it is useful to look at the variation of specific conductance. Figure 5 shows specific conductance versus temperature, and Figure 6 shows specific conductance versus elevation. Nathenson and Thompson (1990) have shown that the chemistry of most springs on Mount Mazama is fairly similar, because it is produced by the weathering of volcanic glass and clinopyroxene. The plot of specific conductance versus temperature indicates that the total dissolved solids correlates well with temperature. Temperature may not actually be the determining factor for the amount of dissolved solids, but it could reflect another mechanism for degree of reaction, such as increasing distance from source to exit at lower elevations. The plot of specific conductance versus elevation shows that specific conductance generally increases with decreasing altitude, just as temperature does, but that the springs of the Wood River group do not follow this relationship. Nathenson and Thompson (1990) have shown that these springs are different from other springs in the area in having significant amounts of dissolved chloride and sulfate, and there has to be an additional mechanism beyond weathering to explain their chemistry. The range of temperature and specific conductance for the springs of the Wood River group reflects mixing of two waters: one that is warm and slightly saline with another that is cool and less saline.

The general chemical characteristics of the springs of the Wood River group are similar to those of Crater Lake (Nathenson and Thompson, 1990). Their respective chloride fluxes can also be compared as a possible indicator of the flow of thermal water (Mariner and others, 1989). Table 4 presents an inventory of chloride flux for the Wood River group. The total flux is 34,000 mg/s. Mariner and others (1989) have also measured the chloride flux for the eastern Wood River Valley using different measuring points and a different methodology to establish the anomalous chloride; they found a higher flux of 60,000 mg/s. Nathenson (1990) has done a chemical balance for Crater Lake and found that the anomalous chloride input is 24,700 mg/s. Thus the chloride flux from the Wood River group is larger than the input to Crater Lake. Temperatures for the Wood River group indicate that the chloride flux is associated with a significant thermal anomaly; however, the available data are inadequate to quantify the thermal anomaly in terms of energy output.

CONCLUSIONS AND DISCUSSION

Data presented in this paper show that spring temperatures have a consistent relationship to air and ground temperatures within a restricted area. Spring temperatures tend to increase with decreasing elevations, just as air temperatures do. Ground temperatures obtained by extrapolating temperatures measured in drill holes in the vicinity of Crater Lake are similar to air temperatures, but the data obtained by Powell and others (1988) show that this relationship is not universal. The trend of the cold-spring data makes it possible to show that temperatures and specific conductances for the Wood River group of springs are anomalous.

The data for the springs in the Wood River group challenge a simple numerical temperature criterion for what is a thermal spring. Compared to other springs in the vicinity of Crater Lake, they are anomalous in temperature, dissolved chloride, sulfate, boron, and lithium, and chloride flux. The magnitude of the anomaly is small for all measures except for chloride flux; however, it is possible that there is a parent water that is high in all measures that is substantially diluted in the samples that have been obtained. The broad similarity of the characteristics of the springs of the Wood River group and the inflow to Crater Lake is intriguing, especially in view of the location of most of the springs of the Wood River group on a fault that trends towards Crater Lake but cannot be followed under the cover of the young volcanic rocks of Mount Mazama and the climactic eruption (Kienle and others, 1981, Sherrod and Pickthorn, in press). By having data on cold-spring temperatures at various elevations, it has been possible to establish that the springs of the Wood River group represent a thermal anomaly. The spring temperatures do not satisfy the numerical criterion for thermal springs, but they do satisfy Meinzer's *appreciable* and Waring's *noticeable* criteria because of the amount of data available to define background temperatures. For most purposes, the use of the numerical criterion is to be preferred, because background data usually are not available for the more careful comparison done for this area.

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Table 1. Mean annual temperatures from weather stations in the vicinity of Crater Lake (National Oceanic and Atmospheric Administration, 1982)

Station		Latitude		Longitude		Elevation	Temp.
Number	Name	Deg	Min	Deg	Min	meters	°C
304	Ashland 1N	42	13	122	43	543	11.1
1546	Chemult	43	14	121	47	1451	5.6
1946	Crater Lake NP HQ	42	54	122	8	1974	3.2
2374	Dorena Dam	43	47	122	58	250	10.7
4506	Klamath Falls 2 SSW	42	12	121	47	1249	8.8
5429	Medford WSO	42	22	122	52	400	12.0
6907	Prospect 2 SW	42	44	122	31	757	10.3
7169	Riddle 2 NNE	42	58	123	21	202	12.2
7331	Roseburg KQEN	43	12	123	21	142	12.1
7354	Round Grove	42	20	120	53	1490	6.7
7698	Sexton Summit WSO	42	37	123	22	1169	8.8
9316	Wickiup Dam	43	41	121	41	1328	6.4

Table 2. Ground temperatures for drill holes in the vicinity of Crater Lake obtained by projecting temperature versus depth to the surface. Data from Black and others (1983a, 1983b), Blackwell and others (1981, 1982, 1986), Hull and others (1977, 1978).

	Township/Range/	Latitude		Longitude		Elevation	Temp.
Name	Section	Deg	Min	Deg	Min	meters	°C
CR-MCHSE	T21S/R4E/28Ad	43	43.1	122	20.0	533	8.8
PCCPG-WW	T22S/R3E/10Dd	43	40.3	122	27.0	490	10.3
SLVRBUTT	T31S/R6W/23Cd	42	51.4	123	22.6	1170	6.9
PHOEN-BL	T37S/R1W/27Cb	42	19.4	122	48.7	529	13.0
COOK	T39S/R1E/2Bc	42	12.7	122	40.6	622	14.4
STURDEVNT	T39S/R1E/15Cdb	42	10.4	122	41.3	731	10.5
Corral Cr.	T40S/R4E/5Db	42	7.1	122	22.5	1055	9.6

Table 3. Data for springs in the vicinity of Crater Lake obtained 18-28 August 1989.

Name	Lat		Long		Elev.	Temp.	Cond.	Flow
	Deg	Min	Deg	Min	m	°C	µS/cm	L/s
Crater Springs group	43	0.0	122	15.1	1634			
Spring 1 (south)						2.8	44	270
Spring 2 (north)						2.7	42	760
Total flow of both springs								1000
Boundary Springs	43	4.1	122	13.7	1603			
northern most spring						3.3	54	
next spring to south						3.1	55	
next spring downstream						3.2	56.4	
spring under nearby point						3.2	57.2	
flow of above group								1700
next spring at middle of hill						3.2	54.4	890
isolated spring around hill						3.3	56.1	150
small stream near main trail						3.8	54.9	19
stream above falls						4.0	55.5	
flow of Rogue River below falls								2500
flow of Rogue River at culvert on Forest Service Road (1.6 km downstream)								850
Oasis Spring	43	1.6	122	14.4	1646	2.1	29.4	5
Thousand Springs	42	53.2	122	16.8	1512			
flow at Forest Service road								1600
spring nearest snow trail						5.2	55.0	
small spring						3.8		
Red Cone Spring	42	59.7	122	11.1	1914	2.2	22.3	2
Lightning Spring	42	56.1	122	10.7	2097	2.4	22.4	5
springs at head of Bybee Creek	42	55.8	122	10.7	2073			11
spring further south	42	55.3	122	11.0	1975			0.8
spring even further south	42	55.1	122	10.8	1999			3
Munson Springs - western group	42	54.2	122	8.2	2073	2.2	15.0	38
Castle Crest Springs	42	53.6	122	7.8	1963	2.9	29.3	85
Cascade Spring	42	57.2	122	1.3	1975	2.0	39.2	94
Anderson Spring	42	54.8	122	2.9	2121	2.2	28.3	57
Springs 89-3 (near Wheeler Creek)	42	53.6	122	4.0	2182	1.5	29.5	14

Table 3. Continued.

Name	Lat Deg	Lat Min	Long Deg	Long Min	Elev. m	Temp. °C	Cond. µS/cm	Flow L/s
Spring at source of Vidae Creek	42	53.2	122	6.0	2097	1.6	33.9	31
Pothole Spring	42	56.3	121	59.9	1999	3.1	25.8	5
Spring 89-1 on Pothole Creek	42	56.6	121	58.6	1890	2.9	42	24
Spring T31S R 7 1/2E S 11 NW 1/4	42	54.3	121	58.4	1804	4.5	37	30
Spring T31S R7 1/2E S9 NE 1/4	42	54.1	121	59.8	1972	6.3	31	20
Spring T31S R7 1/2E S 10 Center	42	54.1	121	59.1	1853	3.9	39	1
Springs 89-4	42	52.3	122	16.7	1597	3.2	53.7	200
Annie Spring	42	52.4	122	10.1	1841	2.9	41.3	140
Spring 88-1 (near Lodgepole Picnic area)	42	50.5	122	8.7	1780	2.4	29.5	1
Maklaks Spring	42	50.0	122	1.9	1658	3.8	25.6	0.1
Egan Springs in old spring box	42	47.4	121	53.0	1451	4.9	50	20
Cedar Springs group								
Cedar Spring	42	47.1	122	5.4	1451	6.7	57.5	0.6
Spring T33S R6E S23 NE 1/4	42	42.0	122	4.6	1277	4.5	80	110
Blue Springs	42	41.7	122	4.5	1274	4.3	70.3	3000
Spring T33S R6E S26 NW 1/4	42	41.0	122	4.8	1274			
north spring under log						4.8	67	9
south spring						5.5	72	38
Spring group T33S R6E S26 SE 1/4	42	40.8	122	4.8	1268			
lower						4.4	63	160
upper						4.8	68	40
Spring T33S R6E S35 NE 1/4	42	40.4	122	4.8	1268			40
Spring T33S R6E S35 Center	42	40.1	122	5.1	1268			
for 3 springs						4.9	62	4
further north on road						6.2	73	9
Mares Egg Spring	42	39.6	122	5.2	1266	5.2	80	60
Fourmile Spring	42	38.0	122	4.6	1266	5.2	71	large

Table 3. Continued.

Name	Lat Deg	Lat Min	Long Deg	Long Min	Elev. m	Temp. °C	Cond. µS/cm	Flow L/s
Wood River group								
Source of Wood River	42	44.5	121	58.8	1280			
[distances from northernmost vent]								
0 ft						5.7	73.8	
100 ft						6.1	75.2	
200 ft						6.5	77	
600 ft						5.2	72.0	
900 ft						6.2	85.8	
1100 ft						5.5	76	
2500 ft						7.5	101	
2550 ft						8.9	117	
South tip of lake 2600 ft						9.7	122	
flow under footbridge at 2500 ft								410
flow of Wood River at road bridge								6700
Reservation Spring	42	42.2	121	57.7	1274	8.2	96.6	1700
Source of Crooked Creek	42	41.2	121	57.8	1273	7.2	78.3	71
Fish Hatchery Springs								
Spring 1	42	39.1	121	56.8	1268	7.6	88	210
Spring 2						7.0	86	130
Spring 3 (sm. pond)						7.4	92	110
Spring 4 (big pond)						8.4	102	300
Sum of flows								750
Tecumseh Spring	42	38.5	121	56.5	1268	10.7	102	250
Source of Spring Creek	42	40.2	121	53.2	1280	6.5	74	280

Table 4. Calculation of chloride flux from the springs of the Wood River group. Flows are from Table 3, and chloride concentrations are from Thompson and others (1990).

Name	Flow L/s	Cl mg/L	Cl flux* mg/s
Source of Wood River	6,700	3.0	16,800
Reservation Spring	1,700	5.8	9,000
Source of Crooked Creek	71	7**	460
Fish Hatchery springs	750	8.4	5,900
Tecumseh Spring	250	4.9	1,100
Source of Spring Creek	280	3.3	780
Total	9,800		34,000

* 0.5 mg/L background concentration subtracted.
** estimated concentration.

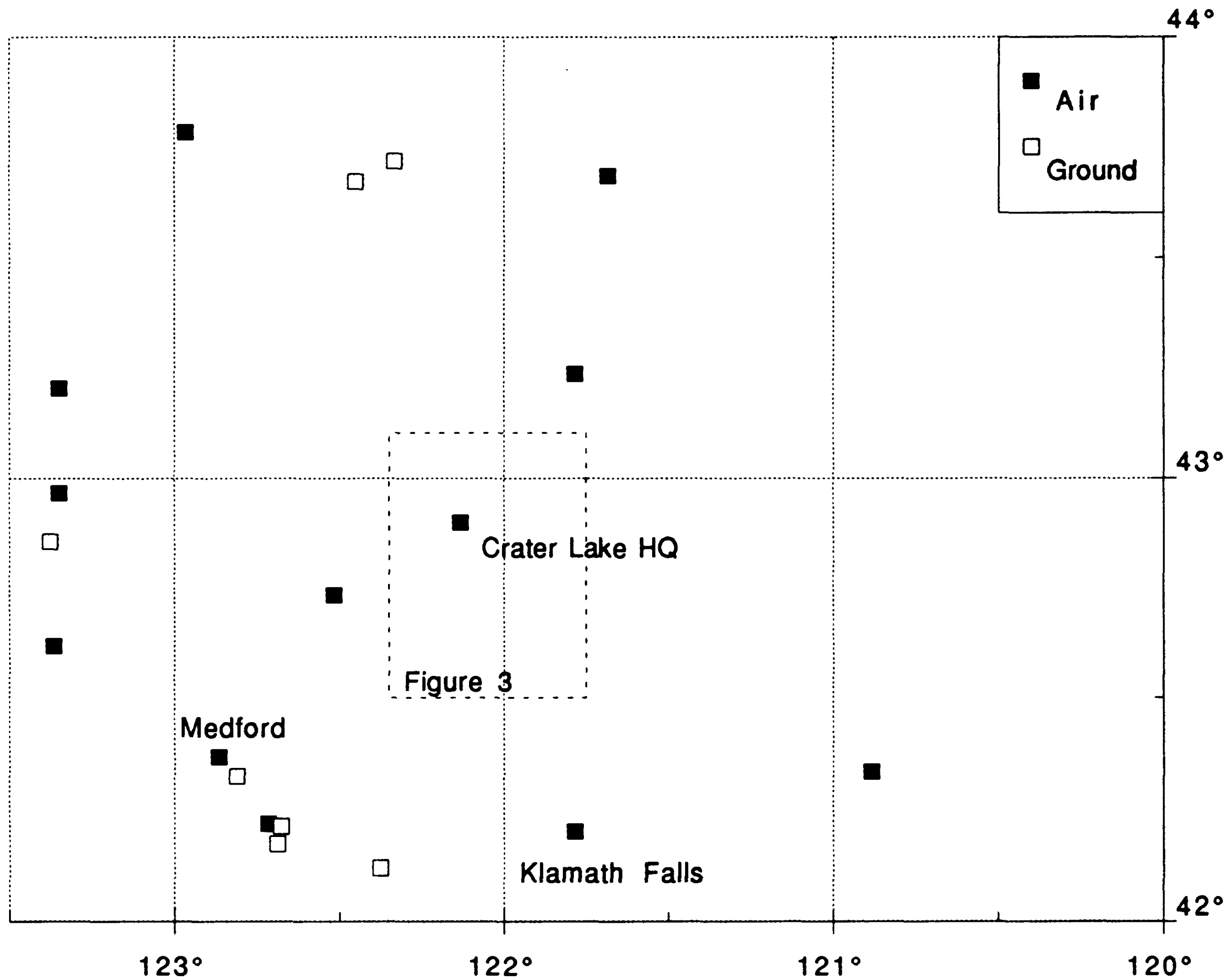

Figure 1. Map of southern Oregon showing locations of weather stations, drill holes used to determine average ground temperatures, and outline of map of Figure 3. Names shown are for places near some of the weather stations.

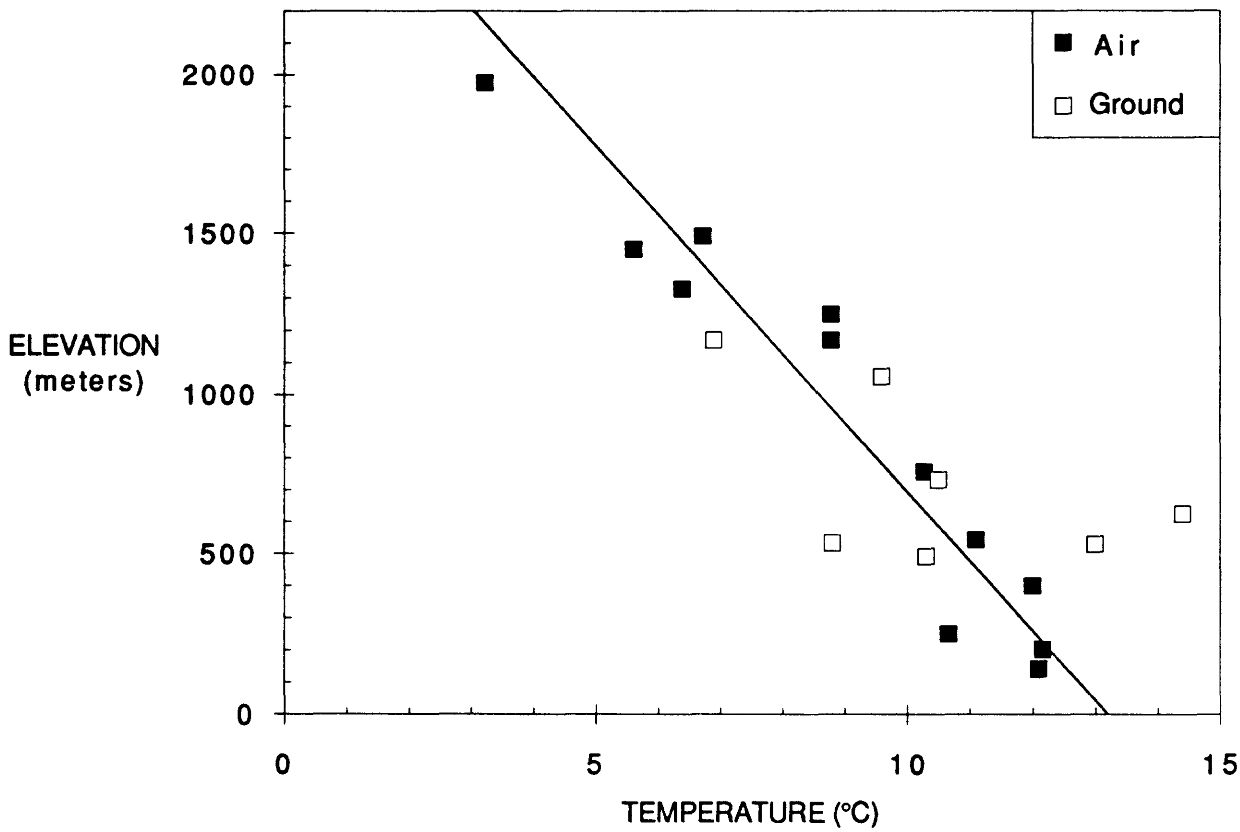

Figure 2. Mean annual air temperatures and average ground temperatures versus elevation for locations given in Figure 1. Line shown is least-squares fit to air temperature versus elevation data.

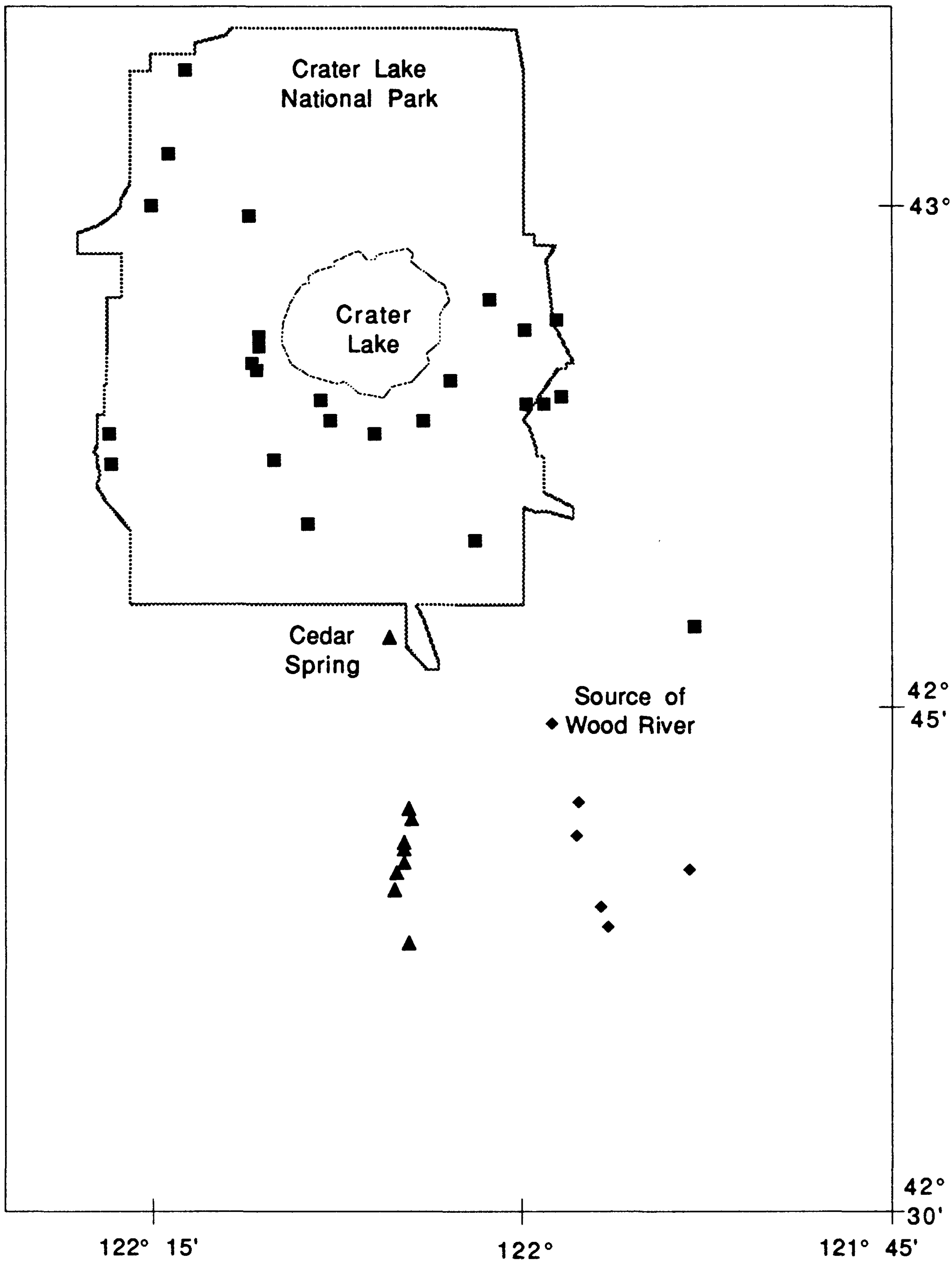

Figure 3. Map of Crater Lake and vicinity showing spring locations with special symbols for the Wood River group (diamonds) and the Cedar Spring group (triangles). Outline of Crater Lake National Park and Crater Lake are shown.

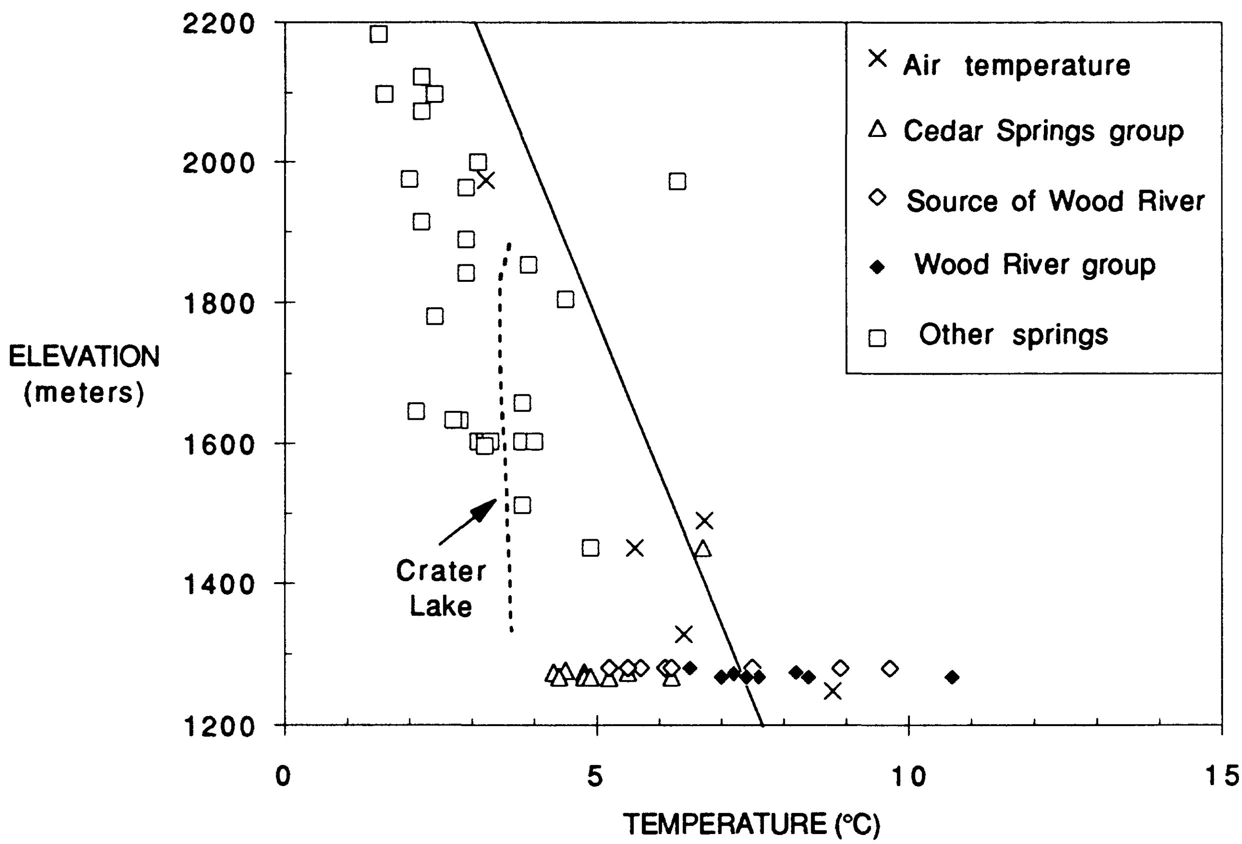

Figure 4. Elevation versus temperature for springs in the vicinity of Crater Lake. Broken line shows water temperature versus elevation for Crater Lake for 19 June 1971 from data of Neal and others (1972). Solid line is least-squares fit to air temperature versus elevation from Figure 2.

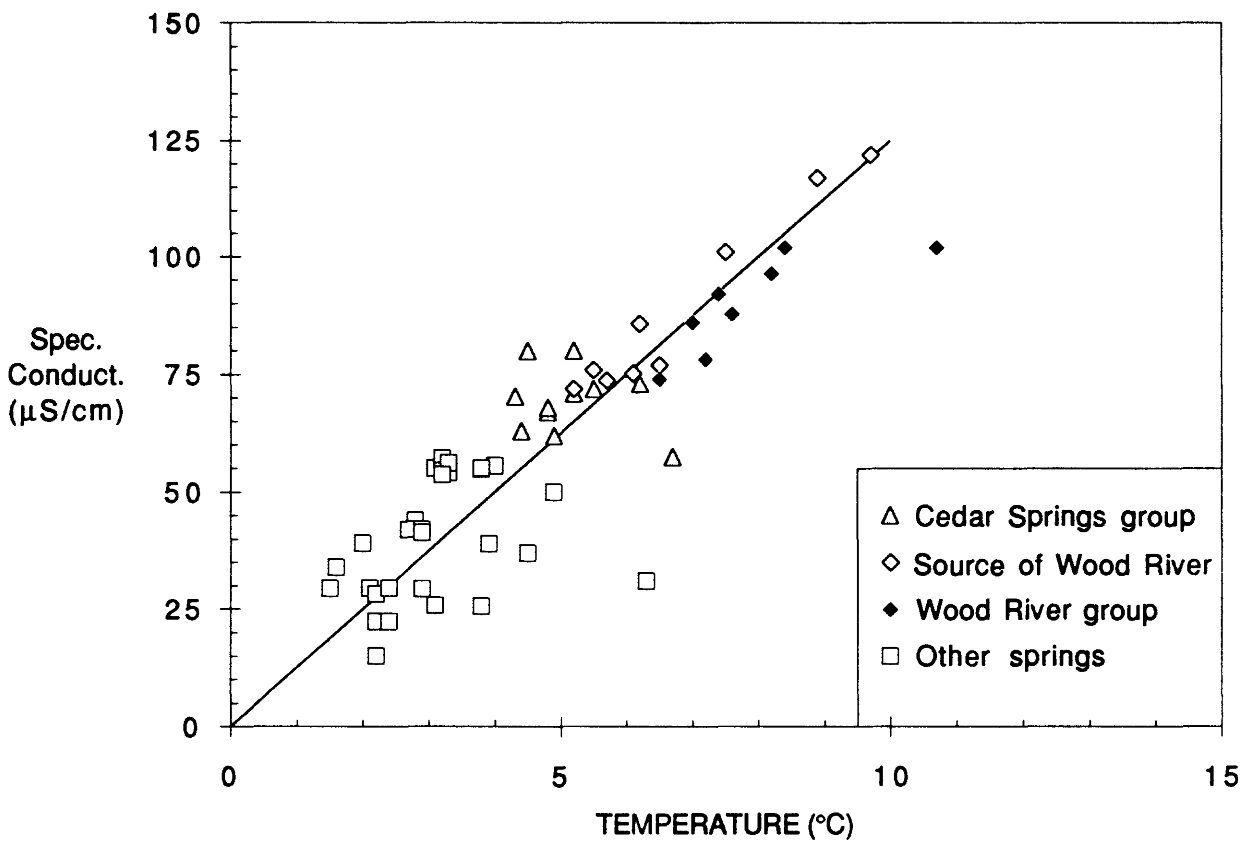

Figure 5. Specific conductance versus temperature for springs in the vicinity of Crater Lake. Line was fitted by eye to show trend.

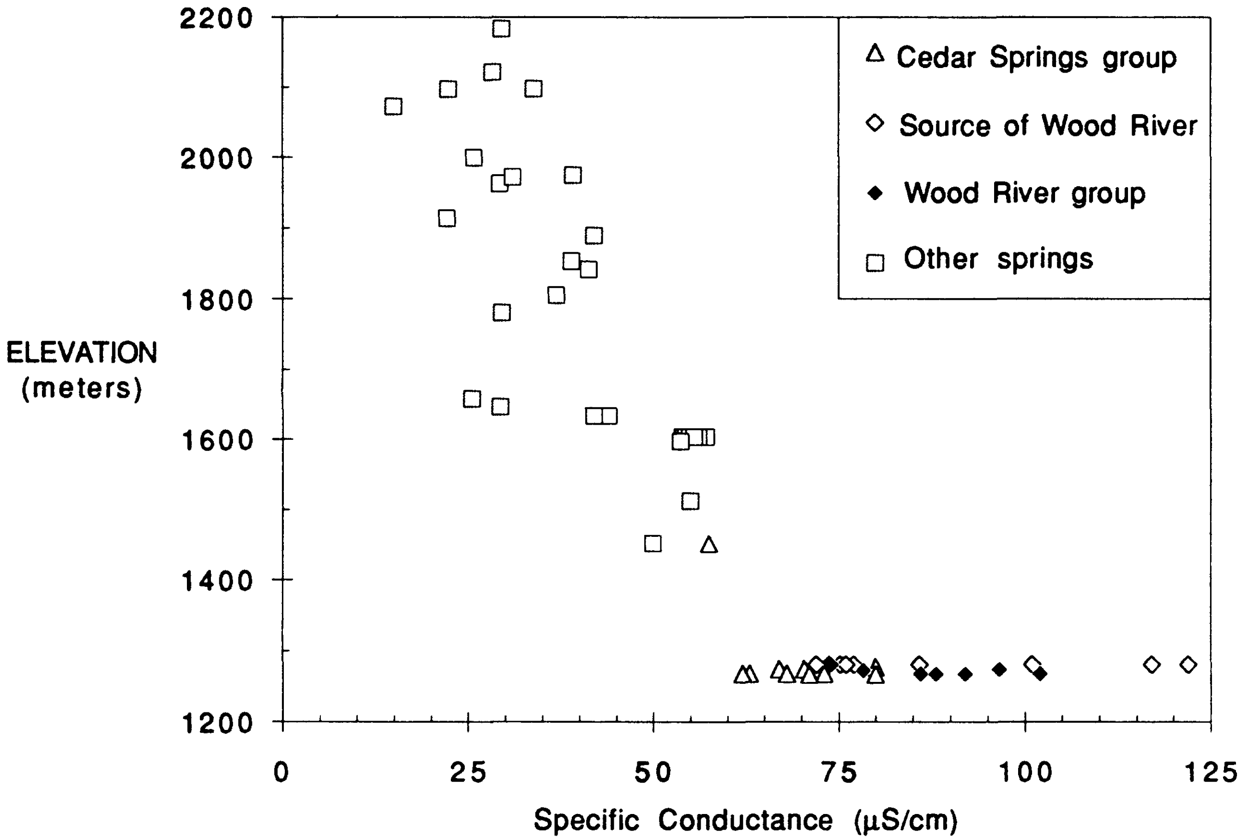

Figure 6. Elevation versus specific conductance for springs in the vicinity of Crater Lake.