U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
MARK SCHAEFER, Acting Director

For additional information write to:

Robert H. Mariner
U.S. Geological Survey
345 Middlefield Road, MS 470
Menlo Park, CA 94025

email:

rmariner@mailrcamnl.wr.usgs.gov

Copies of this report can be obtained from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Preliminary Chemical and Isotopic Data for Waters from Springs and Wells on and near Medicine Lake Volcano, Cascade Range, Northern California

By R.H. Mariner, W.C. Evans, and M. Huebner

U.S. Geological Survey Open-File Report 98-2

Menlo Park, California
1998

Contents

Illustrations

Tables

ABSTRACT

Cold springs on and adjacent to Medicine Lake Volcano discharge dilute mixed cation - bicarbonate waters of neutral to slightly alkaline pH. Chloride values in cold waters from springs and shallow wells on the volcano are low and generally increase radially outward from Medicine Lake. Chloride concentrations at high elevations are similar to values for precipitation. Higher chloride concentrations occur in wells within Lava Beds National Monument (11 mg/L) and at the headquarters for the Tule Lake National Wildlife Refuge (109 mg/L). Little Valley Hot Springs, near the southern edge of the study area, has 120 mg-Cl/L. Leakage from the high temperature geothermal system at Medicine Lake Volcano ($\simeq$ 1,000 mg-Cl/L) has not been found. Isotopic values for cold springs and wells on and adjacent to the volcano range from -84 to -106‰ δD and from -12.2 to -14.4‰ $\delta^{18}O$ and plot near the global meteoric water line. Water discharged by cold springs at the head of the Fall and Tule Rivers change somewhat in chemical and isotopic composition across the complex. Spring temperatures decrease from east to west. Chloride concentrations are highest in springs in the middle of the complex decreasing slowly eastward and sharply at the western edge. Deuterium values are most depleted in the middle of the complex. Deuterium versus chloride plots for these waters show no relationship to known geothermal waters. Deuterium and oxygen-18 values for the large discharge cold springs in the Fall River Valley are compatible with, but do not prove, recharge on Medicine Lake Volcano.

INTRODUCTION

Medicine Lake Volcano (fig. 1) is a large Pleistocene and Holocene shield volcano made up of basaltic to rhyolitic rock. The volcano is located about 35 miles ENE of Mt. Shasta in northern California and it sets on Pliocene basalts that are underlain by tuffs and basalt flows of Miocene age (Anderson, 1941). Medicine Lake, about 3/4 mi.^{2} in surface area, occupies the western end of a caldera-shaped depression in the top of the volcano. Anderson (1941) reported that most of Medicine Lake was less than 20 feet deep, although a depression in the eastern end of the lake was almost 150 feet deep. Medicine Lake Volcano has been active on at least 17 occasions over the last 12,000 years (Donnelly-Nolan, 1990), but no hot springs or major fumaroles discharge on the mountain. The

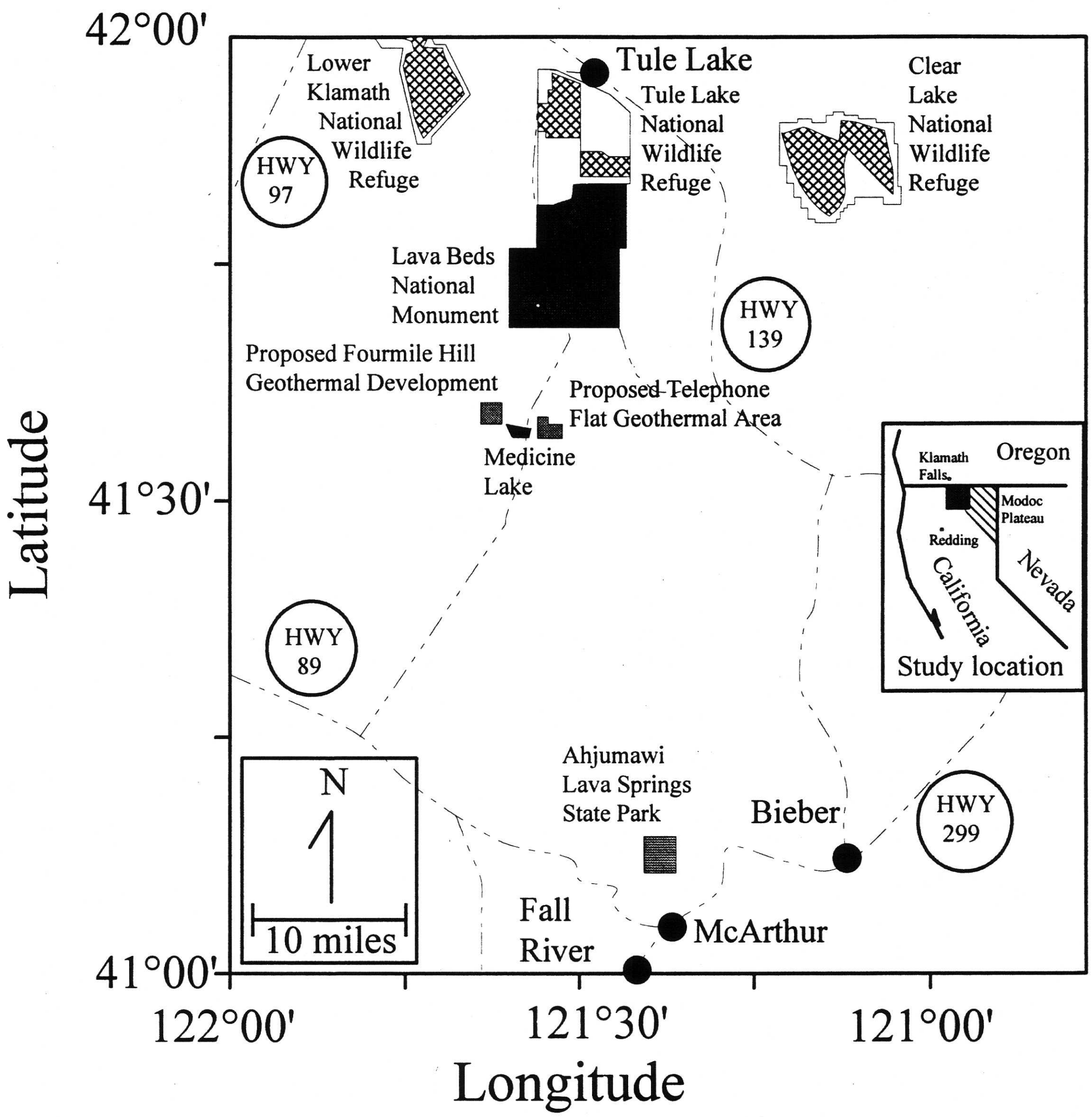


Figure 1. Location map showing study area, northeastern California.

nearest hot spring occurs just north of Ahjumawi Lava Springs State Park, approximately 30 miles SSE of Medicine Lake. The "hot spot", an area of warm ground and several weak fumaroles about 3½ miles ENE of Medicine Lake, is the only visible thermal feature. Cold springs occur on the higher parts of the mountain, but are particularly rare on the flanks of the volcano. The only streams on the mountain are associated with springs and persist for at most a few miles before disappearing into the porous volcanics. A few shallow wells are present near the east end of Medicine Lake and at widely spaced intervals on the flanks of the mountain. The major discharge of cold water near Medicine Lake Volcano occurs at the head of the Fall and Tule Rivers on the north side of the Fall River Valley (fig. 2). These cold springs are located about 35 miles SSE of Medicine Lake (fig. 1) and discharge water at a rate of 1,200 to 1,500 cubic feet per second (Clapp and Hoyt, 1906). Studies by California Department of Water Resources (1960) and Thompson and Chappell (1983) showed that most waters in the Fall River Valley are the sodium bicarbonate type but that the eastern and western edges of the valley have calcium-magnesium bicarbonate waters.

Purpose and Scope

In this report we make available chemical and isotopic data for cold springs, wells, lakes, and streams sampled on and adjacent to Medicine Lake Volcano. This set includes data for the large-discharge cold springs at the head of the Fall and Tule Rivers. Although some interpretation is given, our primary purpose is to make the data available to individuals, companies, and government agencies interested in the potential development of geothermal resources on Medicine Lake Volcano. Some of the data may be relevant to completion of environmental impact statements and/or environmental impact reports for the possible geothermal projects on Medicine Lake Volcano.

Acknowledgments

We would like to thank Whit Budge (Spring Creek Ranch), Andy Lakey (Rainbow Springs), and especially Peter Stent (1000 Springs Ranch) who permitted us to sample springs on their properties in the Fall River Valley. We would also like to thank Rick Poore at Thousand Springs Ranch and Dan Rajnus at Spring Creek Ranch for taking time to show us springs that they thought might be

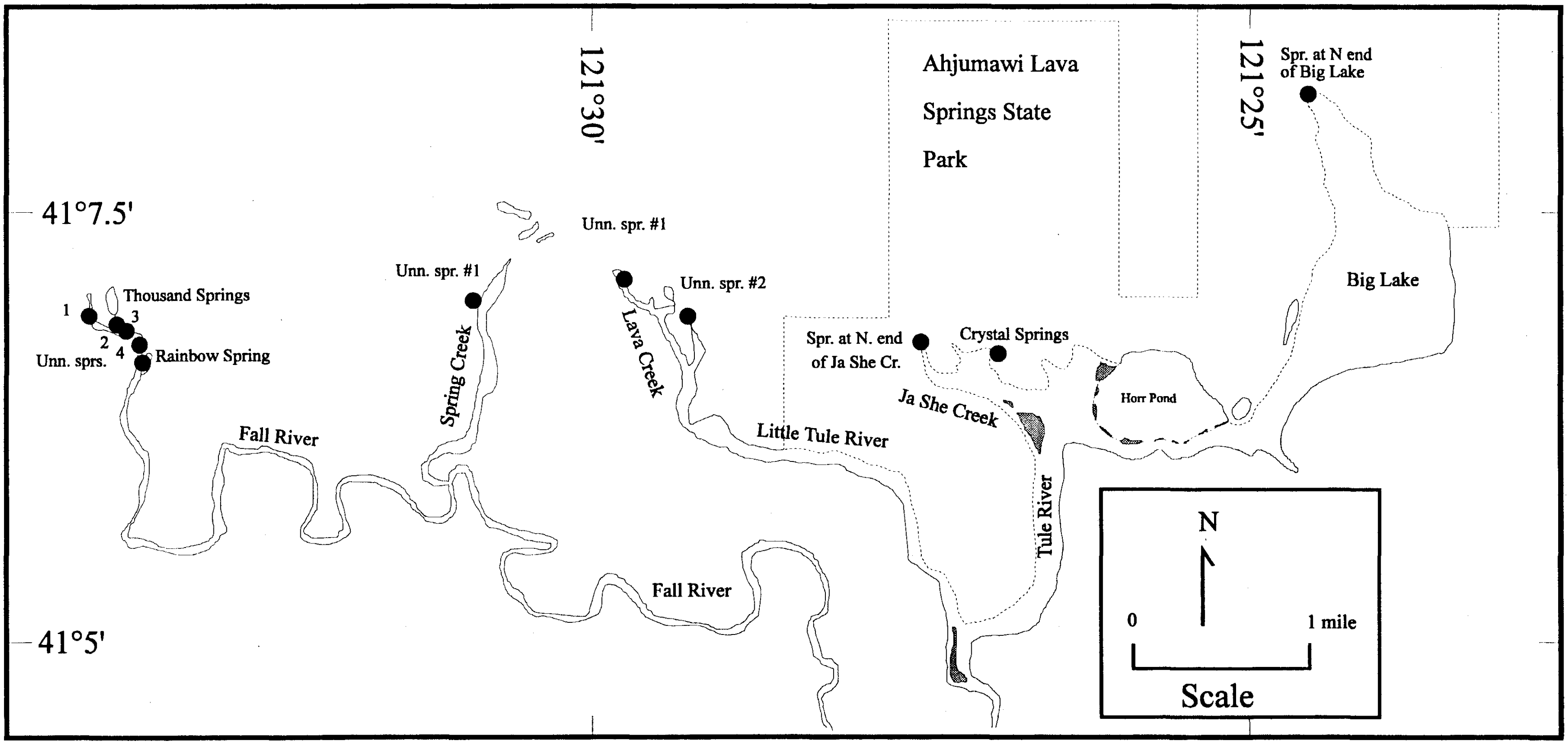


Figure 2. Location map showing springs sampled on the Fall and Tule Rivers

good sampling sites. Janie and Rob Painter were interested enough to contact us and to make a special trip from Mt. Shasta City to let us sample the well at their cabin on the east end of Medicine Lake. Access to U. S. Forest Service wells was provided by Randy Sharp (well near Medicine Lake) and Brad Reed (well east of Medicine Lake and covered by 8 inches of fresh snow). We also wish to thank Craig Dorman and Chuck Barrett at Lava Beds National Monument for their interest in the provenance of waters at the monument.

METHODS AND PROCEDURES

The methods used in sample collection and field determinations of pH and alkalinity are described in detail by Presser and Barnes (1974). The pH was measured in the spring or pumped sample and the pH electrode standardized against two buffers of known pH at each site. Alkalinity was determined by acid titration immediately after the sample was collected from the spring, well, river, or lake. Alkalinity values were determined again in the laboratory as a check on the field-determined values. Both titrations were carried out to the inflection point rather than to a predetermined pH. The raw water sample was filtered through a 0.45µm pore-size filter using compressed nitrogen or compressed air as the pressure source. Filtered samples were stored for later analysis in plastic bottles. Samples for metals and silica were acidified to at least pH 2 with concentrated nitric acid. Water temperatures, where determined, were measured with a combination temperature/conductivity probe or a mercury-in-glass thermometer. Samples for isotope analysis were collected without field treatment in glass bottles with polyseal caps. In the laboratory, silica (SiO_2), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) were determined on an automated inductively-coupled plasma emission spectrometer. Potassium values from this instrument are not as accurate as from a double-beam atomic absorption spectrophotometer. Potassium values are uncertain by about 0.2 mg/L (milligram per liter) when concentrations are less than 10 mg/L. Chloride (Cl), bromide (Br), nitrate (NO_3), phosphate (PO_4), and sulfate (SO_4) were determined on a computer controlled automated ion chromatograph. Isotope samples were analyzed in two different laboratories. Oxygen isotope values were determined in the USGS stable isotope laboratory in Menlo Park. Deuterium values were determined in the USGS stable isotope laboratory in Reston, Virginia because the mass spectrometer used for deuterium in the Menlo Park laboratory was down. These labs often compare samples so the results should be completely interchangeable.

The number of significant figure shown for chemical constituents in this report generally follow the guidelines given by Fishman and Friedman (1989). Exceptions occur for calcium, magnesium, and sodium in the concentration range from 10 to 25 mg/L. Fishman and Friedman (1989) suggest reporting two significant figures for values greater than 10 and units and tenths for values less than 10. To report values of 9.8 or 9.9 infers that the value is known to an accuracy near 1 percent, but to report 10 or 11 with no values in between infers that the value is known to only 10 percent. We believe that between 25 and 10 mg/L the values are known to between 1 and 2 percent. In this concentration range we report values to tenths because it is the tenth value that is uncertain not the units value. Determining pH in dilute waters is very time consuming because the electrodes respond very slowly. Although most meters show pH values to hundredths, we report pH values only to tenths in this report because of uncertainty about the electrode coming to equilibrium.

RESULTS AND DISCUSSION

Chemical and isotopic data for sampled waters are shown in table 1. All cold spring and well waters are dilute (<1,000 mg/L TDS) and have bicarbonate (HCO_3) as the major anion. Calcium (Ca), magnesium (Mg), and/or sodium (Na) are the dominant cations and pH values are neutral to slightly alkaline in most waters. Ca-Mg-HCO_3 waters dominate at higher elevations; Na-Ca-Mg-HCO_3 waters occur only at lower elevations. The only hot spring in the study area (Little Valley Hot Springs with t = 76°C) discharges a Na-HCO_3 water. Isotope values for most cold spring and well waters range from -79 to -108 permil in δD and -12.2 to -14.7 permil in $\delta^{18}O$. The few cold spring and well water outside this range have been altered by evaporation. Thermal water from Little Valley Hot Springs is more depleted in deuterium (δD = -113 permil) than any cold water sampled in the area.

The change from Ca-Mg-HCO_3 waters, which dominate at higher elevations, to Na-HCO_3 and Na-Ca-Mg-HCO_3 waters, which occur only at lower elevations, is due to a series of water-rock reactions that exchange calcium and magnesium from the water with sodium from the rock. This natural softening is a commonly observed process (Hem, 1985). Generally, waters with a higher proportion of sodium have had more water-rock reaction than waters dominated by calcium.

Chloride concentrations are lowest in cold springs and wells at high elevations and generally increase radially from Medicine Lake (fig. 3). However the rates of increase are variable on different sides of the volcano. Chloride concentrations in cold springs and shallow wells increase slowly from 0.25 mg/L at Medicine Lake to 4.6 mg/L in one of the large discharge cold springs at the head of the Fall River. Chloride concentrations increase more rapidly to the east and north of Medicine Lake. Dissolved chloride concentrations of more than 100 mg/L occur only in Little Valley Hot Springs and the well at Tule Lake National Wildlife Headquarters. A chloride concentration of 11 mg/L was found at the well used by the National Park Service in Lava Beds National Monument. Hotchkiss (1968) reported 12 mg-Cl/L for the same well. Water temperatures at both wells are higher than expected at this altitude assuming that temperature-altitude relations are similar to those found by Nathenson (1990) at Crater Lake. However, it is not clear that these chloride-bearing waters are associated with the high temperature system(s) on Medicine Lake volcano. Both waters could be associated with small low-temperature geothermal systems that derive their heat from a higher than normal geothermal gradient, or they could even be associated with geothermal systems similar to those near Bieber (about 40 miles southeast of Medicine Lake), west of Alturas (about 40 miles east-southeast of Medicine Lake), or in the Klamath Valley (about 35 miles northwest of Medicine Lake). The paucity of samples makes it impossible to establish relationships between the nonthermal waters of Lava Beds National Monument or the well at Tule Lake National Wildlife Refuge headquarters and any of the known geothermal waters.

Isotope values for cold springs, shallow water wells, and lakes of Medicine Lake Volcano and the surrounding area cover a wide range of values (table 1 and fig. 4). Samples from lakes (fig. 4) are isotopically shifted by evaporation as are the samples from Lost River (outflow from Clear Lake), the Dock well, Pumice Stone well, and the well at the Tule Lake National Wildlife headquarters. The most depleted water in the study area (-113 permil) is from Little Valley Hot Springs. At -113 permil δD, it is at least 5 permil more depleted in deuterium than any cold water sampled on Medicine Lake Volcano. If the cold spring isotope

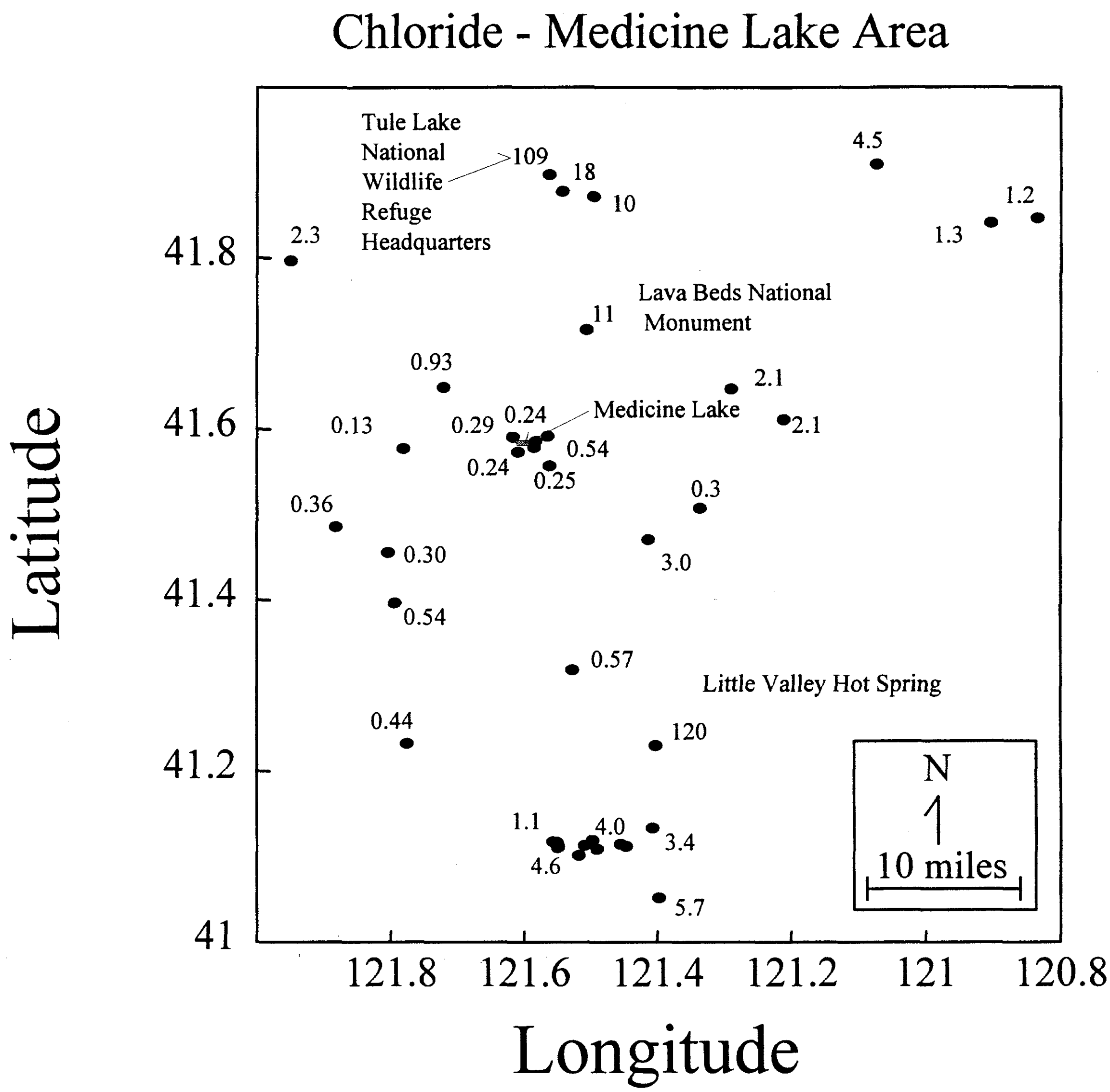


Figure 3. Map showing chloride concentrations in water samples

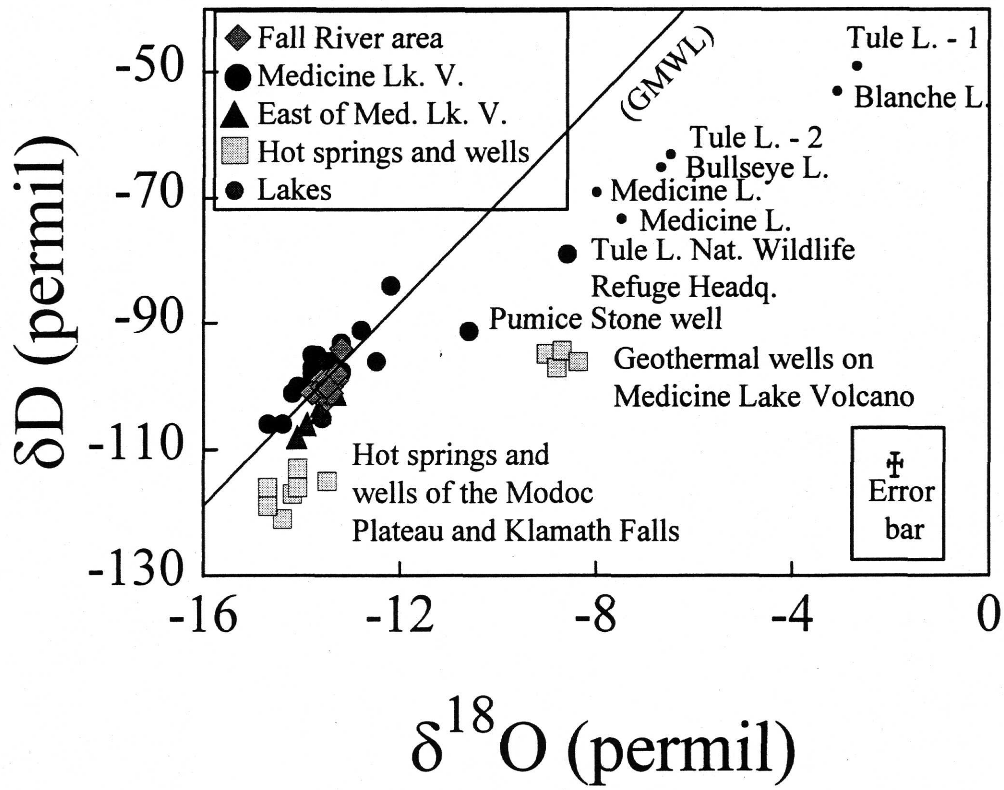


Figure 4. δD vs $\delta^{18}O$ for all samples (GMWL is the global meteoric water line)

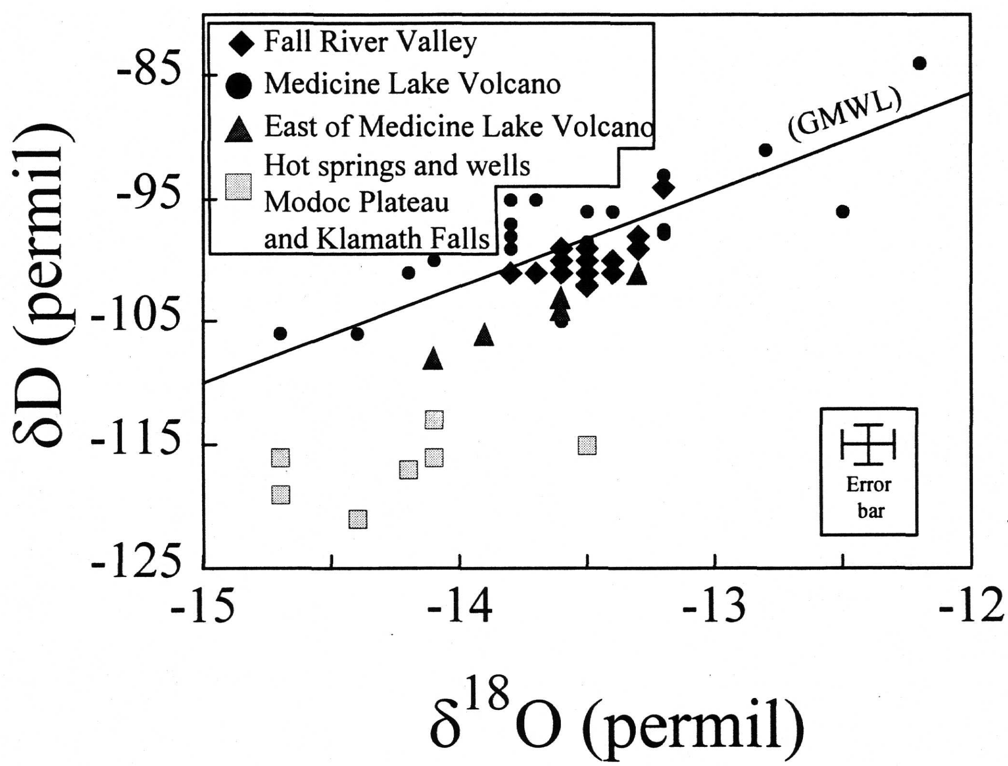


Figure 5. δD vs $\delta^{18}O$ for springs and wells (GMWL is the global meteoric water line)

compositions in table 1 and Figure 4 are typical of current precipitation (and recharge) on Medicine Lake volcano, then Little Valley Hot Springs discharges water that recharges elsewhere or is more than 10,000 years old. Of course, it is possible that a set of cold spring and well samples collected during August and September of 1997 may not be representative of the true isotopic composition of recharge on the volcano over an extended period of time. Precipitation from summer thunder showers may have shifted the composition of short circulation ground waters to more enriched values. At high altitudes in the Steens Mountains of southeastern Oregon, δD values of shallow circulation springs became less depleted in deuterium by 6 to 7 permil between early July and mid September (unpublished data, R. Mariner). Medicine Lake Volcano (most of which is 6,500 to 7,900 feet in elevation) is not as high as the Steens Mountains (up to 9,600 feet in elevation) but meteorological conditions at Medicine Lake Volcano may be influenced by Mt. Shasta (14,162 feet elevation) to the west. A more detailed look at the isotopic data (fig. 5) shows some differences apparently associated with location. Springs and wells east of Medicine Lake all appear to be shifted by about 0.5 permil in $\delta^{18}O$ relative to the global meteoric line of Craig (1961). Springs and wells on, to the west, or south of Medicine Lake Volcano appear to be shifted about -0.2 permil in $\delta^{18}O$ relative to the global meteoric water line. Several springs in the area have been sampled in previous years. Older samples from Crystal, Lost, and Schonchin springs (table 1) are more depleted in deuterium and more enriched in oxygen-18 (generally nearer to the global meteoric water line) than the 1997 sample set.

Springs that generate the Fall River, Spring Creek, Lava Creek, Ja She Creek, and Big Lake (fig. 2) in the Fall River Valley are of particular interest because their discharge rates are unusually large, their site of recharge is unknown, and their relation to the geothermal waters, if any, is uncertain. Although all of the springs discharge at essentially the same elevation, discharge temperatures range from 9.1° to 12.8°C. Temperatures of the springs are variable but generally decrease from east to west (fig. 6) and are higher than the 8.6°C expected based on the temperature-altitude relation noted by Nathenson (1990) for cold springs at Crater Lake. If a high temperature geothermal water is providing the heat then chloride concentrations should also decrease from east to west. However, chloride concentrations (fig. 7) increase slowly from east to west, attaining a maximum of 4.5 and 4.6 mg/L at the unnamed spring on Spring Creek and Rainbow Spring on

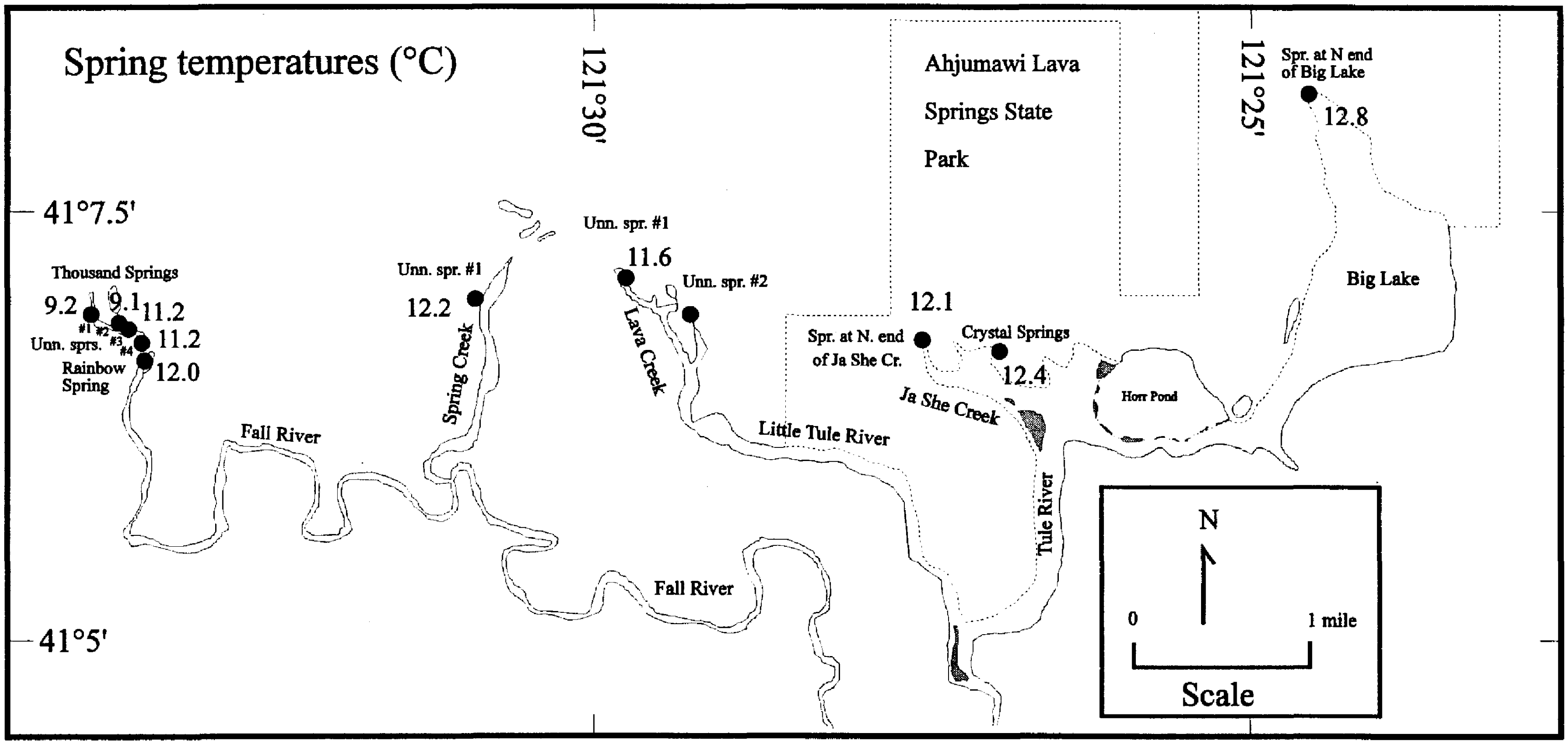


Figure 6. Map of temperatures of springs sampled along the Fall and Tule Rivers.

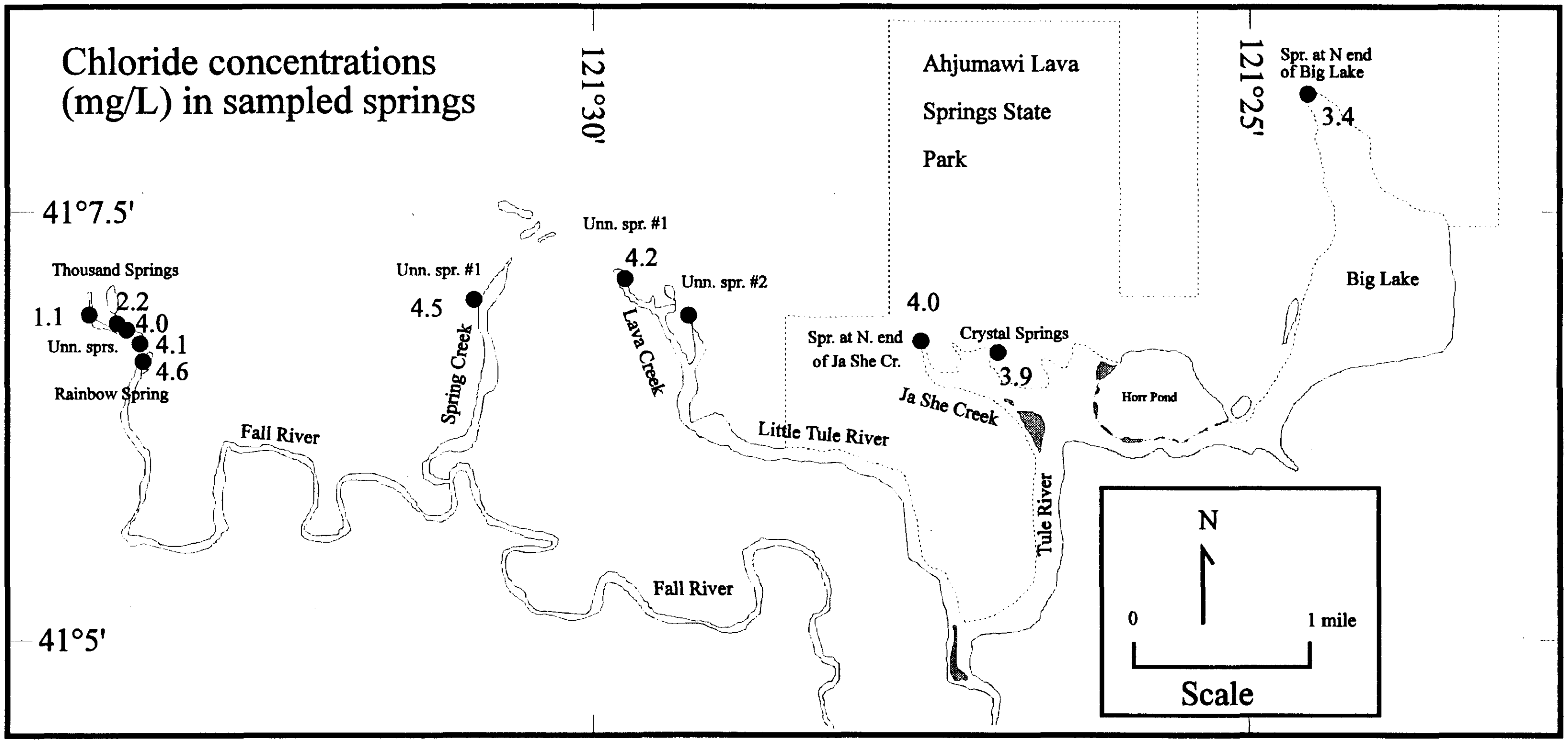


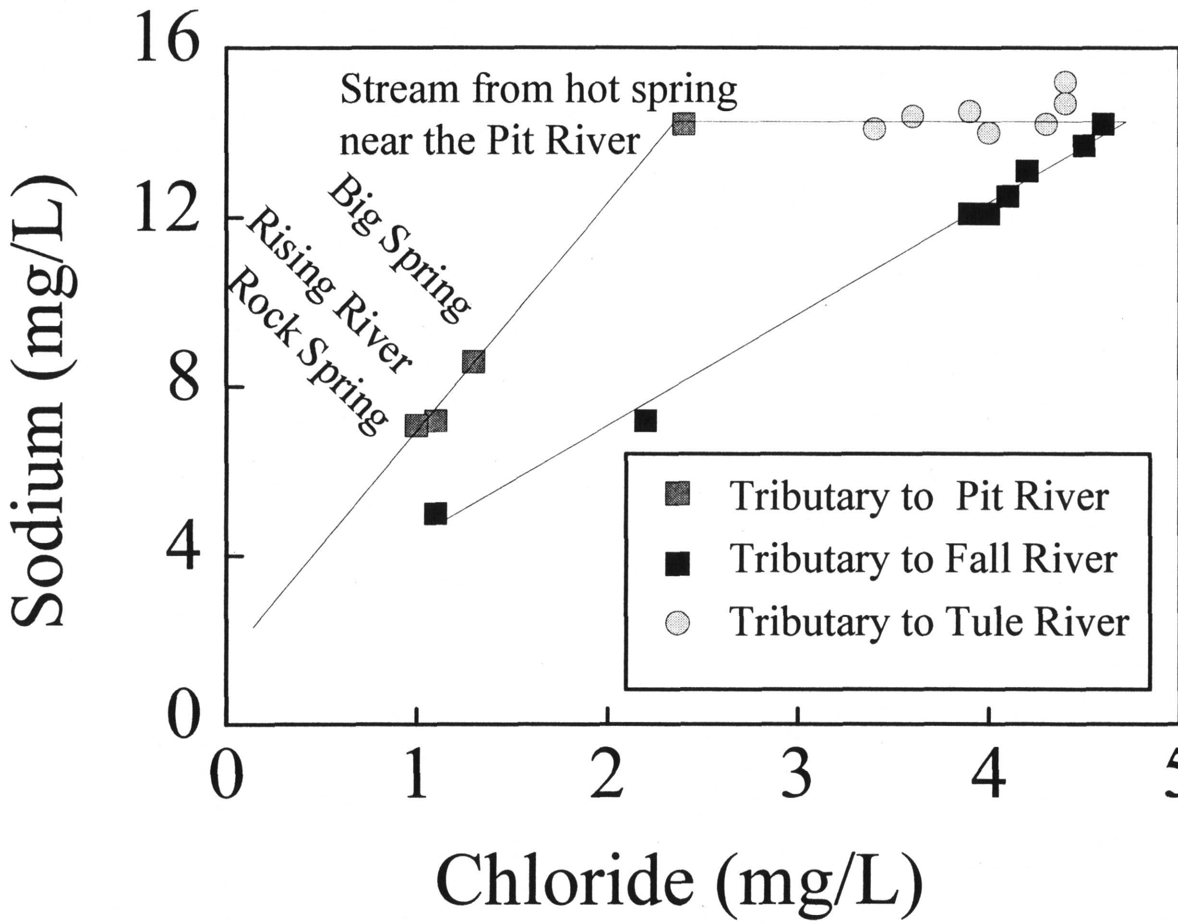
Figure 7. Map of chloride concentrations in sampled springs along the Fall and Tule Rivers.

the Fall River in the western third of the complex and then decrease to a low of 1.1 mg/L in the westernmost unnamed spring on the Fall River.

A plot of Na vs Cl (fig. 8) produces an unusual triangular shaped feature. Mixing water from Rainbow Spring or the unnamed spring on Spring Creek with a dilute ground water could produce all of the sodium and chloride values observed in waters to the west of and including the unnamed spring at the headwaters of Lava Creek. However, most springs on Lava Creek must have sodium and chloride compositions like the springs further east because the sample of Lava Creek taken at the road bridge plots on the constant sodium but variable chloride line (fig. 8). The few springs and streams sampled south of McArthur, along the Pit River and Hat Creek, have ratios of sodium to chloride which are very different from values for the springs along the Fall and Tule Rivers (fig. 8). However, the sample from a stream draining into the Pit River from a hot spring located approximately seven miles east-southeast of McArthur could represent the thermal but low chloride water which makes up part of the discharge of the cold springs along the Tule River. No data appears to be available for the chemical and isotopic composition of this hot spring.

Alkalinity generally decreases from east to west across the complex (fig. 9) and follows discharge temperature. Bicarbonate-rich thermal waters are usually associated with low-temperature geothermal systems. Spring pH values are surprisingly variable (table 1). Four of the five springs at the western edge of the system increase in pH from west to east (fig. 10) but one spring clearly breaks the trend. This site was checked at a later date with two meters and the pH value reproduced. Similar pH values occur in springs on Spring Creek and Lava Creek, and may indicate that some process is altering pH values in these waters shortly prior to discharge. We speculate that this could be contact with the atmosphere or soil gas from which CO_2 could be dissolved. Dissolution of CO_2 shortly prior to discharge would bring the pH down.

Chemical compostion of cold springs can be expected to change over time due to differential rates of fluid movement through the system and to variable amounts of dilution. Three springs in Adjumawi Lava Springs State Park have been sampled in different years (Table 1) and show small differences in dissolved constituent and light stable isotope compositions. Dissolved constituents are



	sodium (mg/L)	chloride (mg/L)
Rock Spring	7.1	2.4
Rising River	7.2	1.1
Big Spring	8.6	1.0
Stream from hot spring	14.2	1.3

Figure 8. Plot of sodium versus chloride for selected springs along the Fall, Tule, and Pit Rivers.

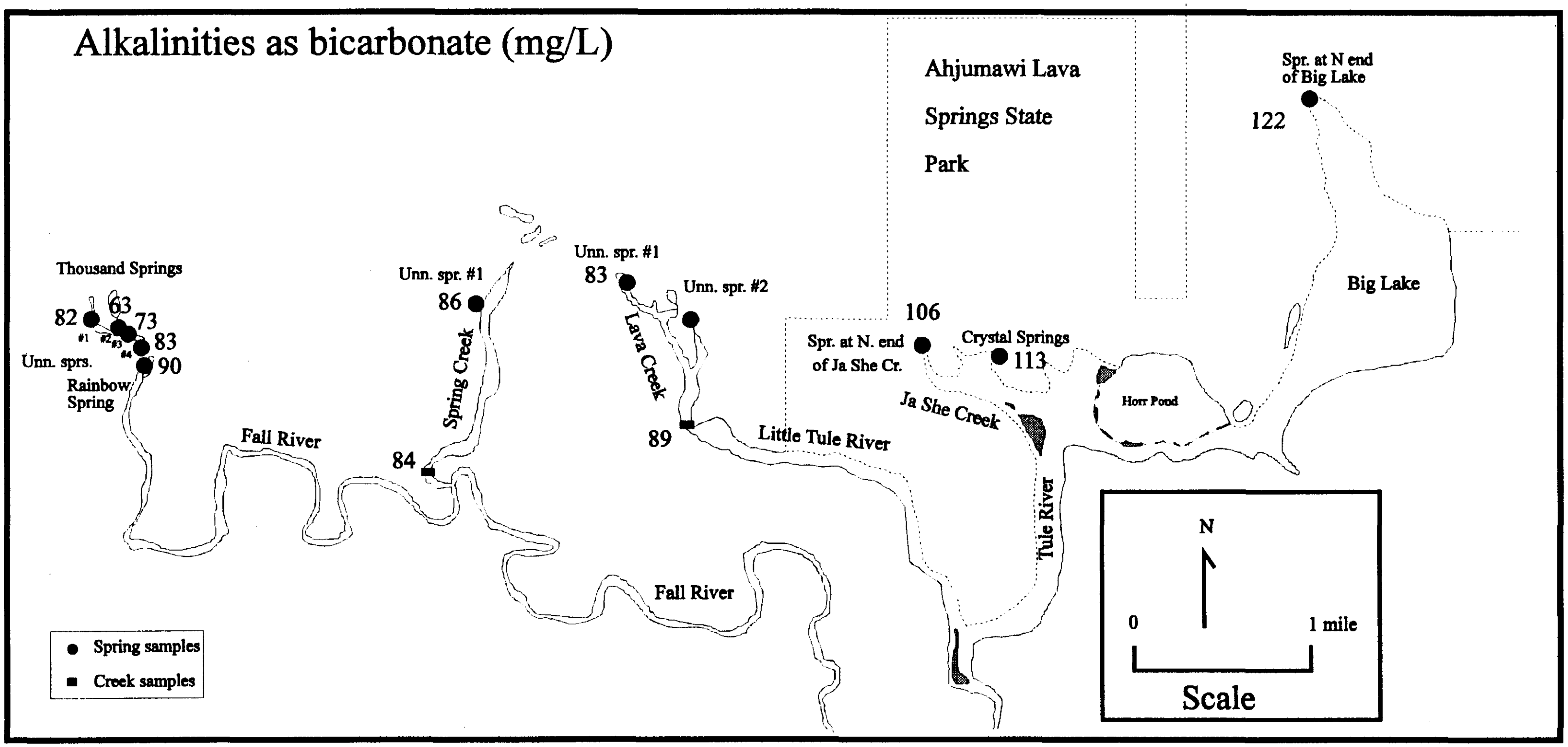


Figure 9. Map of alkalinities of springs sampled along the Fall and Tule Rivers.

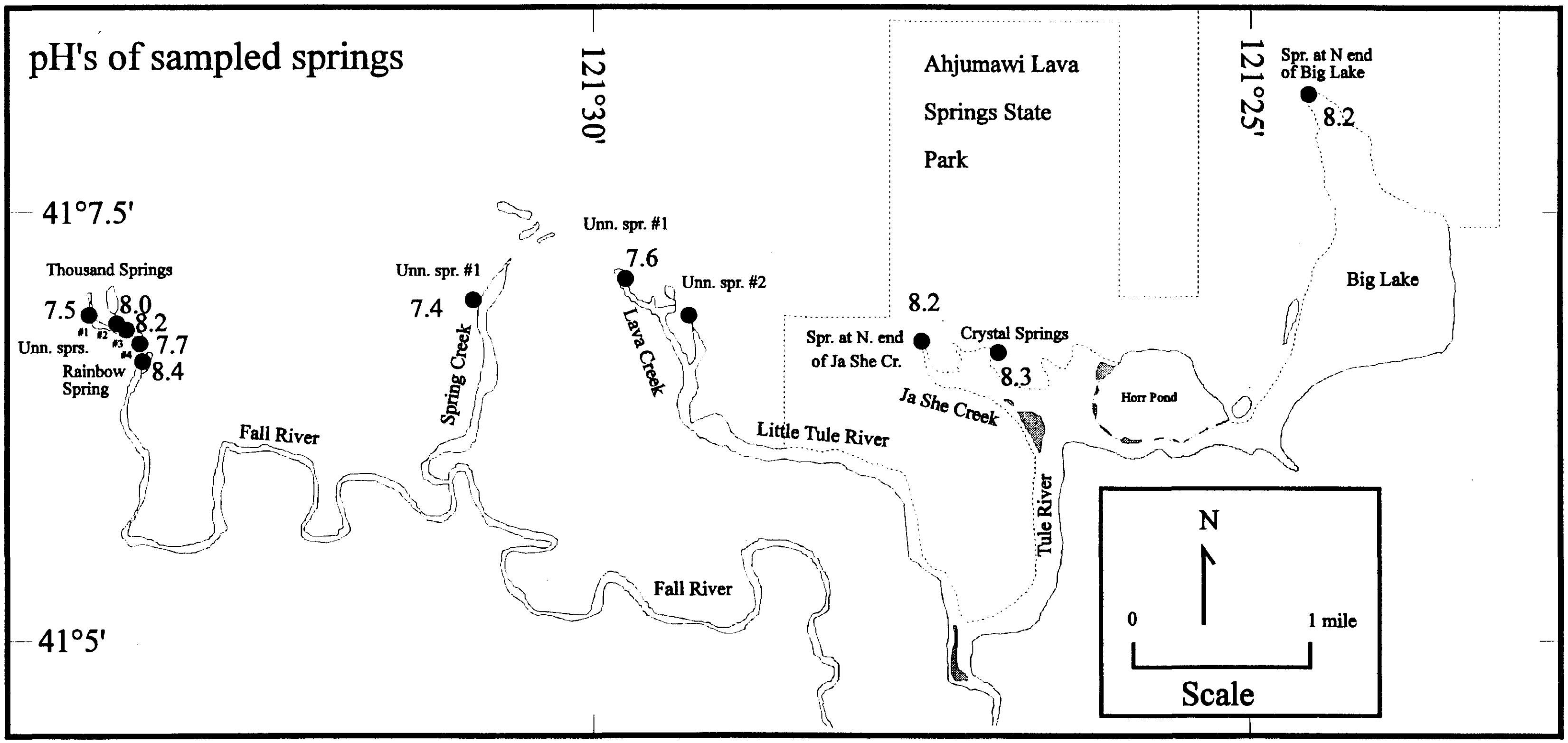


Figure 10. Map of pH's in springs sampled along the Fall and Tule Rivers.

present at lower concentrations in the 1997 samples than in the 1993 samples. Paynes Spring and Crystal Spring near Medicine Lake have been sampled for chemical composition in 1987 and 1997. The 1997 sample from Crystal Spring is more dilute than the 1987 sample but the 1997 sample from Paynes Spring is more concentrated in all dissolved constituents than the 1987 sample.

The large discharge cold springs in the Fall River-Adjumawi area range from -99 to -102 permil in δD and -13.3 to -13.7 permil in $\delta^{18}O$ and are within the envelope of isotopic values determined for waters from cold springs and shallow wells on Medicine Lake Volcano (fig. 4). It is isotopically permissible for these waters to recharge on Medicine Lake Volcano and the highlands that extends to the WSW. However, such evidence does not constitute proof that they recharge there. Informational billboards in Adjumawi Lava Springs State Park proclaim that the large discharge cold springs, which are a prominent feature of the park, are fed by underground streams from Tule Lake. The source of this "information" appears to be MacDonald (1966) and is apparently based on the difference in elevation between Tule Lake and the Fall River-Adjumawi area, and that large quantities of water have been observed to flow into the subsurface at Tule Lake without showing up again. However our chemical and especially our isotopic data (fig. 4) show that it is impossible for a significant amount of Tule Lake (Tule Lake Sump) water to be present in the large-discharge cold springs that feed the Fall and Tule rivers. Isotope data from waters of large-discharge cold springs between the Fall River Valley and Lassen Peak (Rose and others, 1966) are virtually identical to values from the large-discharge cold springs of the Fall River - Ahjumawi Lava Springs State Park. The available data do not allow us to determine the recharge source for the waters of the Fall River - Ahjumawi complex at this time.

A major question has been the relation, if any, of the waters in the large-discharge cold springs at the head of the Tule and Fall rivers to the high-temperature geothermal fluids on Medicine Lake Volcano or thermal waters like Little Valley Hot Springs. This aspect is investigated using the most conservative chemical constituent analyzed, chloride, and the most conservative isotopic constituent, deuterium. A plot of δD vs chloride for data from the large discharge cold springs of the Fall River - Adjumawi area show a strong correlation ($r=0.89$) between the pair (fig. 11). If chloride and deuterium are being provided to the system by a high-chloride thermal water then the least squares line through the

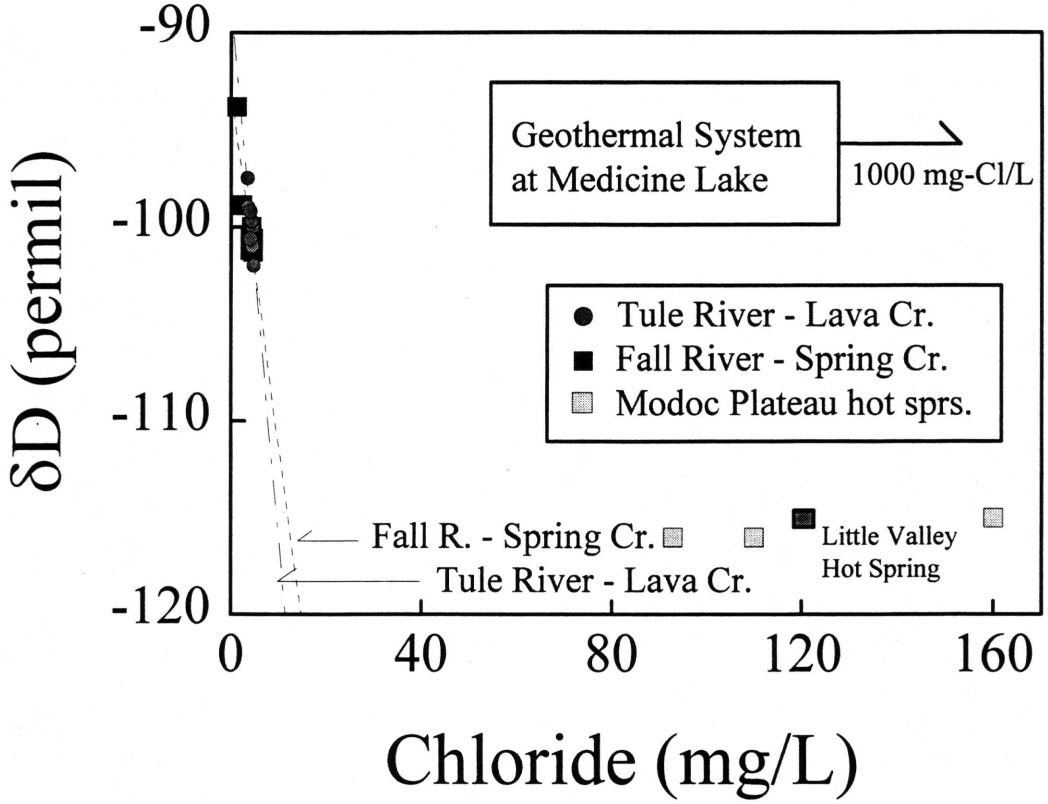


Figure 11. Plot of deuterium versus chloride for springs sampled along the Fall and Tule Rivers.

values for the large discharge cold springs must extrapolate to the composition (δD and chloride) of the saline end member. Thermal fluid in the geothermal system on Medicine Lake volcano is between -94 and -97 permil δD and has a chloride concentration of about 1,000 mg/L (Iovenitti and Hill, written communication 1997). Little Valley Hot Springs discharge water with only 120 mg-Cl/L but a δD of about -115 permil. The least squares line for the data from the large discharge cold springs extrapolates to very depleted deuterium values at very low chloride concentrations (fig. 11). Based on this plot we must conclude that the chloride and deuterium values in these large discharge cold springs are a function of dilution with a low-chloride local ground water. Also, Na/Cl values for waters from these large-discharge cold springs are very constant at about 4, appreciably different from that of Little Valley Hot Spring (Na/Cl = 2) and the geothermal water from Medicine Lake Volcano (Na/Cl = 0.62). No indication exists that the waters discharged in these large-discharge cold springs are associated with the high temperature geothermal waters on Medicine Lake Volcano or with the waters of Little Valley Hot Spring.

SUMMARY

Dilute mixed cation-bicarbonate waters occur in cold springs and shallow wells adjacent to and on Medicine Lake Volcano. High-temperature geothermal waters are usually dominated by sodium and chloride. No trace of the high-chloride thermal water present in deep wells drilled in the area just east of Medicine Lake has been located on, or near the volcano. Chloride concentrations in cold springs and cold wells at high elevations on the volcano are approximately the same as in precipitation. Chloride concentrations increase radially outward to about 5 mg/L in waters near the base of the volcano. Higher chloride concentrations occur in well waters in Lava Beds National Monument, at the headquarters for Tule Lake National Wildlife Refuge, and Little Valley Hot Spring. None of these waters can be shown to be associated with the known high-chloride waters encountered by drilling on the volcano. Isotope values in cold springs and wells range from -106 permil δD at higher elevations to -84 permil δD at lower elevations and most plot near or on the global meteoric water line. All samples from lakes and streams draining lakes have isotopic compositions that show some degree of evaporation. The large discharge cold springs at the head of the Tule and Fall Rivers differ in chemical and isotopic composition in ways that require dilution by low-chloride waters. No chemical connection has been established between the waters from these large-discharge cold springs and known chloride-rich geothermal fluids. Large-discharge cold springs along the Tule River may contain some water similar to that discharged by a hot(?) spring located 7 miles east-southeast of McArthur along the Pit River. Isotope values for the large discharge cold springs of the Fall River Valley are similar to values of cold springs and wells on Medicine Lake Volcano indicating that it is permissible for these waters to recharge on Medicine Lake Volcano. However, it must be emphasized that this does not constitute proof that the waters discharged by these large-discharge cold springs recharge on Medicine Lake Volcano.

References Cited

Anderson, C.A., 1941, Volcanoes of the Medicine Lake Highland, California: University of California Publications Bulletin, Department of Geological Sciences, v. 25, p. 347-422.

California Department of Water Resources, 1960, Water quality investigations of Fall River Valley: California Department of Water Resources, Division of Resource Planning, 15 p.

Clapp, W.B., and Hoyt, J.C., 1906, Report of progress of stream measurements for the calendar year 1905: U.S. Geological Survey Water-Supply Paper 177, 273 p.

Craig, H.W., 1961, Isotopic variations in meteoric waters, Science, p. 1702-1703.

Donnelly-Nolan, J.D., 1990, Geology of Medicine Lake Volcano, northern California Cascade Range: Transactions of the 1990 Annual Meeting of the Geothermal Resources Council, v. 14, pt. 2, p. 1395-1396.

Fishman, M.J., and Friedman, L.C., 1989, Methods for the determination of inorganic substances in water and fluvial sediments: Techniques of Water Resources Investigations of the U.S. Geological Survey, book 5, chap. A1, 545 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hotchkiss, W.R., 1968, A geologic and hydrologic reconnaissance of Lava Beds National Monument and vicinity, California: U.S. Geological Survey Open-File Report, 30 p.

Mac Donald, G.A., 1966, Geology of the Cascade Range and Modoc Plateau, *in* Geology of northern California, E.A. Bailey, ed., California Division of Mines and Geology Bulletin 190, p. 65-96.

Nathenson, Manuel, 1990, Temperatures in the vicinity of Crater Lake, Oregon, in relation to air and ground temperatures: U.S. Geological Survey Open-File Report 90-671, 19 p.

Presser, T.S., and Barnes, Ivan, 1974, Special techniques for determining chemical properties of geothermal water: U.S. Geological Survey Water-Resources Investigations 74-22, 11 p.

Rose, T.P., Davisson, M.L., and Criss, R.E., 1996, Isotope hydrology of voluminous cold springs in fractured rock from an active volcanic region, northeastern California: Journal of Hydrology, v. 179, p. 207-236.

Thompson, T.H., and Chappell, R., 1983, Maps showing distribution of dissolved solids and dominant chemical type in ground water, Basin and Range province, northern California: U.S. Geological Survey Water Resources Investigations Report 83-4115-B, 6 p., 1 plate.

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes on and adjacent to Medicine Lake Volcano

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
ML01RM97	-	-	108	26.3	10.3	5.7	3.6	0.9	0.36	0.17	62	-	-	7/29/97	121°52.9'	41°29.2'
McCloud River at Algoma Campground																
ML02RM97	-	-	25	15.3	2.0	1.1	1.1	.4	.44	.10	15	-84	-12.2	7/29/97	121°46.6'	41°14.0'
Cub Spring																
ML03RM97	-	-	106	39.3	10.8	4.4	4.2	1.6	.57	.36	63	-93	-13.2	7/29/97	121°31.7'	41°19.1'
Water tank below Mayfield Spring																
GT05RM97	5.2	-	-	20	7.3	4.9	2.9	1.3	.60	-	62	-	-	--/--/94	121°31.2'	41°21.3'
Indian Spring																
ML04RM97	-	-	47	22.2	4.0	2.2	2.0	.5	.54	.10	38	-91	-12.8	7/29/97	121°47.7'	41°23.8'
Belnap Spring																
ML05RM97[4]	-	-	76	28.9	6.7	4.3	2.4	<0.1	.30	.09	42	-96	-13.4	7/29/97	121°48.3'	41°27.4'
Bear Spring																
ML06RM97[4]	-	6.68/17°	64	26.8	8.3	1.7	2.6	<0.1	.13	.04	39	-96	-13.5	7/29/97	121°46.9'	41°34.7'
GT33JD79[1]	-	-	-	-	-	-	-	-	-	-	-	-98	-13.2	7/8/79		
Lost Spring																
ML07RM97[5]	-	-	67	45.9	5.5	2.6	3.8	1.6	.25	.56	50	-	-13.6	7/30/97	121°33.7'	41°33.4'
GT44RM87	-	7.6	-	44	4.8	2.3	3.9	.4	.2	.6	36	-95	-13.7	8/25/87		
GT68JD82[1]	-	-	-	-	-	-	-	-	-	-	-	-105	-13.6	7/16/82		
Paynes Spring																

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes on and adjacent to Medicine Lake Volcano -- continued

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
ML08RM97	-	7.10/11°	58	26.2	6.8	2.0	2.1	.4	.24	.60	31	-100	-14.1	7/30/97	121°35.0'	41°35.1'
Forest Service well at Medicine Lake																
ML09RM97	4.8	6.87	80	35.2	9.9	2.5	3.4	0.8	0.29	0.36	49	-97	-13.8	7/30/97	121°33.7'	41°33.5'
GT11JD81[1]	-	-	-	-	-	-	-	-	-	-	-	-98	-13.2	7/5/81		
Schonchin Spring																
ML10RM97[5]	2.6	6.71	46	31.8	4.9	1.6	2.4	.7	.24	.27	38	-98	-13.8	7/31/97	121°36.5'	41°34.4'
GT48RM87		7.9	-	35	8.3	3.1	4.6	1.3	.1	.4	28	-95	-13.8	8/25/87		
GT35JD79[1]	-	-	-	-	-	-	-	-	-	-	-	-98	-13.5	7/8/79		
Crystal Spring at Medicine Lake																
ML42RM97	5.1	7.74	61	24.3	8.0	1.5	2.1	.7	.54	.27	35	-99	-13.8	11/18/97	121°35.1'	41°34.7'
Private well at Medicine Lake																
ML45RM97[2]	-	-	69	-	-	-	-	-	.68	1.2	50	-	-13.8	11/18/97	121°33.9'	41°35.5'
Forest Service well in Arnica Sink																
ML32RM97[4]	12.5	6.82	104	42.7	6.1	3.9	5.2	3.9	.93	1.3	51	-96	-12.5	9/7/97	121°43.3'	41°39.0'
Dock well																
GT31JD79[1]	-	-	-	-	-	-	-	-	-	-	-	-106	-14.4	7/8/79	121°51.0'	41°34.3'
Baird Spring																
GT31JD79[1]	-	-	-	-	-	-	-	-	-	-	-	-91	-10.6	7/7/79	121°42.4'	41°34.3'
Pumice Stone well																

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes on and adjacent to Medicine Lake Volcano -- continued

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
GT36JD79[1] Tule Lake Municipal well	-	-	-	-	-	-	-	-	-	-	-	-127?	-13.4	9/3/79	121°28.7'	41°57.3'
ML29RM97[4] Well at Tionesta Mountain Store	11.2	7.60	190	40.9	14.7	10.9	6.9	1.5	2.1	2.3	107	-103	-13.6	9/6/97	121°17.4'	41°38.8'
ML30RM97[4] Well at quarantine station	13.9	7.67	181	40.5	14.8	11.9	4.8	0.7	2.1	2.3	109	-104	-13.6	9/6/97	121°12.7'	41°36.7'
ML31RM97[4] Well at Long Bell Station	17.5	8.01	201	41.4	12.2	9.5	15.7	2.9	3.0	1.8	120	-101	-13.3	9/6/97	121°24.9'	41°28.3'
ML44RM97[4] Quaking Aspen Spring (pond) in Long Bell Game Refuge	-	7.38	122	.6	15.5	5.7	1.5	2.1	.33	.3	70	-31	+0.8	11/06/97	121°20.2'	41°30.5'
ML26RM97 Well at Lava Beds National Monument	16.4	8.25	193	52.0	6.7	5.0	27.6	2.2	11	2.9	94	-106	-14.7	9/5/97	121°30.4'	41°43.0'
ML27RM97[3] Well at Tule Lake National Wildlife Refuge Headquarters	18.7	8.01	1170	52.8	43.1	52.1	124.	16.4	109	79	459	-79	-8.6	9/5/97	121°33.8'	41°53.9'
ML28RM97[5] Lost River at the gage	21	7.74	162	20.9	13.4	7.2	9.6	2.9	4.5	3.7	96	-65	-6.7	9/6/97	121°44.4'	41°54.6'
ML22RM97 Quaking Aspen Spring	-	-	68	38.6	5.0	2.0	5.3	1.2	1.31	1.58	45	-108	-14.1	8/15/97	120°54.2'	41°50.5'

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes on and adjacent to Medicine Lake Volcano -- continued

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
ML23RM97 Blue Mountain Spring	-	-	252	63.4	24.1	15.3	9.2	.7	1.21	.08	179	-106	-13.9	8/15/97	120°50.1'	41°50.8'
ML33RM97[4] Irrigation well in Red Rock Valley	-	-	162	-	-	-	-	-	2.3	2.1	102	-101	-14.2	9/7/97	121°57.0'	41°47.8'
Fall River Valley																
ML14RM97[4] Unnamed spring #1 on the Fall River	9.2	7.47	136	30.6	11.8	7.2	5.0	1.5	1.1	1.15	82	-94	-13.2	7/31/97	121°33.4'	41°07.1'
ML11RM97 Unnamed spring #2 on the Fall River	9.1	7.95	113	34.2	8.6	5.2	7.2	1.8	2.2	1.04	63	-99	-13.6	7/31/97	121°33.1'	41°07.0'
ML12RM97 Unnamed spring #3 on the Fall River	11.2	8.17	142	39.8	8.4	6.0	12.1	2.5	4.0	1.58	73	-101	-13.7	7/31/97	121°33.1'	41°07.0
ML13RM97 Unnamed spring #4 on the Fall River	11.2	7.68	146	40.3	8.5	6.2	12.5	2.2	4.1	1.67	83	-101	-13.7	7/31/97	121°33.0'	41°06.9'
ML25RM97[4] Rainbow Spring	12.0	8.36	161	41.6	8.8	6.7	14.2	2.7	4.6	1.75	90	-101	-13.6	9/5/97	121°33.0'	41°06.7'
ML15RM97 Spring Creek at the road bridge	-	-	146	37.9	9.0	6.3	12.1	2.2	3.9	1.59	84	-100	-13.5	7/31/97	121°31.1'	41°06.1'
ML40RM97 Unnamed spring on Spring Creek	12.2	7.41	157	40.1	8.7	6.3	13.7	2.7	4.5	1.63	86	-101	-13.8	11/4/97	121°30.6'	41°06.8'

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes in and adjacent to Medicine Lake Volcano -- continued

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
ML41RM97[4]	11.6	7.59	152	40.4	8.7	6.3	13.1	2.5	4.2	1.54	83	-100	-13.6	11/4/97	121°29.9'	41°07.2'
Unnamed spring #1 at the head of Lava Creek																
GT01JD81[1]	-	-	-	-	-	-	-	-	-	-	-	-102	-13.5	--/--/81	121°29.4'	41°07.0'
Unnamed spring #2 on Lava Creek																
ML19RM97	-	-	156	40.6	9.0	6.8	14.2	2.4	4.3	1.78	89	-100	-13.6	8/2/97	121°29.4'	41°06.6'
Lava Creek at the road bridge																
ML16RM97	12.1		172	39.1	9.8	7.1	14.0	2.1	4.0	1.9	106	-101	-13.4	8/1/97	121°27.4'	41°06.9'
GT24RM93	12.0	8.15	-	39.2	10.4	7.3	14.7	2.9	4.4	-	-	-101	-13.5	8/9/93		
Spring north of Fish Trap at head of Ja She Creek																
ML17RM97	12.4	-	177	38.7	10.5	7.4	14.5	2.2	3.9	1.9	113	-99	-13.5	8/1/97	121°26.9'	41°06.7'
GT27RM93	12.0	8.26	-	39.2	11.2	7.7	15.2	2.7	4.4	1.8	-	-100	-13.4	8/9/93		
Crystal Spring at Adjumawi Lava Springs State Park																
ML18RM97	12.8	8.28	184	37.3	11.9	8.6	14.1	2.6	3.4	1.7	122	-98	-13.3	8/1/97	121°24.5'	41°08.0'
GT26RM93	12.8	8.16	-	37.6	12.1	8.5	14.4	3.1	3.6	1.1	-	-99	-13.3	8/9/93		
Spring at the north end of Big Lake																
ML43RM97[4]	-	8.70	203	24.6	15.8	2.6	22.8	2.5	5.7	15.2	90	-100	-13.5	11/6/97	121°23.9'	41°03.1'
City well for McArthur and Fall River																
Hot springs																
GT73RM83	46	8.1	-	80.0	48	.3	235	5.4	120	53	390	-113	-14.1	6/6/83	121°24.2'	41°13.8'
Little Valley Hot Spring																

Table 1. --Chemical and isotopic data for selected springs, wells, and lakes in and adjacent to Medicine Lake Volcano -- continued

[Chemical concentrations in milligrams per liter; isotope concentrations in parts per mil relative to standard mean ocean water]

ID/Name	t(°C)	pH	µS/cm	SiO_2	Ca	Mg	Na	K	Cl	SO_4	HCO_3	δD	$\delta^{18}O$	Coll. date	Long.	Lat.
Lakes																
GT45RM87 Blanche Lake	-	8.2	-	2.7	.6	.3	.8	.1	.2	.2	3	-53	-3.1	8/25/87	121°33.3'	41°34.1'
GT46RM87 Bullseye Lake	-	7.6	-	1.3	.8	.4	1.2	.4	.2	0.7	8	-65	-6.7	8/25/87	121°34.4'	41°33.4'
GT47RM87	-	7.8	-	.9	1	.5	.9	.4	.2	.3	7	-69	-8.0	8/25/87	121°35.9'	41°34.7'
GT35JD79[1] Medicine Lake	-	-	-	-	-	-	-	-	-	-	-	-73	-7.5	8/17/79		
ML20RM97 Tule Lake Sump #1	-	-	800	-	-	-	-	-	18	218	234	-49	-2.7	8/15/97	121°32.6'	41°52.7'
ML21RM97[5] Tule Lake Sump #2	-	-	800	-	-	-	-	-	10	88	211	-63	-6.5	8/15/97	121°29.8'	41°52.3'

[1] Isotope sample collected by Julie Donnelly-Nolan

[2] Sample collected by running a bailer down the discharge pipe for the submersible pump. Analysis for cations and silica still pending

[3] All samples collected in 1997 had less than 0.05 milligrams bromide (Br) per liter of water except for the well at Tule Lake National Wildlife Refuge Headquarters (0.44 mg/L).

[4] All samples collected in 1997 had less than 0.05 milligrams nitrate (NO_3) per liter of water except for Bear Spring (1.13 mg/L), Lost Spring (0.13 mg/L), Dock well (0.14 mg/L), well at Tionesta (0.74 mg/L), well at quarantine station (0.74 mg/L), well at Long Bell Station (0.40 mg/L), Lost River (0.23 mg/L), Quaking Aspen Spring (0.10), well in Red Rock Lake Valley (0.53 mg/L), unnamed spring #1 on the Fall River (0.08 mg/L), Rainbow Spring (0.16 mg/L), unnamed spring #1 on Lava Creek (0.10 mg/L), and the city well for McArthur and Fall River (0.13 mg/L)

[5] All samples collected in 1997 had less than 0.05 milligrams of phosphate (PO_4) per liter of water except for Paynes Spring (0.08 mg/L) Crystal Spring at MedicineLake (0.07 mg/L), Lost River (0.05 mg/L), Tule Lake Sump #2 (0.12 mg/L)