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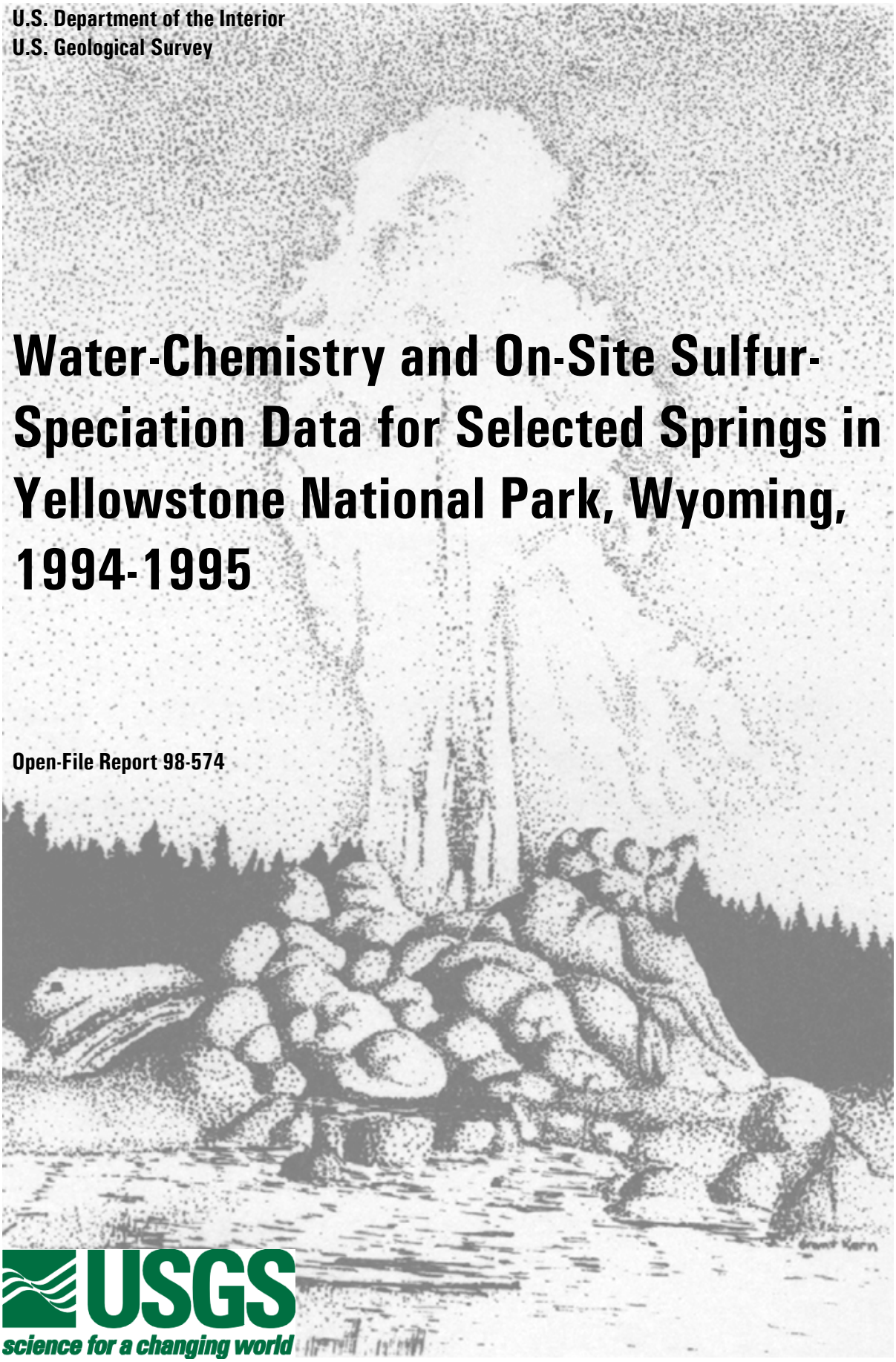
Water-Chemistry and On-Site Sulfur-Speciation Data for Selected Springs in Yellowstone National Park, Wyoming, 1994-1995

Open-File Report 98-574



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Water-Chemistry and On-Site Sulfur-Speciation Data for Selected Springs in Yellowstone National Park, Wyoming, 1994-1995

By James W. Ball[1], D. Kirk Nordstrom[1], Kirk M. Cunningham[1], Martin A. A. Schoonen[2], Yong Xu[2], and Jennifer M. DeMonge[3]

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
L (liter)	0.2642	gal (gallon)
g (gram)	0.03527	oz (ounce)
m (meter)	3.28084	ft (foot)

Temperature in degrees Fahrenheit (ºF) can be converted to degrees Celsius (ºC) as follows:

$$ºF = 1.8 \times ºC + 32$$

Explanation of abbreviations

g/mL (grams per milliliter)
kw (kilowatts)
m (meters)
meq/L (milliequivalents per liter)
mg/L (milligrams per liter)
mL (milliliter)
mm (millimeter)
M (moles per liter)
：m (micrometer)
：S/cm (microsiemens per centimeter at 25 degrees Celsius)
n.a. (not analyzed)
n.m. (not measured)
psi (pounds per square inch)
V (volts)
v/v (volume/volume)
COLOR (colorimetry)
COND (conductance)
*^{2}H ($^{2}H/^{1}H$ ratio referenced to the VSMOW standard)
*^{18}O ($^{18}O/^{16}O$ ratio referenced to the VSMOW standard)
D.O. (dissolved oxygen)
DOC (dissolved organic carbon)
EC (electro-chemical method)
FAAS (flame atomic absorption spectrometry)
FIAS (flow injection analysis system)
IC (ion chromatography)
ICP (inductively-coupled plasma atomic emission spectrometry)
ISOT (stable isotope analysis)
MHZ (megahertz)
PTFE (polytetrafluoroethylene)
RF (radio frequency)
SLAP (Standard Light Antarctic Precipitation)
spec. cond. (specific conductance)
SRWS (standard reference water sample)
TITR (titrimetry)
UV (ultraviolet)
VSMOW (Vienna Standard Mean Ocean Water)
YNP (Yellowstone National Park)
ZGFAAS (Zeeman-corrected graphite furnace atomic absorption spectrometry)

Water-Chemistry and On-Site Sulfur-Speciation Data for Selected Springs in Yellowstone National Park, Wyoming, 1994-1995

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ABSTRACT

Forty-two water analyses are reported for samples collected at 8 hot springs and their overflow drainages, two geysers, and two ambient-temperature acid streams in Yellowstone National Park during 1994-95. These water samples were collected and analyzed as part of the initial research investigations on sulfur redox speciation in the hot springs of Yellowstone and to document chemical changes in overflows that affect major ions, redox species, and trace elements. The sulfur redox speciation research is a collaboration between the State University of New York (SUNY) at Stony Brook and the U.S. Geological Survey (USGS). Four hot springs, Ojo Caliente, Azure, Frying Pan, and Angel Terrace, were studied in detail. Analyses were performed adjacent to the sampling site or in an on-site mobile lab truck constructed by the USGS, or later in a USGS laboratory.

Water temperature, specific conductance, pH, Eh, D.O., and dissolved H_2S were determined adjacent to the sample source at the time of sampling. Alkalinity and F^- were determined on-site on the day of sample collection. Thiosulfate and polythionates were determined as soon as possible (minutes to hours later) by ion chromatography (IC). Other major anions (Cl^-, SO_4^{2-}, Br^-) also were determined on-site by IC within two days of sample collection. Ammonium, Fe(II), and Fe(total) were determined on-site by ultraviolet/visible spectrophotometry within two days of sample collection. Later in the USGS laboratory, densities were determined. Concentrations of Ca, Mg, Li, Na, and K were determined by flame atomic absorption and emission (Na, K) spectrometry. Concentrations of Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe(total), K, Mg, Mn, Na, Ni, Pb, Si, Sr, V, and Zn were determined by inductively-coupled plasma optical emission spectrometry. Trace concentrations of Al and Mg were determined by Zeeman-corrected graphite furnace atomic absorption spectrometry.

Three important conclusions from the sampling and analyses are: (1) variability in H_2S concentrations can be caused as much by sampling and preservation artifacts as by actual variations in water composition over time, (2) historical determinations of $S_2O_3^{2-}$ were subject to overestimation, most likely because of inadequate preservation leading to H_2S oxidation, and (3) $S_2O_3^{2-}$ is a common constituent of hot spring waters.

INTRODUCTION

Spectacular hot spring and geyser activity led to the designation of Yellowstone National Park (YNP) as the first national park in the world and inspired numerous scientific investigations. Investigations into the water chemistry of hot springs, geysers, streams, and rivers have been accomplished primarily by the USGS, dating back to the report of Gooch and Whitfield (1888) and the comprehensive study by Allen and Day (1935). More recent water-chemistry data are available for 6 samples reported by White and others (1963), 166 samples reported by Rowe and others

(1973), 541 samples reported by Thompson and others (1975), 422 samples reported by Thompson and Yadav (1979), 45 samples reported by Stauffer and others (1980), 38 samples reported by Thompson and Hutchinson (1981), 17 samples reported by Kharaka and others (1991), and over 450 samples reported by Thompson and DeMonge (1996). Additional data are reported by White and others (1988), Fournier (1989), Fournier and others (1994), and Ball and others (1998).

Waters at YNP have a wide range of compositions. The pH values range from 1 to 10, temperatures range from ambient to boiling, and there are high concentrations of As, H_2S, SO_4^{2-}, and HCO_3^-. Numerous redox reactions and mineral-precipitation reactions occur. As well as being valuable natural resources, active geothermal areas such as YNP provide enormous insight into formation of mineral deposits, microbiological processes in extreme environments, and water-rock interactions.

The present study is the first phase of collaborative research between the USGS, SUNY at Stony Brook, and Northern Arizona University. The purpose of this investigation is to study the occurrence, origin, rates of formation and disappearance, and hydrogeochemical significance of unstable redox species of sulfur in mineral springs and geothermal waters.

Forty-two water samples were collected and analyzed for major and trace constituents from five areas (fig. 1): Mammoth Hot Springs (Angel Terrace), Norris Geyser Basin (including Frying Pan Spring), Lower Geyser Basin (Ojo Caliente and Azure Spring), Washburn Hot Springs, and Brimstone Basin. Hot springs with well-defined overflow channels were sampled in detail, especially those at Angel Terrace, Frying Pan Spring, Ojo Caliente, and Azure Spring. Water discharging from these springs provided a range of pH values and dissolved constituent concentrations. Discharge from each spring flowed into a small, well-defined channel, facilitating collection of samples and permitting study of chemical reactions during downstream transport. These analyses for the five hot-spring areas may be some of the most complete available, containing major ions, trace elements, and some redox species such as Fe(II)/Fe(total), H_2S, $S_2O_3^{2-}$, and SO_4^{2-}.

The authors thank the following USGS personnel: G. R. Aiken for dissolved organic carbon analyses, R. C. Antweiler and B. Kumler for ammonium analyses, and T. B. Coplen, J. A. Hopple, and C. Kendall for isotope determinations. We acknowledge the contributions of Cherie Ball in preparing publication versions of the figures for this report. The participation of SUNY at Stony Brook in this project is sponsored by the National Science Foundation-Earth Sciences.

We extend our appreciation to the staff of Yellowstone National Park for permission to collect water samples. We are especially thankful to the late Rick Hutchinson for his advice and his interest in our work since 1974. We thank Bob Lindstrom for arranging transportation and accompanying us to Brimstone Basin. We also thank Mike Thompson, formerly of the USGS, for leading us through Norris and Lower Geyser Basins.

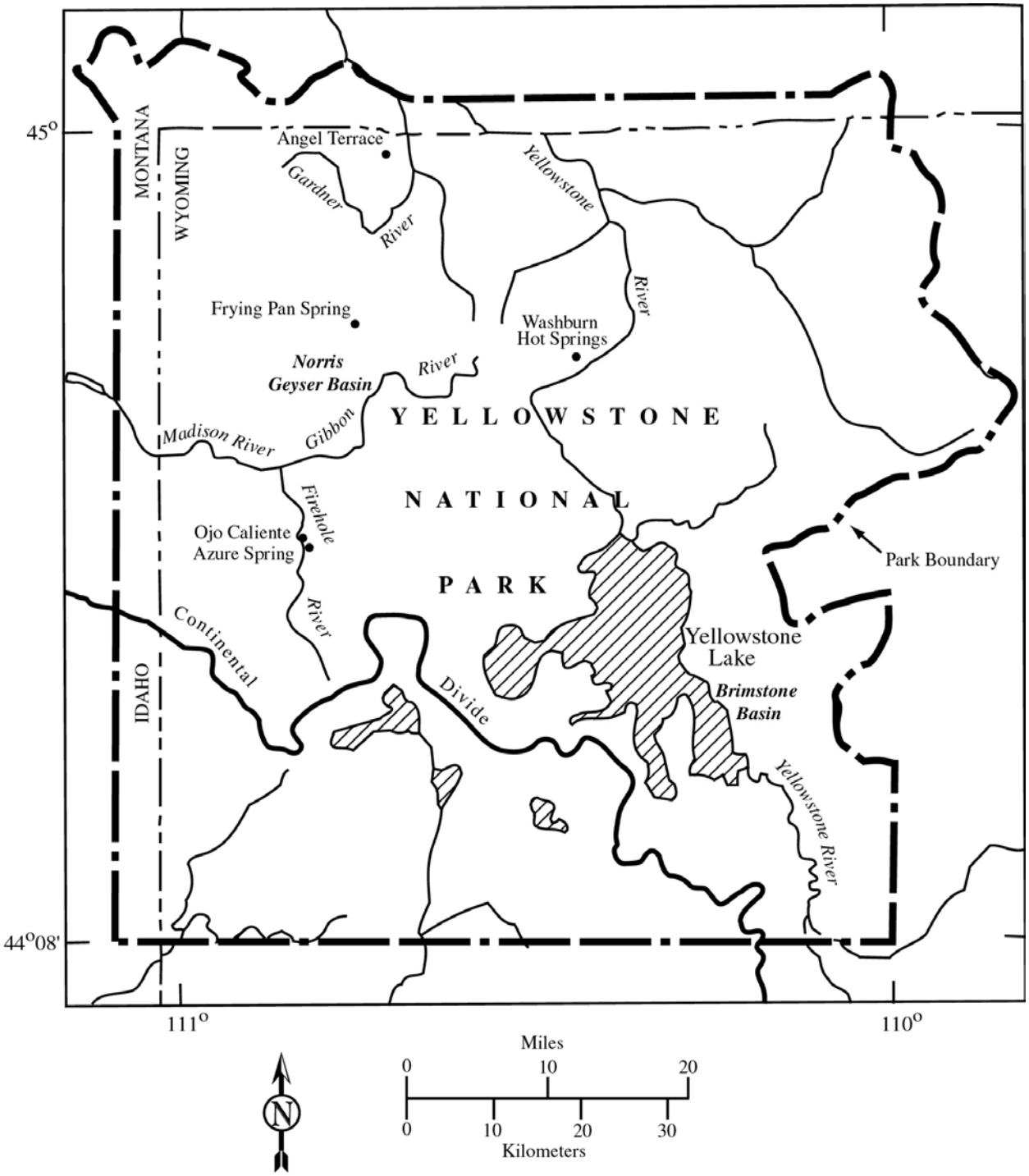

Figure 1. Locations of sampled springs in Yellowstone National Park, Wyo.

METHODS OF SAMPLE COLLECTION, STABILIZATION, AND ANALYSIS

Many analyses were performed on each sample. Physical properties determined included temperature, pH, specific conductance, and density. Concentrations of D.O., H_2S, NH_4^+, SiO_2, major cations, trace metals, Fe(II), Fe(total), major anions, alkalinity, $S_2O_3^{2-}$, and DOC, as well as stable isotopes of H and O, were determined.

Sample Collection

Samples were collected as close to the source of each spring as possible and at various locations along the downstream overflow channel, as illustrated schematically in figs. 2-5 for Ojo Caliente Spring, Frying Pan Spring, Angel Terrace Spring, and Azure Spring, respectively. For safety, to protect fragile hot spring mineral formations, and to minimize changes in temperature, pH, and water chemistry during sampling, samples from the middle of pools were taken using an insulated stainless steel container attached to the end of an extendable aluminum pole. The container was rinsed several times with sample water to assure thermal equilibration and to minimize sample contamination. At more easily accessible sites, spring water was withdrawn directly from the source or channel.

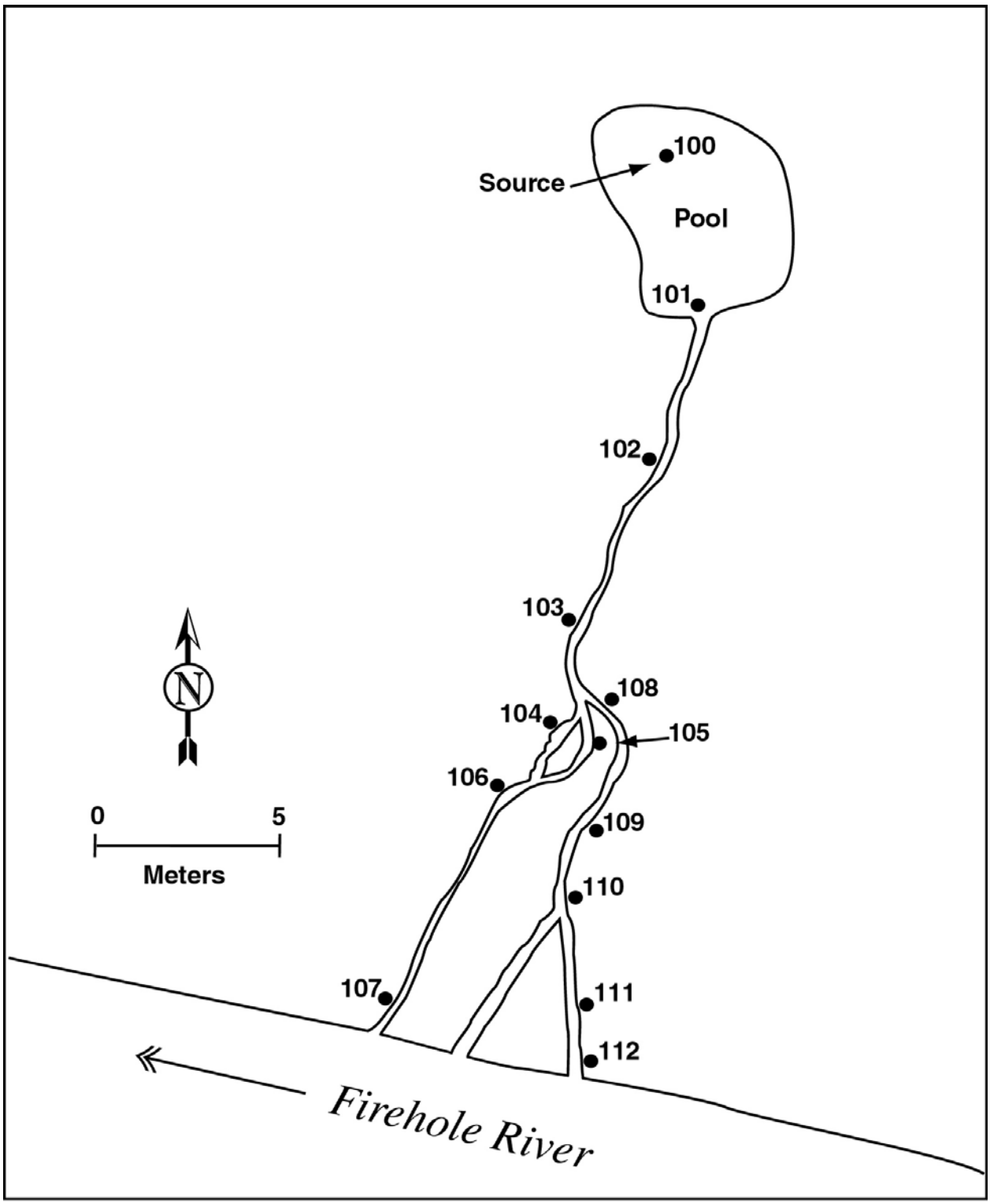

Figure 2. Sampling sites for Ojo Caliente Spring and its overflow channel, Lower Geyser Basin, 1994.

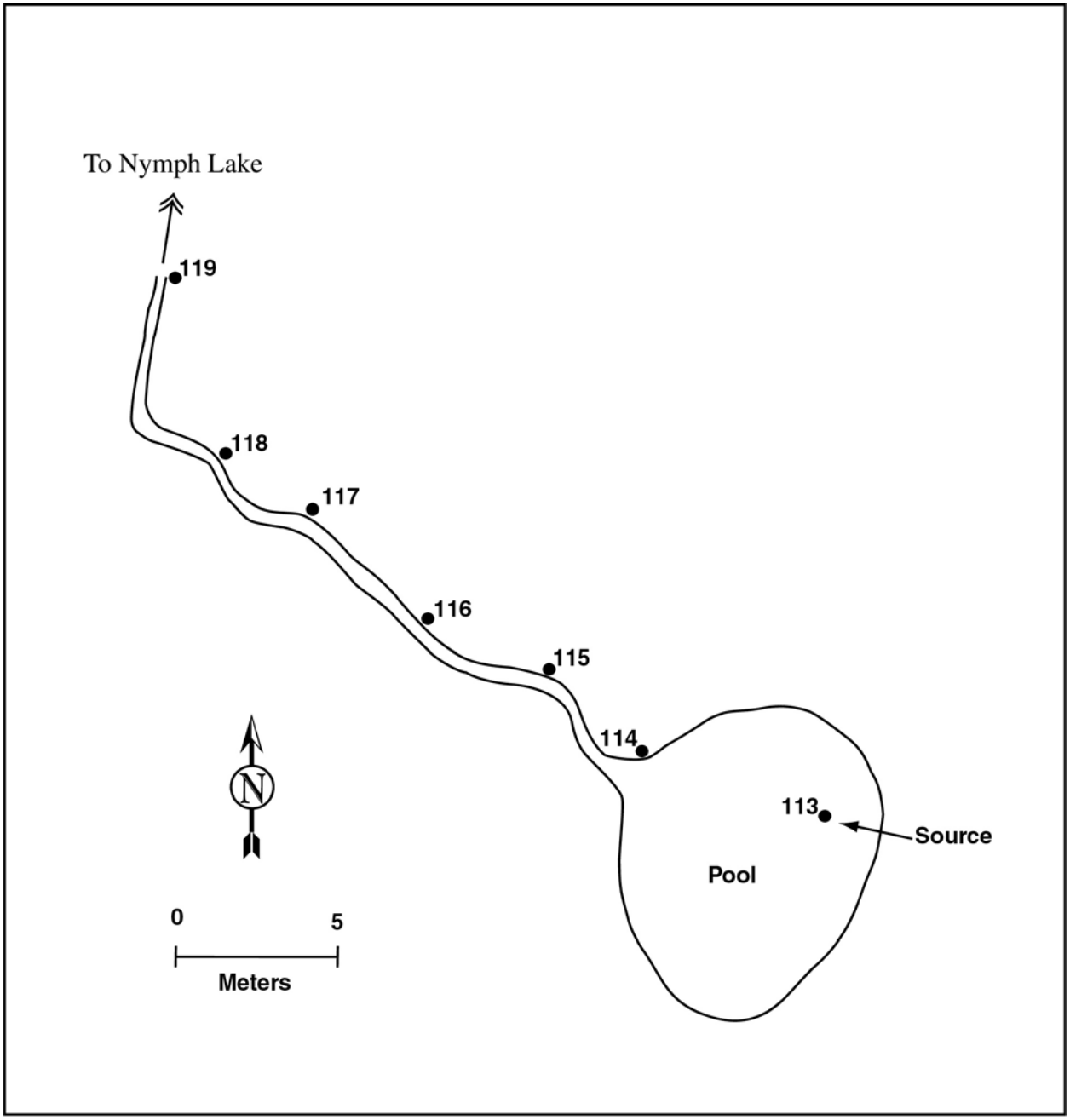

Figure 3. Sampling sites for Frying Pan Spring and its overflow channel, Norris Geyser Basin, 1994.

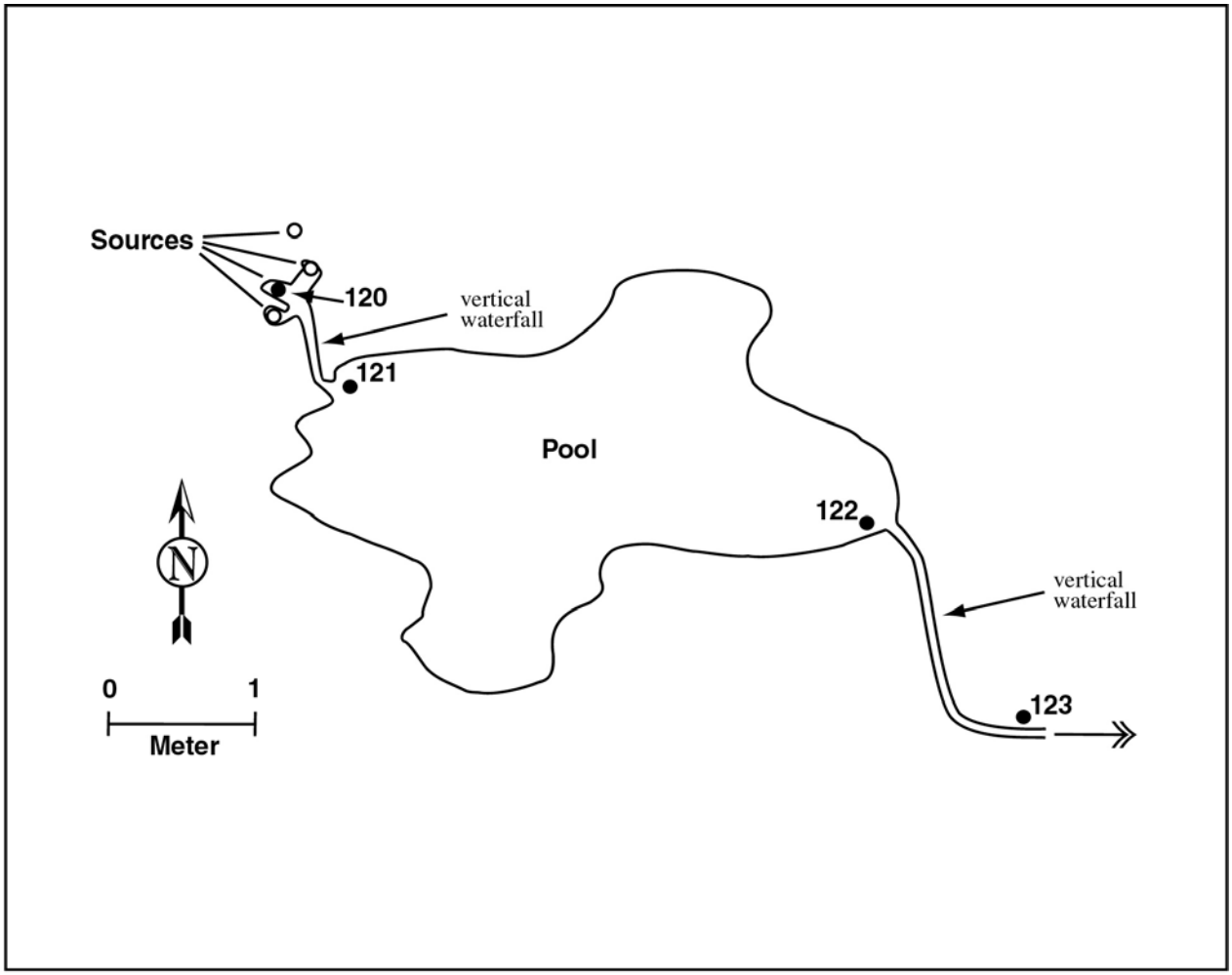

Figure 4. Sampling sites for Angel Terrace Spring and its overflow channel, Mammoth Hot Springs complex, 1994.

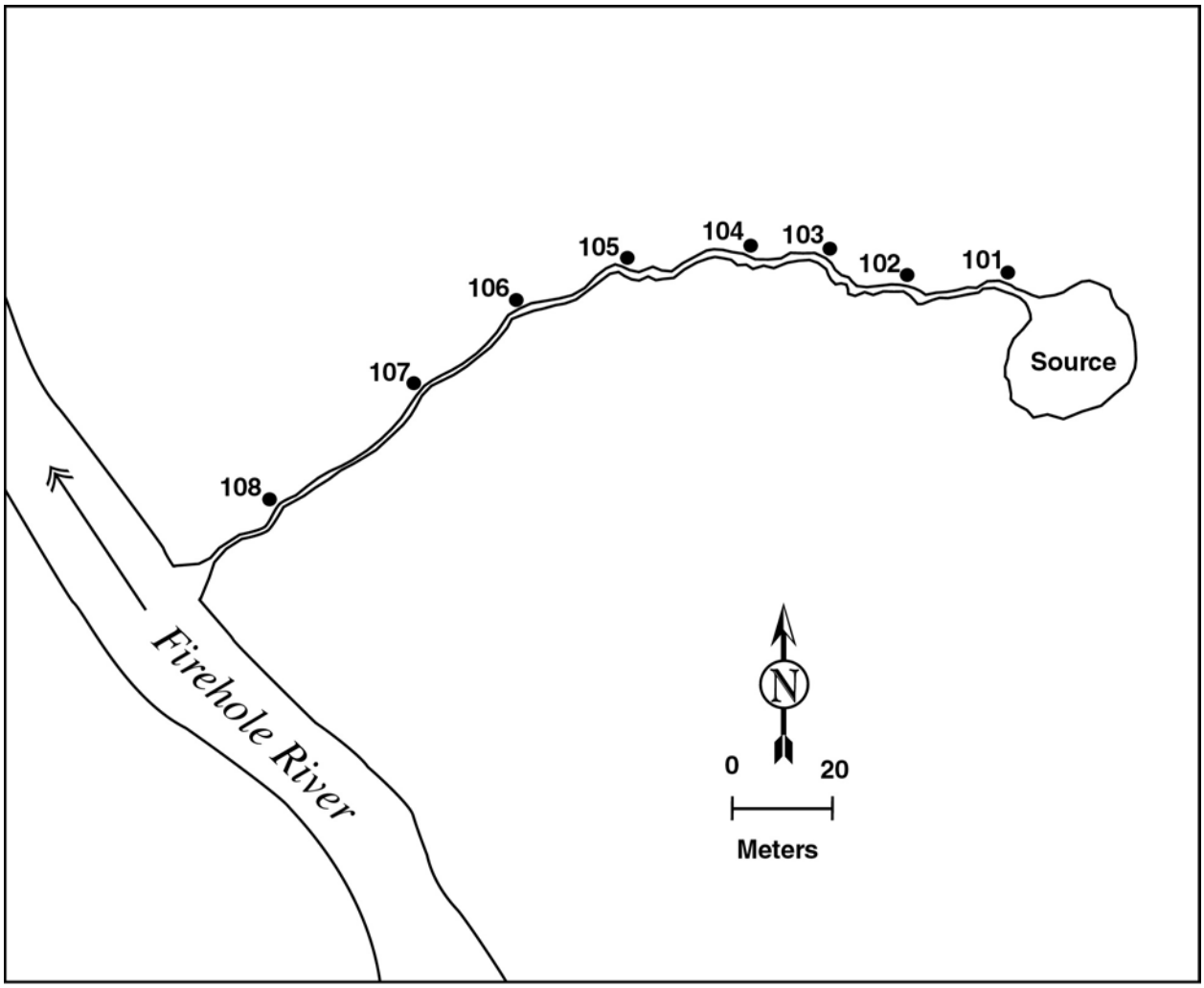

Figure 5. Sampling sites for Azure Spring and its overflow channel, Lower Geyser Basin, 1995.

At all sites, samples for the following determinations were filtered upon withdrawal from the source: major cations, trace metals, Fe(II) and Fe(total), major anions, alkalinity, density, DOC, NH_4^+, dissolved SiO_2, H_2S, SO_4^{2-}, $S_2O_3^{2-}$, and isotopes of H and O. Samples for H_2S, SO_4^{2-}, and $S_2O_3^{2-}$ analyses were suctioned by hand into a plastic syringe to avoid the formation of head space, then pressure-filtered through syringe-mounted 0.45-：m membrane filters; stabilizing reagents were put into the syringe before the sample was drawn into it. All other samples were pumped from the spring with a portable peristaltic pump through medical-grade silicone tubing, then through a 142-mm diameter all-plastic filter holder (Kennedy and others, 1976) containing a 0.45-：m Millipore filter membrane, except for samples 94WA110 and 95WA116 where a 0.1-：m filter membrane was used. Storage and stabilization of filtered samples are summarized in table 1.

Unfiltered samples were used for analyses of pH, Eh, D.O., temperature, and specific conductance. Temperature, specific conductance, and D.O. measurements were made by immersing probes directly into the source or into a sample collected in the insulated container. Measurements for Eh and pH were made on unfiltered sample water pumped from the spring through an acrylic plastic flow-through cell containing a thermometer, Eh and pH electrodes, and test tubes containing calibrating solutions.

Table 1. Storage and stabilization methods for filtered samples

Sample type(s)	Storage container	Stabilization treatment in addition to refrigeration
Major cations, trace metals, Fe(II), and Fe(total)	Polyethylene or PTFE bottles, soaked in 10% HNO_3 and rinsed with double-distilled water	1% (v/v) redistilled 6 N HCl added
Major anions, alkalinity, and density	Polyethylene bottles, rinsed in 10% HNO_3 and soaked in double-distilled water aliquots for >48 hours	None
DOC	Baked (450°C) amber glass bottles with PTFE-lined caps	None
NH_4^+	Same as major cations, trace metals, Fe(II), and Fe(total)	1% (v/v) 1:10 redistilled H_2SO_4 added
Dissolved SiO_2	Same as major anions, alkalinity, and density	Diluted 1:10 immediately with distilled H_2O
SO_4^{2-}, $S_2O_3^{2-}$	60 mL plastic syringe	1.6% (v/v) 1 M Cd-(OOC-$CH_3)_2$, $CdCl_2$, or $ZnCl_2$ plus 0.2% (v/v) 5 M NaOH added to precipitate S(-II)

Analytical Methods

The analytical methods are summarized in the Appendix at the back of the report (tables 10 and 11). Because most determinations were accomplished using established procedures, the method corresponding to each descriptor in table 10 is described briefly in table 11. In the following paragraphs, only general conditions or variants of standard procedures are discussed.

All reagents were of purity at least equal to the reagent-grade standards of the American Chemical Society. Doubly-distilled de-ionized water and re-distilled acids were used in all preparations. For inductively-coupled plasma, flame atomic-absorption, and graphite-furnace atomic-absorption spectrometric analyses, external standards, blanks, sample dilutions, and spiking solutions were made with commercial ICP elemental standard solutions or standard solutions composed of elements or their compounds of the highest commercially-available purity. USGS standard reference water samples (SRWS) were used as independent standards.

Samples were diluted as necessary to bring the analyte concentration within the optimal range of the method. For elemental analyses, several dilutions of each sample, with the extremes of the range differing by dilution factors of 2 to 10, were analyzed to check for concentration effects on the analytical method.

Calibration curves were determined by using standards within each set of analyses. If matrix effects were evident, spike-recovery and/or standard-addition measurements were performed. USGS SRWS T-117, T-115, and T-111 were used to check the analytical methods for major and trace metals, and SRWS M-102 was used to check the analytical methods for major anions. The SRWS data are presented in table 12 in the Appendix. Estimates of ICP detection limits are reported in table 11 in the Appendix and were assumed equal to $3\sigma_{blank}$, where σ_{blank} is the standard deviation of several dozen measurements of the constituent in a blank solution treated as a sample. Also listed in table 11 are typical values of analytical reproducibility for each method of analysis in samples containing the analyte at concentrations at least ten times the detection limit. These parameters were estimated for FAAS and ZGFAAS in a similar manner, but using only about a dozen measurements of blanks.

Sample Treatment for Thiosulfate and Sulfate Determinations

Determination of dissolved sulfur species presents particularly difficult analytical challenges, making the evaluation of sampling and analytical procedures critical to the success of the research. Hence, methods of collection and analysis are reported. For example, dissolved H_2S can volatilize rapidly or oxidize to S, $S_2O_3^{2-}$, other S species of intermediate oxidation state, and SO_4^{2-}. Without proper precautions, all these species can be considered unstable and subject to change. Because on-site determinations or special preservation techniques are crucial for reliable determination of unstable species concentrations, a USGS mobile lab truck with an on-board ion chromatograph, autotitrator, and UV-visible spectrophotometer was used to determine unstable species concentrations within minutes to hours of sample collection.

The distribution of sulfur species during oxidation of H_2S will change with storage time according to the rates of several competing reactions. These reactions, based on the works of Chen and Morris (1972), O'Brien and Birkner (1977), and Zhang and Millero (1994), are listed in table 2.

Table 2. Reactions of reduced sulfur species

Reaction	Conditions where reaction rate is at a maximum
$HS^- + H^+$: H_2S 6 H_2S8	pH # 6
$HS^- + 2O_2$ 6 $SO_4^{2-} + H^+$	6 # pH # 8.5, $[HS^-]:[O_2]$ low
$2HS^- + 2O_2$ 6 $S_2O_3^{2-} + H_2O$	pH $ 6, $[HS^-]:[O_2]$ low
$HS^- + {}^3/_2O_2$ 6 $SO_3^{2-} + H^+$	pH $ 7, $[HS^-]:[O_2]$ low
$HS^- + ½O_2 + H^+$6 $S + H_2O$	6 # pH # 8.5, $[HS^-]:[O_2]$ high
$S_n + HS^-$: $S_{n+1}^{2-} + H^+$ (n = 4,5)	6 # pH # 8, $[HS^-]:[O_2]$ high
$S_n^{2-} + {}^3/_2O_2$ 6 $SO_3^{2-} + (n-1)S$	6 # pH # 8, $[HS^-]:[O_2]$ high
$S_n^{2-} + 2O_2 + 2H^+$ 6 $S_2O_3^{2-} + H_2O + (n-2)S$	6 # pH # 8, $[HS^-]:[O_2]$ high
$SO_3^{2-} + ½O_2$ 6 SO_4^{2-}	All pH
$S + SO_3^{2-}$: $S_2O_3^{2-}$	7 # pH # 8
$S_2O_3^{2-} + {}^5/_2O_2$ 6 $2SO_4^{2-}$	Temperature $ 100°C

In the hot springs, high temperature and the presence of oxidation-catalyzing bacteria cause these reactions to proceed at a much faster rate than in cooled and filtered samples stored for later analysis. For example, $S_2O_3^{2-}$ is oxidized rapidly to $SO_4^{2!}$ at high temperatures, but this reaction proceeds at a negligible rate (Rolla and Chakrabarti, 1982) under typical sample-storage conditions. However, at the neutral pH and high initial $[HS^!]:[O_2]$ ratio of Ojo Caliente Spring, Azure Spring, and Angel Terrace Spring waters, the oxidation reactions of S(-II) occur with a half-life comparable to that of the storage time between sample collection and analysis. In these types of samples, major oxidation products are expected to be SO_4^{2-} and $S_2O_3^{2-}$, with elemental S, SO_3^{2-}, polythionates ($S_nO_6^{2-}$), and polysulfides (S_n^{2-}) as minor products.

To prevent over-estimation of the *in-situ* concentration of SO_4^{2-} and $S_2O_3^{2-}$, S(-II) oxidation was minimized by drawing unfiltered sample into a 60 mL syringe containing either 1 mL of 1 M Cd-$(OOC\text{-}CH_3)_2$ (1994 sampling) or 1 mL of 1 M $ZnCl_2$ (1995 sampling), plus 0.5 mL 5 M NaOH. This technique caused the oxidation-resistant ZnS or CdS species to precipitate. The sample was then pressure-filtered directly into the ion chromatograph on-site in the mobile laboratory or was stored on ice and analyzed a few days to weeks later at the USGS laboratory in Boulder, Colorado, or SUNY at Stony Brook. The H_2S concentrations range from <0.005 to 8 mg/L. For samples having H_2S concentrations toward the higher end of this range, $S_2O_3^{2-}$ concentrations were higher in the stored sample splits than in those analyzed on-site. For samples containing H_2S concentrations toward the lower end of the range, $S_2O_3^{2-}$ concentrations were lower in the stored sample splits than in those analyzed on-site. This result suggests that preservation using $CdCl_2$ or $ZnCl_2$ does not prevent oxidation of either S(-II) to $S_2O_3^{2-}$ or $S_2O_3^{2-}$ to SO_4^{2-} upon longer term storage.

Cd initially appeared to be the superior precipitating agent because the smaller solubility product constant of CdS ($K = 10^{-27.0}$) compared with the solubility product constant for ZnS ($K = 10^{-22.5}$) (Smith and Martell, 1976) should result in better preservation of the S(-II). However, recent work (Xu and Schoonen, 1995; Xu and others, 1996) has established that semiconductors such as pyrite (FeS_2) and CdS can catalyze the oxidation of $S_2O_3^{2-}$ by O_2. The catalytic effect depends on the energy position of the conduction and valence bands of the semiconductor relative to the standard potential of the $S_2O_3^{2-}/SO_4^{2-}$ redox couple in solution. By contrast, the conduction and valence band energies of ZnS cannot facilitate the $S_2O_3^{2-}$ oxidation reaction.

Based on the observations and discussions above, $S_2O_3^{2-}$ in water samples needs to be stabilized by adding 1 mL of 1 M $ZnCl_2$ and 0.5 mL of 5 M NaOH to 60 mL of sample, storing the sample on ice, and analyzing it as quickly as possible, preferably within 2 days.

WATER-CHEMISTRY DATA

Site data and water analyses for YNP springs sampled in 1994 and 1995 are presented in tables 3-7. The results of ^{2}H and ^{18}O isotope analyses are listed in table 8. Methods used in these analyses are listed in table 11 in the Appendix. Samples are sorted by spring, then by date of sample collection, and then by sampling site along the downstream overflow channel (if present). In these tables, "source" samples were collected at the origin of the spring, and "overflow channel" samples were collected at various distances downstream from the source. For data sets that contained alkalinity and concentrations of major anions and major cations, the WATEQ4F program (Ball and Nordstrom, 1991) was used to calculate ion sums and charge imbalance (C.I.), using the following calculation:

$$\text{C.I. (percent)} = \frac{100 \times (\text{meq cations - meq anions})}{(\text{meq cations + meq anions}) \div 2} .$$

Note that the result of this calculation is twice the value that would be reported by an analytical laboratory, because equation (1) relates the cation-anion difference to the average of the two rather than to the sum of the ions comprising them. Those data sets having charge imbalances exceeding 10 percent are footnoted if an explanation for the problem could be determined.

SULFUR-SPECIATION DATA

Sulfur-species data from historical reports and this study are compared in table 9 for six locations: Ojo Caliente, Azure, Frying Pan, and Angel Terrace springs, Echinus Geyser, and Cinder Pool. Chloride concentrations are included so that the consistency of the analysis can be checked and changes in concentration resulting from mixing of different subsurface waters can be ruled out. Two important points are made with these data. The first point is that H_2S concentrations can be highly variable. This variability may be caused as much by sampling and preservation artifacts as by actual variations in water chemistry over time. The second point is that while early analyses of $S_2O_3^{2-}$ such as those by Allen and Day (1935) were carefully done, they were subject to overestimation. The accepted method of that time, used by Allen and Day (1935), consisted of capturing the sample in a glass bottle, adding $CdCO_3$, and letting the sample stand overnight to react and remove dissolved H_2S. It is now known that excess $S_2O_3^{2-}$ is likely to form by oxidation of HS^-,

and determination of the remaining $S_2O_3^{2-}$ by titration with starch iodine solution suffered from uncertainties. Allen and Day (1935) did not attempt to determine $S_2O_3^{2-}$ in acid springs such as Frying Pan because it was well known that $S_2O_3^{2-}$ is unstable in acid solutions. However, the oxidation rate for $S_2O_3^{2-}$ is much slower than that for H_2S so that $S_2O_3^{2-}$ can be found in these springs where a constant supply of hydrogen sulfide is provided. Ignoring Frying Pan Spring, which is poorly-defined in terms of input sources of water and gases, and ignoring Echinus Geyser because it occurs primarily as a geyser and thus always exhibits transient flow conditions, the remaining data show remarkable consistency in concentrations of sulfur species over long periods of time.

Two publications (Xu and others, 1998; 2000) discuss the origin of $S_2O_3^{2-}$ in hot spring waters and the formation and decomposition of $S_2O_3^{2-}$ and $S_nO_6^{2-}$ in Cinder Pool, Norris Geyser Basin. Data that form the basis of the discussions and conclusions in those reports are in tables 3-9.

Table 3. Site data and water analyses for Ojo Caliente Spring and its overflow channel, Lower Geyser Basin

Sample code number	94WA100	94WA101	94WA102	94WA103
Date collected	6/28/94	6/28/94	6/28/94	6/28/94
Flow channel distance (m)	0 (source)	0 (pool)	5.5	11
Temperature (°C)	93	91.9	88.5	85.8
Density (g/mL) at 20°C	0.99936	0.99929	0.99906	0.99916
pH (field/lab)	7.72/8.61	7.6/8.65	7.69/8.69	7.79/8.61
Spec. cond. (: S/cm) (field/lab)	1517/1595	1517/1596	1517/1614	1526/1614
Eh (V)	-0.156	-0.086	0.029	0.090
D.O. (mg/L)	0.1	0.5	0.75	1.1
Constituent (mg/L)				
Ca	1.00	0.91	0.88	0.91
Mg	0.001	0.0006	0.001	0.0007
Na	331	331	331	332
K	9.45	9.5	9.7	9.58
SO_4	20.7	21.0	20.9	21.2
S_2O_3	0.269	0.275	0.351	0.477
H_2S	1.09	1.06	0.74	0.55
Alkalinity (as HCO_3)	231.7	234.2	236.4	233.3
F	31.6	30.9	31.5	31.4
Cl	324	326	328	330
Br	1.15	1.17	1.17	1.18
SiO_2	243	236	248	248
NO_3	[1]0.132	0.032	0.032	<0.031
NH_4	0.089	0.028	0.03	0.033
Al	0.280	0.275	0.278	0.278
Fe(tot)	0.0232	0.0237	0.014	0.0118
Fe(II)	0.0232	0.0237	0.014	0.0118
B	3.98	3.89	3.97	3.98
Li	3.96	3.99	3.98	4.01
Sr	0.008	0.007	0.006	0.006
Ba	<0.04	<0.04	<0.04	<0.04
Mn	<0.12	<0.12	<0.12	<0.12
Zn	<0.01	<0.01	<0.01	<0.01
Pb	<0.15	<0.15	<0.15	<0.15
Be	<0.001	<0.001	<0.001	<0.001
V	<0.02	<0.02	<0.02	<0.02
Cr	<0.09	<0.09	<0.09	<0.09
Co	<0.04	<0.04	<0.04	<0.04
Ni	<0.04	<0.04	<0.04	<0.04
Cu	<0.14	<0.14	<0.14	<0.14
Cd	<0.04	<0.04	<0.04	<0.04
As(total)	0.86	1.1	0.99	1.27
DOC (mg/L)	1.0	0.8	0.6	0.4
Sum cations (meq/L)	14.6	15.2	15.2	15.3
Sum anions (meq/L)	14.9	15.0	15.0	15.3
Charge imbalance (percent)	-1.8	1.7	1.3	0.02

[1]Likely to be contaminated.

Table 3. Site data and water analyses for Ojo Caliente Spring and its overflow channel, Lower Geyser Basin--continued

Sample code number	94WA104	94WA105	94WA106	94WA107
Date collected	6/28/94	6/28/94	6/28/94	6/28/94
Flow channel distance (m)	14.9	14.9	17.7	26.2
Temperature (°C)	82.8	78.8	79.1	73.8
Density (g/mL) at 20°C	0.99903	0.99912	0.99935	0.99906
pH (field/lab)	7.86/8.66	7.94/8.70	7.92/8.72	8.12/8.71
Spec. cond. (: S/cm) (field/lab)	1542/1623	1568/1631	1556/1628	1580/1646
Eh (V)	0.142	0.183	0.148	0.171
D.O. (mg/L)	1.15	1.5	1.7	2.7
Constituent (mg/L)				
Ca	0.84	0.83	0.93	0.97
Mg	0.0004	0.0005	0.0003	0.0004
Na	336	325	339	340
K	9.67	9.74	9.66	9.84
SO_4	21.1	21.7	21.8	22.2
S_2O_3	0.574	0.756	0.702	0.629
H_2S	0.33	0.17	0.16	0.12
Alkalinity (as HCO_3)	237.6	240.1	245.2	233.9
F	31.6	32.0	31.9	32.7
Cl	331	331	332	335
Br	1.19	1.21	1.21	1.23
SiO_2	257	260	262	259
NO_3	<0.031	<0.031	<0.031	<0.031
NH_4	0.031	0.014	0.013	0.008
Al	0.277	0.290	0.290	0.280
Fe(tot)	0.0021	<0.0005	0.004	<0.0005
Fe(II)	0.0021	<0.0005	0.004	<0.0005
B	3.98	4.02	4.16	4.01
Li	4.02	4.07	4.02	4.09
Sr	0.005	0.005	0.005	0.006
Ba	<0.04	<0.04	<0.04	<0.04
Mn	<0.12	<0.12	<0.12	<0.12
Zn	<0.01	<0.01	<0.01	<0.01
Pb	<0.15	<0.15	<0.15	<0.15
Be	<0.001	<0.001	<0.001	<0.001
V	<0.02	<0.02	<0.02	<0.02
Cr	<0.09	<0.09	<0.09	<0.09
Co	<0.04	<0.04	<0.04	<0.04
Ni	<0.04	<0.04	<0.04	<0.04
Cu	<0.14	<0.14	<0.14	<0.14
Cd	<0.04	<0.04	<0.04	<0.04
As(total)	1.5	1.53	1.29	1.48
DOC (mg/L)	0.4	0.3	0.4	0.3
Sum cations (meq/L)	15.4	15.5	15.6	15.6
Sum anions (meq/L)	15.2	15.3	15.4	15.3
Charge imbalance (percent)	1.5	1.5	1.0	1.8

Table 3. Site data and water analyses for Ojo Caliente Spring and its overflow channel, Lower Geyser Basin--continued

Sample code number	94WA108	94WA109	94WA110	94WA111	94WA112
Date collected	6/29/94	6/29/94	6/29/94	6/29/94	6/29/94
Flow channel distance (m)	13.4	16.8	20.4	25.3	29.9
Temperature (°C)	78	71.2	66.6	55	50.5
Density (g/mL) at 20°C	0.99906	0.99905	0.99935	0.99935	0.99927
pH (field/lab)	8.06/8.55	8.13/8.65	8.21/8.73	8.37/8.76	8.47/8.81
Spec. cond. (: S/cm) (field/lab)	1580/1626	1595/1640	1628/1647	1650/1687	1683/1710
Eh (V)	0.093	0.146	0.195	0.217	0.234
D.O. (mg/L)	2	2.3	2.7	3.3	3.7
Constituent (mg/L)					
Ca	0.95	0.94	1.01	1.00	1.01
Mg	0.0004	0.0007	[1]0.010	0.0011	0.0003
Na	336	338	342	353	353
K	9.8	9.8	9.9	10.1	10.3
SO_4	21.6	22.5	22.5	23.2	23.7
S_2O_3	0.718	0.594	0.589	0.562	0.550
H_2S	0.17	0.09	0.06	0.03	0.03
Alkalinity (as HCO_3)	241.4	241.8	244.1	249	251.4
F	32.5	32.8	33.1	34.0	34.3
Cl	332	334	335	343	345
Br	1.23	1.23	1.24	1.28	1.29
SiO_2	257	253	257	263	263
NO_3	<0.031	<0.031	<0.031	<0.031	<0.031
NH_4	0.013	0.009	0.013	<0.006	<0.006
Al	0.300	0.296	0.278	0.275	0.288
Fe(tot)	<0.0005	<0.0005	0.0007	<0.0005	<0.0005
Fe(II)	<0.0005	<0.0005	0.0007	<0.0005	<0.0005
B	4.02	3.97	4.02	4.15	4.16
Li	4.07	4.11	4.13	4.25	4.25
Sr	0.006	0.006	0.006	0.007	0.007
Ba	<0.04	<0.04	<0.04	<0.04	<0.04
Mn	<0.12	<0.12	<0.12	<0.12	<0.12
Zn	<0.01	<0.01	<0.01	<0.01	<0.01
Pb	<0.15	<0.15	<0.15	<0.15	<0.15
Be	<0.001	<0.001	<0.001	<0.001	<0.001
V	<0.02	<0.02	<0.02	<0.02	<0.02
Cr	<0.09	<0.09	<0.09	<0.09	<0.09
Co	<0.04	<0.04	<0.04	<0.04	<0.04
Ni	<0.04	<0.04	<0.04	<0.04	<0.04
Cu	<0.14	<0.14	<0.14	<0.14	<0.14
Cd	<0.04	<0.04	<0.04	<0.04	<0.04
As(total)	1.44	1.53	1.44	1.43	1.5
DOC (mg/L)	0.3	0.3	[1]1.1	0.4	0.3
Sum cations (meq/L)	15.4	15.5	15.7	16.2	16.2
Sum anions (meq/L)	15.3	15.4	15.5	15.9	16.0
Charge imbalance (percent)	0.7	0.5	1.2	2.1	1.2

[1]Likely to be contaminated.

Table 4. Site data and water analyses for Frying Pan Spring and its overflow channel, Norris Geyser Basin

Sample code number	94WA113	94WA114	94WA115	94WA116
Date collected	6/29/94	6/29/94	6/29/94	6/29/94
Flow channel distance (m)	0 (source)	0 (outflow)	4.6	9.4
Temperature (°C)	78.2	58.1	52	48.5
Density (g/mL) at 20°C	0.99889	0.99895	0.9988	0.99893
pH (field/lab)	2.34/2.42	2.3/2.40	2.32/2.39	2.33/2.40
Spec. cond. (: S/cm) (field/lab)	1230/2070	1575/2260	1675/2150	1760/2190
Eh (V)	0.182	0.294	0.327	0.358
D.O. (mg/L)	2.4	2	2.5	2.65
Constituent (mg/L)				
Ca	2.41	2.76	2.56	2.52
Mg	0.53	0.59	0.49	0.46
Na	54.6	59.8	57.5	58.1
K	13	14.3	13.4	13.7
SO_4	437	460	458	456
S_2O_3	0.632	0.696	n.d.	n.d.
H_2S	1.03	0.04	0.01	<0.005
Alkalinity (as HCO_3)	n.a.	n.a.	n.a.	n.a.
F	2.95	3.24	3.21	3.23
Cl	8.69	9.48	9.14	9.23
Br	<0.040	<0.040	<0.040	<0.040
SiO_2	221	235	236	239
NO_3	<0.031	<0.031	<0.031	<0.031
NH_4	1.16	1.10	1.08	1.13
Al	5.65	6.49	5.85	6.10
Fe(total)	1.09	1.14	1.05	1.07
Fe(II)	1.09	1.14	1.05	1.07
B	0.64	0.78	0.64	0.72
Li	0.31	0.33	0.32	0.32
Sr	0.014	0.015	0.015	0.013
Ba	<0.06	0.072	<0.05	<0.05
Mn	<0.12	<0.12	<0.12	<0.12
Zn	0.108	<0.01	<0.01	<0.01
Pb	<0.15	<0.15	<0.15	<0.15
Be	<0.001	<0.001	<0.001	<0.001
V	<0.02	<0.02	<0.02	<0.02
Cr	<0.09	<0.09	<0.09	<0.09
Co	<0.04	<0.04	<0.04	<0.04
Ni	<0.04	<0.04	<0.04	<0.04
Cu	<0.14	<0.14	<0.14	<0.14
Cd	<0.04	<0.04	<0.04	<0.04
As(total)	0.19	0.21	0.21	0.21
DOC (mg/L)	1.8	1.9	1.5	1.5
Sum cations (meq/L)	8.3	9.1	8.7	8.6
Sum anions (meq/L)	6.7	7.6	7.8	7.9
Charge imbalance (percent)[1]	22.0/8.4	19.0/2.3	11.4/-0.3	9.5/-1.9

[1]Where two charge imbalance values appear, they are field pH C.I./lab pH C.I.

Table 4. Site data and water analyses for Frying Pan Spring and its overflow channel, Norris Geyser Basin--continued

Sample code number	94WA117	94WA118	94WA119
Date collected	6/29/94	6/29/94	6/29/94
Flow channel distance (m)	14.6	18.6	24.6
Temperature (°C)	47.4	46.2	45.7
Density (g/mL) at 20°C	0.99874	0.99901	0.99955
pH (field/lab)	2.28/2.38	2.31/2.40	2.3/2.40
Spec. cond. (: S/cm) (field/lab)	1795/2180	1802/2190	1820/2220
Eh (V)	0.359	0.270	0.326
D.O. (mg/L)	2.7	2.75	2.95
Constituent (mg/L)			
Ca	2.64	2.49	2.61
Mg	0.45	0.46	0.51
Na	58	57.4	59.3
K	13.6	12.8	13.7
SO_4	465	463	470
S_2O_3	n.a.	n.a.	0.550
H_2S	<0.005	0.02	0.01
Alkalinity (as HCO_3)	n.a.	n.a.	n.a.
F	3.13	3.23	3.25
Cl	9.32	9.18	9.28
Br	<0.040	<0.040	<0.040
SiO_2	236	228	239
NO_3	<0.031	<0.031	<0.031
NH_4	1.09	1.11	1.12
Al	5.97	5.87	6.04
Fe(total)	1.08	1.05	1.08
Fe(II)	1.08	1.05	1.08
B	0.69	0.77	0.73
Li	0.33	0.34	0.34
Sr	0.015	0.014	0.015
Ba	<0.05	<0.055	<0.057
Mn	<0.12	<0.12	<0.12
Zn	<0.01	<0.01	<0.01
Pb	<0.15	<0.15	<0.15
Be	<0.001	<0.001	<0.001
V	<0.02	<0.02	<0.02
Cr	<0.09	<0.09	<0.09
Co	<0.04	<0.04	<0.04
Ni	<0.04	<0.04	<0.04
Cu	<0.14	<0.14	<0.14
Cd	<0.04	<0.04	<0.04
As(total)	0.22	0.21	0.22
DOC (mg/L)	1.5	1.6	1.6
Sum cations (meq/L)	9.2	8.8	9.0
Sum anions (meq/L)	7.9	8.0	8.1
Charge imbalance (percent)[1]	15.2/-1.7	9.8/-5.2	11.3/-5.1

[1]Where two charge imbalance values appear, they are field pH C.I./lab pH C.I.

Table 5. Site data and water analyses for Angel Terrace Spring and its overflow channel, Mammoth Hot Springs complex

Sample code number	94WA120	94WA121	94WA122	94WA123
Date collected	6/30/94	6/30/94	6/30/94	6/30/94
Flow channel distance (m)	0 (source)	1 (pool)	1 (outlet)	2
Temperature (°C)	71.4	70.6	61.9	56.5
Density (g/mL) at 20°C	1.00013	0.99999	0.99996	0.99975
pH (field/lab)	6.43/8.47	6.51/8.37	7.14/8.47	7.52/8.32
Spec. cond. (：S/cm) (field/lab)	2170/2340	2195/2340	2230/2090	2245/1810
Eh (V)	-0.041	-0.030	0.158	0.178
D.O. (mg/L)	0.5	1.1	2.2	2.9
Constituent (mg/L)				
Ca	320	308	298	270
Mg	74.8	73.2	73.4	72.9
Na	136	132	133	132
K	57.4	58.5	57.9	53.6
SO_4	547	544	553	557
S_2O_3	<0.09	0.452	0.620	0.553
H_2S	3.01	0.95	0.33	0.09
Alkalinity (as HCO_3)	734	734.5	629.1	633.7
F	2.93	2.72	2.35	1.98
Cl	165	166	168	170
Br	0.554	0.561	0.568	0.573
SiO_2	54	51.9	58.4	54.4
NO_3	0.034	<0.031	<0.031	<0.031
NH_4	0.913	0.863	0.873	0.881
Al	0.012	0.010	0.007	0.006
Fe(tot)	0.0297	0.0253	0.0055	0.0025
Fe(II)	0.0297	0.0253	0.0055	0.0025
B	3.56	3.5	3.6	3.48
Li	1.64	1.64	1.66	1.67
Sr	1.63	1.59	1.49	1.31
Ba	<0.1	<0.1	<0.1	<0.1
Mn	<0.3	<0.3	<0.3	<0.3
Zn	<0.025	<0.025	<0.025	<0.025
Pb	<0.375	<0.375	<0.375	<0.375
Be	<0.001	<0.001	<0.001	<0.001
V	<0.05	<0.05	<0.05	<0.05
Cr	<0.225	<0.225	<0.225	<0.225
Co	<0.1	<0.1	<0.1	<0.1
Ni	<0.1	<0.1	<0.1	<0.1
Cu	<0.35	<0.35	<0.35	<0.35
Cd	<0.1	<0.1	<0.1	<0.1
As(total)	0.47	0.42	0.55	0.62
DOC (mg/L)	1.1	1.1	0.8	n.a.
Sum cations (meq/L)	24.3	23.5	23.2	21.7
Sum anions (meq/L)	22.5	22.6	21.2	21.6
Charge imbalance (percent)	7.5	3.9	8.7	0.5

Table 6. Site data and water analyses for Azure Spring and its overflow channel, Lower Geyser Basin

Sample code number	95WA101	95WA101A	95WA101B (unfiltered)	95WA102	95WA103
Date collected	8/20/95	8/20/95	8/20/95	8/20/95	8/20/95
Flow channel distance (m)	6.4	6.4	6.4	25	42
Temperature (°C)	72.8	(75)[1]	(75)	66	(64)
Density (g/mL) at 20°C	n.a.	0.9992	0.9993	0.9991	0.9989
pH (field/lab)	8.75/9.21	n.m./9.29	n.m./9.28	8.76/9.26	8.77/9.28
Spec. cond. (: S/cm) (field/lab)	1510	n.m./1652	n.m./1575	1530/1577	1520/1578
Eh (V)	-0.038	n.m.	n.m.	-0.026	0.016
D.O. (mg/L)	n.m.	n.m.	n.m.	n.m.	n.m.
Constituent (mg/L)					
Ca	1.5	1.9	1.7	1.3	1.4
Mg	0.0056	0.0095	0.0118	0.0065	0.0061
Na	315	346	321	318	316
K	13.5	13.8	13.8	13.5	13.7
SO_4	41	44	46	43	45
S_2O_3	5.26	n.a.	n.a.	4.49	4.08
H_2S	0.36	n.a.	n.a.	0.237	0.149
Alkalinity (as HCO_3)	206	205.6	206.8	198.5	199.3
F	30.1	31.9	31.0	30.6	31.1
Cl	306	310	305	308	316
Br	0.9	0.8	0.9	1.0	1.1
SiO_2	294	277	272	293	283
NO_3	0.96	1.01	1.07	1.07	1.06
NH_4	0.05	0.06	n.a.	0.06	0.01
Al	0.200	0.205	0.241	0.218	0.200
Fe(total)	0.030	0.025	0.026	0.035	0.027
Fe(II)	0.030	0.023	0.026	0.035	0.027
B	4.30	4.70	4.80	4.40	4.38
Li	2.91	3.21	2.95	2.83	2.87
Sr	0.010	0.015	0.015	0.010	0.008
Ba	<0.015	<0.015	<0.015	<0.015	<0.015
Mn	<0.010	<0.006	<0.006	<0.011	<0.010
Zn	0.009	<0.010	<0.009	0.009	0.009
Pb	<0.11	<0.11	<0.11	<0.11	<0.11
Be	<0.001	<0.001	<0.001	<0.001	<0.001
V	<0.021	<0.021	<0.021	<0.021	<0.021
Cr	<0.21	<0.21	<0.21	<0.21	<0.21
Co	<0.024	<0.024	<0.024	<0.024	<0.024
Ni	<0.070	<0.042	<0.042	<0.070	<0.070
Cu	<0.20	<0.20	<0.20	<0.20	<0.20
Cd	<0.009	<0.009	<0.009	<0.009	0.011
As(total)	1.5	1.5	1.7	1.4	1.9
DOC	n.a.	n.a.	n.a.	n.a.	n.a.
Sum cations (meq/L)	14.39	15.94	14.79	15.54	14.47
Sum anions (meq/L)	14.38	14.76	14.57	14.41	14.73
Charge imbalance (percent)	0.11	7.64	1.51	0.90	-1.78

[1]Temperatures in ( ) were estimated from data collected 8/18/96.

Table 6. Site data and water analyses for Azure Spring and its overflow channel, Lower Geyser Basin--continued

Sample code number	95WA104 (unfiltered)	95WA105 (unfiltered)	95WA106 (unfiltered)	95WA107 (unfiltered)	95WA108 (unfiltered)
Date collected	8/20/95	8/19/95	8/20/95	8/20/95	8/20/95
Flow channel distance (m)	57	85	107	132	168
Temperature (°C)	n.m.	(57)[1]	n.m.	n.m.	n.m.
Density (g/mL) at 20°C	0.9990	0.9991	0.9991	0.9991	0.9990
pH (field/lab)	n.m./9.32	8.95/9.29	n.m./9.29	n.m./9.31	n.m./9.30
Spec. cond. (: S/cm) (field/lab)	n.m./1572	n.m./1607	n.m./1607	n.m./1613	n.m./1632
Eh (V)	n.m.	0.039	n.m.	n.m.	n.m.
D.O. (mg/L)	n.m.	n.m.	n.m.	n.m.	n.m.
Constituent (mg/L)					
Ca	1.40	1.41	1.44	1.49	1.48
Mg	0.0084	0.0120	0.0161	0.0090	0.0074
Na	317	325	327	325	327
K	13.5	13.7	14.0	14.3	14.7
SO_4	45	46	47	45	52
S_2O_3	4.08	3.64	4.04	4.12	2.23
H_2S	0.143	0.047	0.086	0.064	0.011
Alkalinity (as HCO_3)	200.4	201.9	201.6	202.4	204.2
F	41.4	43.3	43.5	44.0	44.0
Cl	311	314	312	305	310
Br	<0.3	0.8	0.9	0.9	0.9
SiO_2	294	291	286	287	289
NO_3	0.98	0.99	0.82	0.76	1.11
NH_4	0.02	<0.01	0.07	0.01	<0.01
Al	0.209	0.216	0.299	0.205	0.193
Fe(total)	0.025	0.026	0.038	0.025	0.022
Fe(II)	0.025	0.026	0.038	0.025	0.022
B	4.40	4.50	4.35	4.74	4.50
Li	2.98	3.06	3.09	3.10	3.04
Sr	0.008	0.008	0.009	0.013	0.014
Ba	<0.015	<0.015	<0.015	<0.015	<0.015
Mn	<0.010	<0.006	<0.006	<0.006	<0.008
Zn	<0.009	<0.009	<0.009	<0.009	<0.009
Pb	<0.11	<0.11	<0.11	<0.11	<0.11
Be	<0.001	<0.001	<0.001	<0.001	<0.001
V	<0.021	<0.021	<0.021	<0.021	<0.021
Cr	<0.21	<0.21	<0.21	<0.21	<0.21
Co	<0.024	<0.024	<0.024	<0.024	<0.024
Ni	<0.070	<0.042	<0.042	<0.042	<0.042
Cu	<0.20	<0.20	<0.20	<0.20	<0.20
Cd	<0.009	<0.009	<0.009	<0.009	<0.009
As(total)	1.9	1.7	1.5	1.7	1.7
DOC	n.a.	n.a.	n.a.	n.a.	n.a.
Sum cations (meq/L)	14.61	14.89	15.05	14.97	15.06
Sum anions (meq/L)	15.14	15.37	15.35	15.15	15.46
Charge imbalance (percent)	-3.56	-3.15	-1.96	-1.15	-2.66

[1]Temperatures in ( ) were estimated from data collected 8/18/96.

Table 7. Site data and water analyses for miscellaneous springs

Name	Echinus Geyser, Norris Geyser Basin	Cinder Pool, Norris Geyser Basin	Black Pool, Norris Geyer Basin	Unnamed drainage, Brimstone Basin
Sample code number	95WA109	95WA110	95WA116	95WA114
Date collected	8/22/95	8/22/95	8/25/95	8/24/95
Temperature (°C)	85	95	89.2	6.5
Density (g/mL) at 20°C	0.9990	0.9993	0.9993	0.9991
pH (field/lab)	3.53/3.33	4.22/3.95	2.61/2.54	2.84/2.86
Spec. cond. (：S/cm) (field/lab)	1090/1230	n.m./2320	1980/2990	1473/1315
Eh (V)	0.336	0.022	0.127	0.473
D.O. (mg/L)	n.m.	0.5	n.m.	n.m.
Constituent (mg/L)				
Ca	5.1	5.9	2.4	32.0
Mg	0.690	0.024	0.182	21.4
Na	160	373	293	14.2
K	54.8	57.6	71.4	17.8
SO_4	296	96	300	602
S_2O_3	0.03	5.10	0.02	n.a.
H_2S	0.03	1.6	1.6	2.6
Alkalinity (as HCO_3)	n.a.	n.a.	n.a.	n.a.
F	5.11	6.24	5.28	0.364
Cl	109	601	463	0.6
Br	0.3	1.7	1.4	<0.3
SiO_2	335	433	426	90.4
NO_3	0.55	1.63	1.41	0.37
NH_4	2.1	18	19	0.34
Al	2.00	1.13	6.10	51.0
Fe(tot)	2.63	0.088	2.15	5.33
Fe(II)	2.62	0.088	2.15	5.28
B	2.31	9.60	8.50	<0.20
Li	0.840	4.70	4.24	0.040
Sr	0.006	0.011	0.008	0.650
Ba	0.065	<0.025	0.090	<0.015
Mn	0.280	<0.006	0.06	0.51
Zn	0.050	<0.009	0.016	<0.009
Pb	<0.11	<0.11	<0.11	<0.11
Be	0.006	<0.001	<0.001	<0.001
V	<0.021	<0.021	<0.02	0.05
Cr	<0.21	<0.21	<0.21	<0.21
Co	<0.024	<0.024	<0.024	<0.024
Ni	<0.042	<0.042	<0.04	<0.04
Cu	<0.20	<0.20	<0.20	<0.20
Cd	<0.009	<0.009	<0.009	<0.009
As(total)	0.29	2.4	1.5	<0.001
DOC	n.a.	n.a.	n.a.	n.a.
Sum cations (meq/L)	9.18	19.70	19.51	8.44
Sum anions (meq/L)	8.82	19.09	17.87	8.78
Charge imbalance (percent)	3.96	3.16	8.80	-3.93

Table 7. Site data and water analyses for miscellaneous springs--continued

Name	Unnamed drainage, Brimstone Basin	Acid Ink Pot, Washburn Hot Springs complex	Unnamed spouter, Washburn Hot Springs complex	Unnamed acid spring, Washburn Hot Springs complex
Sample code number	[1]95WA115	95WA111	95WA112	95WA113
Date collected	8/24/95	8/23/95	8/23/95	8/23/95
Temperature (°C)	8	75.5	93	82
Density (g/mL) at 20°C	0.9987	1.0012	0.9995	1.0019
pH (field/lab)	4.79/4.03	2.92/2.49	6.71/6.77	1.83/1.63
Spec. cond. (∶S/cm) (field/lab)	n.m.-/758	5790/7260	3250/3300	7670/13600
Eh (V)	0.337	0.067	0.157	0.223
D.O. (mg/L)	n.m.	0.3	n.m.	n.m.
Constituent (mg/L)				
Ca	40.3	42	7.0	14.6
Mg	41.0	19.7	4.40	9.30
Na	11.7	31.0	11.0	11.0
K	11.9	18.3	12.5	13.1
SO_4	430	3120	1280	4200
S_2O_3	n.a.	0.09	0.13	n.a.
H_2S	0.4	8	<0.03	5.7
Alkalinity (as HCO_3)	7.23	n.a.	9.25	n.a.
F	0.410	0.338	0.222	0.182
Cl	0.4	<10	1.8	6.7
Br	<0.3	<22	<0.2	<0.2
SiO_2	88.0	262	263	316
NO_3	0.38	0.26	0.30	0.42
NH_4	0.19	884	478	628
Al	27.5	34.0	0.820	68.0
Fe(tot)	6.42	23.6	2.22	71.0
Fe(II)	6.35	23.6	2.21	65.0
B	<0.20	9.40	14.3	15.0
Li	<0.055	0.050	0.050	<0.070
Sr	0.530	0.240	0.050	0.490
Ba	<0.015	0.030	<0.015	0.070
Mn	0.96	0.510	0.120	0.34
Zn	<0.009	0.080	<0.009	0.060
Pb	<0.11	<0.11	<0.11	<0.11
Be	<0.001	<0.001	<0.001	<0.001
V	<0.02	0.050	<0.021	0.11
Cr	<0.21	<0.21	<0.21	<0.21
Co	<0.024	<0.024	<0.024	0.060
Ni	<0.04	<0.042	<0.042	0.18
Cu	<0.20	<0.20	<0.20	<0.20
Cd	<0.009	<0.009	<0.009	<0.009
As(total)	<0.001	<0.001	<0.001	<0.001
DOC	n.a.	n.a.	n.a.	n.a.
Sum cations (meq/L)	7.16	51.12	26.06	57.90
Sum anions (meq/L)	6.75	51.18	24.78	50.81
Charge imbalance (percent)[2]	5.97	-0.11	5.04	13.1/-21.4

[1]This unfiltered sample contained visible colloidal precipitate.
[2]Where two charge imbalance values appear, they are field pH C.I./lab pH C.I.

Table 8. ^{2}H and ^{18}O isotope analyses

Name	Sample code	*^{2}H*	*^{18}O*
Ojo Caliente at source	94WA100	-142	-16.4
Ojo Caliente at pool outflow	94WA101	-139	-16.3
Ojo Caliente overflow channel	94WA104	-140	-16.3
Ojo Caliente overflow channel	94WA106	-139	-16.2
Ojo Caliente overflow channel	94WA107	-139	-16.1
Ojo Caliente overflow channel	94WA108	-140	-16.1
Ojo Caliente overflow channel	94WA110	-138	-15.9
Ojo Caliente overflow channel	94WA112	-136	-15.4
Frying Pan Spring at source	94WA113	-123	-11.9
Frying Pan Spring overflow channel	94WA114	-121	-10.7
Frying Pan Spring overflow channel	94WA116	-119	-10.8
Frying Pan Spring overflow channel	94WA119	-119	-10.5
Angel Terrace Spring at source	94WA120	-148	-18.2
Angel Terrace Spring in pool	94WA121	-148	-18.2
Angel Terrace Spring pool outlet	94WA122	-146	-17.9
Azure Spring overflow channel	95WA101	-141	-15.9
Azure Spring overflow channel	95WA101A	-142	-15.5
Azure Spring overflow channel	95WA101B	-139	-15.5
Azure Spring overflow channel	95WA102	-138	-15.7
Azure Spring overflow channel	95WA103	-138	-15.6
Azure Spring overflow channel	95WA104	-139	-15.6
Azure Spring overflow channel	95WA105	-137	-15.3
Azure Spring overflow channel	95WA106	-138	-15.4
Azure Spring overflow channel	95WA107	-134	-15.2
Azure Spring overflow channel	95WA108	-133	-15.0
Echinus Geyser, Norris Geyser Basin	95WA109	-137	-16.4
Cinder Pool, Norris Geyser Basin	95WA110	-124	-10.7
Black Pool, Norris Geyser Basin	95WA116	-122	-9.7
Unnamed drainage, Brimstone Basin, upper site	95WA114	-140	-18.6
Unnamed drainage, Brimstone Basin, lower site	95WA115	-139	-18.9
Acid Ink Pot, Washburn Hot Springs	95WA111	-106	-4.0
Unnamed spouter, Washburn Hot Springs	95WA112	-115	-6.5
Unnamed acid spring, Washburn Hot Springs	95WA113	-119	-7.3

*Permil relative to VSMOW.

Table 9. Comparison of historic data on sulfur species concentrations for selected locations

Location and Data Source	Date	SO_4	H_2S	S_2O_3	Cl
		- - - - - - - - - - - - - - - - - - mg/L - - - - - - - - - - - - - - - - - - -			
Ojo Caliente					
Allen and Day (1935)		29	n.m.	5	324
Thompson and others (1975)	Jun 1966	n.m.	n.m.	n.m.	345
Thompson and others (1975)	Jun 1967	27	n.m.	n.m.	331
Thompson and others (1975)	Sep 1972	24	1.3	n.m.	331
Thompson and DeMonge (1996)	Oct 1979	22	0.11	n.m.	338
Thompson and DeMonge (1996)	Oct 1981	14	0.29	n.m.	318
Thompson and DeMonge (1996)	Sep 1986	28	0.3	n.m.	326
Thompson and DeMonge (1996)	Sep 1990	15	0.28	n.m.	312
This study	Jun 1994	21	1.09	0.27	324
Azure Spring					
Stauffer and others (1980)	Sep 1974	50	1.5	n.m.	310
This study	Aug 1995	41	0.36	5.26	306
Frying Pan Spring					
Allen and Day (1935)		486	n.m.	n.m.	4
Thompson and others (1975)	Sep 1973	335	n.m.	n.m.	39
This study	Jun 1994	437	1.03	0.63	8.7
Angel Terrace					
Allen and Day (1935)		490	n.m.	n.m.	178
This study	Jun 1994	547	3.01	0-0.6	165
Echinus Geyser					
Gooch and Whitfield (1888)	Aug 1884	232	trace	n.m.	121
Scott (1964)		310	n.m.	n.m.	105
White (unpub. data)		286	n.m.	n.m.	108
Rowe and others (1973)		284	n.m.	n.m.	108
Rowe and others (1973)		280	n.m.	n.m.	115
Rowe and others (1973)		270	n.m.	n.m.	107
Thompson and others (1975)	Oct 1967	370	n.m.	n.m.	106
Thompson and Yadav (1979)		273	n.m.	n.m.	103
Thompson and DeMonge (1996)		120-360	0.01-0.12	n.m.	107-154
This study		296	0.03	0.03	109
Cinder Pool					
White (unpub. data)	Sep 1947	n.m.	n.m.	n.m.	668
White (unpub. data)	Sep 1957	n.m.	n.m.	n.m.	790
White (unpub. data)	Sep 1960	125	n.m.	n.m.	727
Rowe and others (1973)		87	n.m.	n.m.	720
Thompson and DeMonge (1996)		147	n.m.	n.m.	569
This study		96	1.6	[1]5.1	601

[1]S_4O_6 . 1 mg/L.

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APPENDIX

Table 10. Methods of analysis

Parameter or Element	Descriptor
pH	PH
Spec. cond.	COND
Eh	EC1
D. O.	EC2
Ca	ICP, FAAS
Mg	ICP, FAAS, ZGFAAS
Na	ICP, FAAS
K	ICP, FAAS
SO_4	IC1
S_2O_3	IC2
H_2S	COLOR1
Alkalinity	TITR
F	IC1, EC3
Cl, Br	IC1
SiO_2	ICP, COLOR2
NO_3	IC1
NH_4	COLOR3, COLOR4, IC3
Al	ICP, ZGFAAS
Fe (total)	ICP, COLOR5
Fe (II)	COLOR5
B	ICP
Li	FAAS
Sr, Ba, Mn, Zn, Pb, Be, V	ICP
Cr, Co, Ni, Cu, Cd	ICP
As (total)	ICP, FIAS
Dissolved organic carbon	DOC
$*^{2}H$	ISOT1
$*^{18}O$	ISOT2

Table 11. Explanation of methods of analysis
[rsd, relative standard deviation]

Descriptor	Species Determined	Analyst(s)	Equipment Used	Reference(s) or comments	Typical **rsd** or *detection limit (mg/L)*
COLOR1	H_2S	Cunningham	Hach model DR-2000 UV-Vis absorption spectrometer and Hach method # 8131 reagents	Method based on APHA (1985)	*0.005*
COLOR2	SiO_2	Cunningham	Hach model DR-2000 UV-Vis absorption spectrometer	Method based on Shapiro and Brannock (1962)	**3%**, *0.4*
COLOR3	NH_4	R.C. Antweiler, USGS, Boulder, CO	Alpkem model RFA-300 flow injection analyzer	Method based on Solorzano (1969)	**3%**, *0.012*
COLOR4	NH_4	Cunningham	Hach model DR-2000 UV-Vis absorption spectrometer and Hach method # 8155	Method based on Reardon and others (1966)	
COLOR5	Fe(II) and Fe(total)	Ball	Hewlett-Packard model 8452A diode array spectrometer (1992-1994) with 1 and 5 cm cells	Ferrozine method (Stookey, 1970)	**3%**, *0.0005*
COND	Spec. Cond.	Authors	Orion Research model 126 meter	Automatic temperature correction, conductance check with 0.0100 N KCl	**#0.5%**
DOC	DOC	G.R. Aiken, USGS, Boulder, CO	Oceanography International model 700 carbon analyzer	Some samples were diluted to reduce interference from Cl^- (Aiken, 1992)	**~10%**, *0.2*
EC1	Eh	Nordstrom, Ball	Orion Research model 96-78-00 Pt electrode	Electrode checked using ZoBell's solution (ZoBell, 1946; Nordstrom, 1977), at the sample temperature	
EC2	D.O.	Authors	Orion Research model 840 DO meter and probe	Automatic sample temperature and barometric pressure correction	**1%**
EC3	F^-	Nordstrom	Orion Research model 96-09 comb. F^- electrode	Barnard and Nordstrom (1980)	**~3%**

Table 11. Explanation of methods of analysis--continued

Descriptor	Species Determined	Analyst(s)	Equipment Used	Reference(s) or comments	Typical **rsd**, *detection limit (mg/L)*
FAAS	Na, K, Ca, Mg, and Li	Cunningham	Perkin-Elmer model 5000 flame atomic absorption spectrometer with air/acetylene flame, single-slot burner head, and continuum background correction, in absorption (Ca, Mg, Li, Na, K) or emission (Na*, K*) mode	1000 mg/L Cs ionization buffer.	**~2%** *Na: 0.005(0.040*)* *K : 0.025(0.007*)* *Ca: 0.030* *Mg: 0.030* *Li: 0.003*
FIAS	As(total)	Cunningham	Perkin-Elmer model 5000 atomic absorption spectrometer in absorption mode with a FIAS-200 flow injection analysis system hydride generator, quartz cell, and furnace	Pre-reduction of As(V) using KI + HCl	**- 10%**, *0.001*
IC1	F^-, Cl^-, SO_4^{2-}, NO_3^-, and Br^-	Schoonen, Xu, Cunningham	Dionex model 2000i/2010i ion chromatograph with AG4A guard and AS4A separator columns and an Anion Micromembrane Suppressor-II column	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent	**2-3%**, *F^- = 0.03, Cl^- = 0.05, SO_4^{2-} = 0.16, NO_3^- = 0.09, Br^- = 0.11*
IC2	$S_2O_3^{2-}$	Schoonen, Xu	Dionex model 2000i/2010i ion chromatograph with two AG4A guard columns and AS4A separator column and an Anion Micromembrane Suppressor-II column	0.028 M $NaHCO_3$ + 0.022 M Na_2CO_3 eluent	2-3%, *0.09*
IC3	NH_4	B. Kumler, USGS, Boulder, CO	Dionex model DX-300 ion chromatograph with CS12A IonPac column and 22 mN H_2SO_4 eluent	Analysis performed on year-old samples preserved in 1% HCl	**~2%**

Table 11. Explanation of methods of analysis--continued

Descriptor	Species Determined	Analyst(s)	Equipment Used	Reference(s) or comments	Typical **rsd** or *detection limit (mg/L)*
ICP	Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe(total), K, Mg, Mn, Na, Ni, Pb, Si, Sr, V, Zn	Cunningham	Leeman Labs Plasma-Spec III, simultaneous, multi-element, inductively coupled plasma spectrometer. Hildebrand grid nebulizer and polyethylene spray chamber. RF frequency - 27.5 MHZ at 1 kw. Ar coolant and nebulizer gas. Inter-element interferences were corrected with MEGACRUNCH software (J.W. Ball, unpub. data).	Analytical wavelengths - nanometers: Al - 309.27 As - 193.70 B - 249.68 Ba - 455.40 Be - 313.04 Ca - 315.90 Cd - 214.44 Co - 228.62 Cr - 205.55 Cu - 324.75 Fe - 238.20 K - 766.46 Mg - 279.08 Mn - 257.61 Na - 589.59 Ni - 231.60 Pb - 220.35 Si - 288.16 Sr - 407.77 V - 292.40 Zn - 213.86	**~2% for all elements** *Al: 0.220* *As: 0.170* *B : 0.090* *Ba: 0.020* *Be: 0.001* *Ca: 0.050* *Cd: 0.020* *Co: 0.020* *Cr: 0.045* *Cu: 0.070* *Fe: 0.150* *K : 0.870* *Mg: 0.090* *Mn: 0.060* *Na: 0.400* *Ni: 0.020* *Pb: 0.075* *Si: 1.02* *Sr: 0.001* *V : 0.010* *Zn: 0.005*
ISOT1	$*^2H$	T.B. Coplen and J.A. Hopple, USGS, Reston, VA (1994 samples) and C. Kendall, USGS, Menlo Park, CA (1995 samples)	V.G. Micromass model 602 mass spectrometer	Coplen and others (1991). Standardization against VSMOW ($*^2H$ = 0 per mil) and SLAP ($*^2H$ = -428 per mil)	**1.5 per mil**

Table 11. Explanation of methods of analysis--continued

Descriptor	Species Determined	Analyst(s)	Equipment Used	Reference(s) or comments	Typical **rsd** or *detection limit (mg/L)*
ISOT2	$*^{18}O$	T.B. Coplen and J.A. Hopple, USGS, Reston, VA (1994 samples) and C. Kendall, USGS, Menlo Park, CA (1995 samples)	DuPont model 21-491 mass spectrometer	Epstein and Mayeda (1953). Standardization against VSMOW ($*^{18}O$ = 0 per mil) and SLAP ($*^{18}O$ = -55.5 per mil)	**0.1 per mil**
PH	$[H^+]$	Nordstrom, Ball	Orion Research SA 250 meter, Orion Ross comb. electrode	Two buffer calibration at sample temp. using 9.18, 7.00, 4.01, and 1.68 pH buffers	**0.02 pH units**
TITR	Alkalinity (as mg/L HCO_3)	Ball	Orion Research model 960/940 autotitrator, potentiometric detection	Fishman and Friedman (1989)	**2%**, *0.4*
ZGFAAS	Al, Mg	Cunningham	Perkin-Elmer Zeeman 5000 graphite furnace atomic absorption spectrometer, with pyrolytically coated graphite platform cell and Ar purge gas	Analytical wavelength, nanometers: Al - 396.2 Mg - 285.2 Atomization temp.,°C: Al - 2550 Mg - 1700 Char temp., °C: Al - 1500 Mg - 900 Matrix modifier: Al - $Mg(NO_3)_2$ Mg - none	**~5%** *Al: 0.005* *Mg: 0.0005*

Table 12. Measurements of Standard Reference Waters
[Number in brackets represents one sample standard deviation]

	Combined 1994 Data				Combined 1995 Data			
Element	Analytical method	USGS SRWS	Observed concentration	Most probable value	Analytical method	USGS SRWS	Observed concentration	Most probable value
			mg/L				mg/L	
Ca	ICP	T117	21.6 [0.5]	20.9 [1.2]	ICP	T117	21.5 [0.5]	20.9 [1.2]
Mg	ICP	T117	10.3 [0.3]	10.05 [0.44]	ICP	T117	10.9 [0.4]	10.05 [0.44]
Mg	ZGFAAS	T115	26.6 [1.1]	27.6 [1.0]	ZGFAAS	T117	9.47 [0.48]	10.05 [0.44]
Na	FAAS	T111	61.2 [1.0]	53.8 [0.5]	ICP	T117	20.8 [0.6]	20.00 [1.26]
Na	ICP	T117	20.6 [0.6]	20.00 [1.26]	FAAS	T117	18.9 [---]	20.00 [1.26]
K	FAAS	T111	2.59 [0.06]	2.67 [0.07]	ICP	T117	<2.65	2.11 [0.19]
K	ICP	T117	2.16 [0.35]	2.11 [0.19]	FAAS	T115	5.24 [0]	5.41 [0.32]
K					FAAS	T117	2.01 [0.02]	2.11 [0.19]
SO_4					IC	M102	423 [15]	420 [16]
F					IC	M102	1.1 [0.2]	1.1 [0.1]
Cl					IC	M102	40 [3]	44 [2]
Br					IC	M102	<0.11	0.100 [0.022]
SiO_2	ICP	T117	12.6 [0.8]	11.85 [0.64]	ICP	T117	12.7 [0.4]	11.85 [0.64]
Al	ICP	T117	<0.35	0.079[0.0194]	ICP	T117	<0.32	0.0790 [0.0194]
Al	ZGFAAS	T115	0.028 [0.002]	0.040 [0.020]	ZGFAAS	T117	0.074 [0.002]	0.0790 [0.0194]
Fe (total)	ICP	T117	0.489 [0.015]	0.474 [0.0182]	ICP	T117	0.497 [0.015]	0.4740 [0.0182]
B	ICP	T117	0.176 [0.024]	0.151 [0.021]	ICP	T117	0.197 [0.018]	0.151 [0.0208]
Li	FAAS	T115	0.136 [0.002]	0.132 [0.012]	FAAS	T115	0.126	0.132 [0.012]
Sr	ICP	T117	0.269 [0.009]	0.265 [0.011]	ICP	T117	0.273 [0.008]	0.265 [0.0111]
Ba	ICP	T117	0.096 [0.005]	0.0985 [0.0063]	ICP	T117	0.098 [0.005]	0.0985 [0.0063]
Mn	ICP	T117	0.216 [0.011]	0.220 [0.015]	ICP	T117	0.217 [0.006]	0.220 [0.0149]
Zn	ICP	T117	0.179 [0.005]	0.176 [0.0093]	ICP	T117	0.182 [0.006]	0.176 [0.0093]
Pb	ICP	T117	<0.113	0.005 [0.0013]	ICP	T117	<0.63	0.0050 [0.0013]
Be	ICP	T117	0.004 [0.001]	0.0048 [0.0004]	ICP	T117	0.004 [0.001]	0.0048 [0.0004]
V	ICP	T117	<0.015	0.0047 [0.0018]	ICP	T117	<0.013	0.0047 [0.0018]
Cr	ICP	T117	<0.068	0.0103 [0.0016]	ICP	T117	<0.128	0.0103 [0.0016]
Co	ICP	T117	<0.030	0.0043 [0.0007]	ICP	T117	<0.015	0.0043 [0.0007]
Ni	ICP	T117	<0.030	0.0100 [0.0025]	ICP	T117	<0.028	0.0100 [0.0025]
Cu	ICP	T117	<0.105	0.0060 [0.0018]	ICP	T117	<0.122	0.0060 [0.0018]
Cd	ICP	T117	<0.030	0.0022 [0.0004]	ICP	T117	<0.006	0.0022 [0.0004]
As (total)	ICP	T117	<0.26	0.0069 [0.0014]	ICP	T117	<0.22	0.0069 [0.0014]

[1]Number in square brackets represents 1 standard deviation.