Title
Geochemical Studies at Four Northern Nevada Hot Spring Areas

Author
Wollenberg, H.

Publication Date
1977-08-01

594
11/22/77

sh. 1608

LBL-6808
UC-66b
TID-4500-R66

MASTER

Energy and Environment Division

Geochemical Studies At Four Northern Nevada Hot Spring Areas

H. Wollenberg, H. Bowman
and F. Asaro

August 1977

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

LBL-6808

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $~~4.50~~ Microfiche $3.00

6.00

DISCLAIMER

GEOCHEMICAL STUDIES AT FOUR NORTHERN NEVADA HOT SPRING AREAS

H. Wollenberg, H. Bowman and F. Asaro

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 97420

I. INTRODUCTION

The Lawrence Berkeley Laboratory is conducting a program to define parameters for the assessment of geothermal resources and to develop and evaluate techniques to measure these parameters. The results of the geochemical studies presented here will be combined with interrelated geological and geophysical data to select sites for deep test holes. Geochemical studies furnish information on the nature of a potential resource and provide a baseline upon which the effects of future geothermal developments may be compared.

To date, most efforts have been centered in northern Nevada where high regional heat-flow, numerous hot-springs, and available government lands combined to furnish satisfactory test areas. This region of high heat flow (>2.5 μcal cm^{-2}sec^{-1}) is shaded in Fig. 1, and shown within this area are the four locations studied: Kyle Hot Springs in Buena Vista Valley, Leach Hot Springs in Grass Valley, Buffalo Valley Hot Springs and Beowawe Hot Springs in Whirlwind Valley. The geologic and geophysical settings of the sites are described in reports by Wollenberg et al., (1975), Beyer et al., (1976) and Goldstein et al, (1977). As well as being a region of high heat flow (Sass et al., (1971), temperatures at depth within several spring systems may exceed 150^{o}C (Mariner et al., 1974).

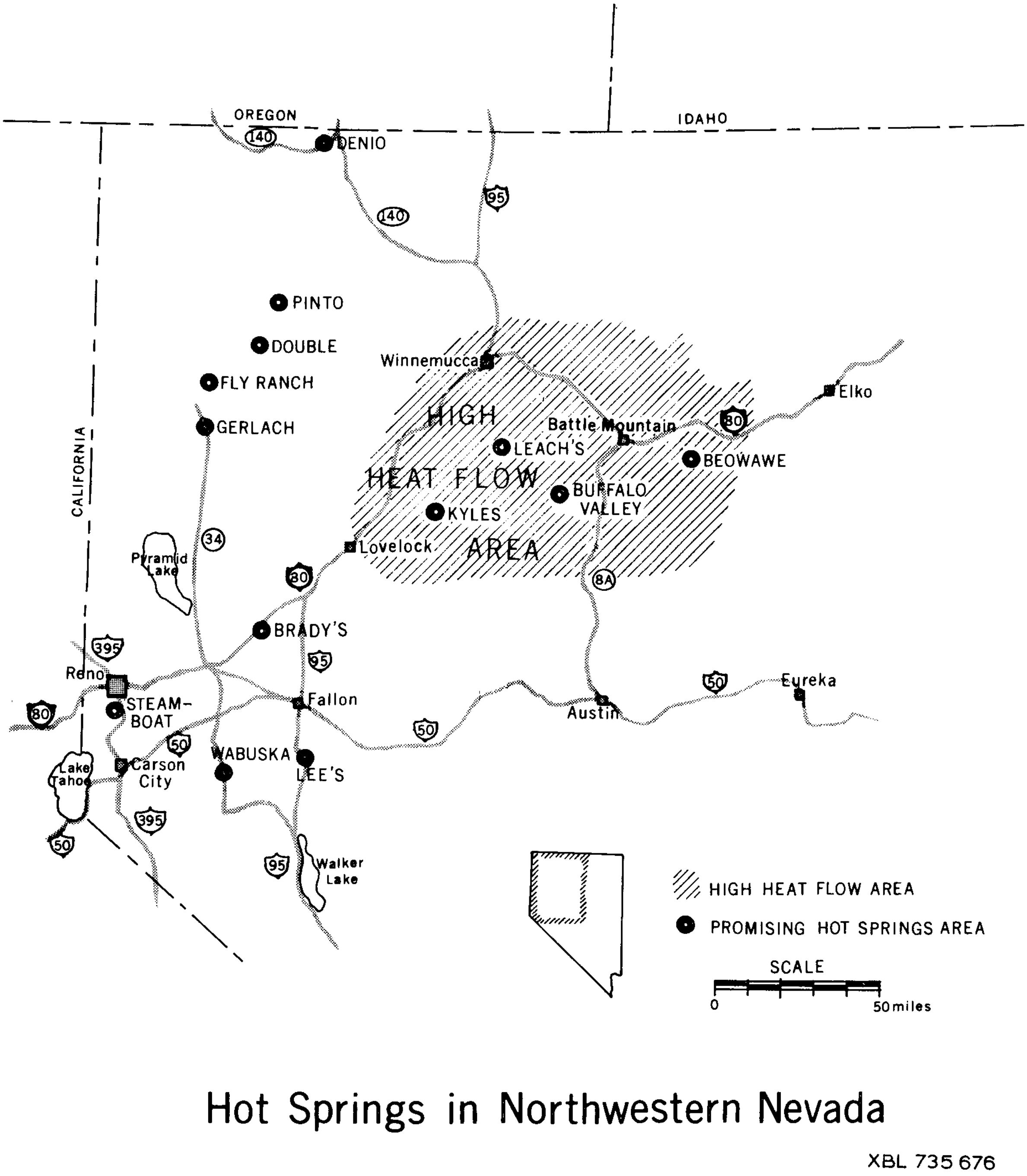


Fig. 1. Location map, northwestern Nevada, showing prominent thermal spring areas within and outside of the Battle Mountain high heat flow region.

Hose and Taylor (1974) have proposed a model of a geothermal system considered typical for the Basin-and-Range geomorphic province. Fault zones, penetrating several km into this region of high geothermal gradient (40-60°C/km), occasionally furnish pathways for meteoric water to percolate deeply. Convecting systems are formed where permeability is afforded, at times "daylighting" as a hot spring.

We have collected and analyzed water samples from both hot and cold sources in the hydrologic areas surrounding the hot springs. Analyses of major, trace, and radio-element abundances of the water samples and of associated rock samples may indicate the pathways the water takes from its source, into and through the geothermal systems. These analyses may also be used to disclose the amount of near-surface cold water that has mixed with hot water, and the temperature of the unmixed hot water (Fournier and Truesdell, 1974). From this study it is possible that trace- and major-element abundances and/or ratios may be discerned which are diagnostic as chemical geothermometers, complementing those of silica and alkali elements that are presently used.

In this report we emphasize a presentation of the analytical data. However, we also include brief discussions of mixing calculations, possible new chemical geothermometers, and interelement relationships.

II. SAMPLING, PREPARATION AND ANALYSIS

Field sampling techniques and laboratory analytical methods were described in detail in papers by Bowman et al. (1974, 1975), Hebert and Bowman (1975), and Wollenberg (1975).

A. Major and Trace Elements

Water samples were obtained for laboratory radiometry, X-ray fluorescence analyses and neutron activation analyses. Collection methods were devised to retain all solid material, including that which precipitates. Springs sampled included boiling pools, hot pools, cold pools and seeps.

From a number of sampling methods evaluated, the most reproducible results were obtained by inserting a 1/4-in. diameter tygon tube into a spring and drawing the water through a 0.45 micron filter, using a hand-operated vacuum pump. The apparatus is shown on Fig. 2. Most often, the water was introduced to the filter directly from the spring, but occasionally conditions demanded that samples be obtained in bottles and then filtered by pumping from the bottle in the field or laboratory. Generally, 500-ml Nalgene bottles were used to collect and store the samples.

In the laboratory the water samples were evaporated in the original collecting bottles at 80°C, and aliquots of each were taken for both neutron activation analysis (NAA) and x-ray fluorescence analysis (XRF). In general the XRF measurements determine the major element abundances, while NAA is used for the trace and minor elements. Fortunately, some elements are determined by both methods so that cross-checks can be made.

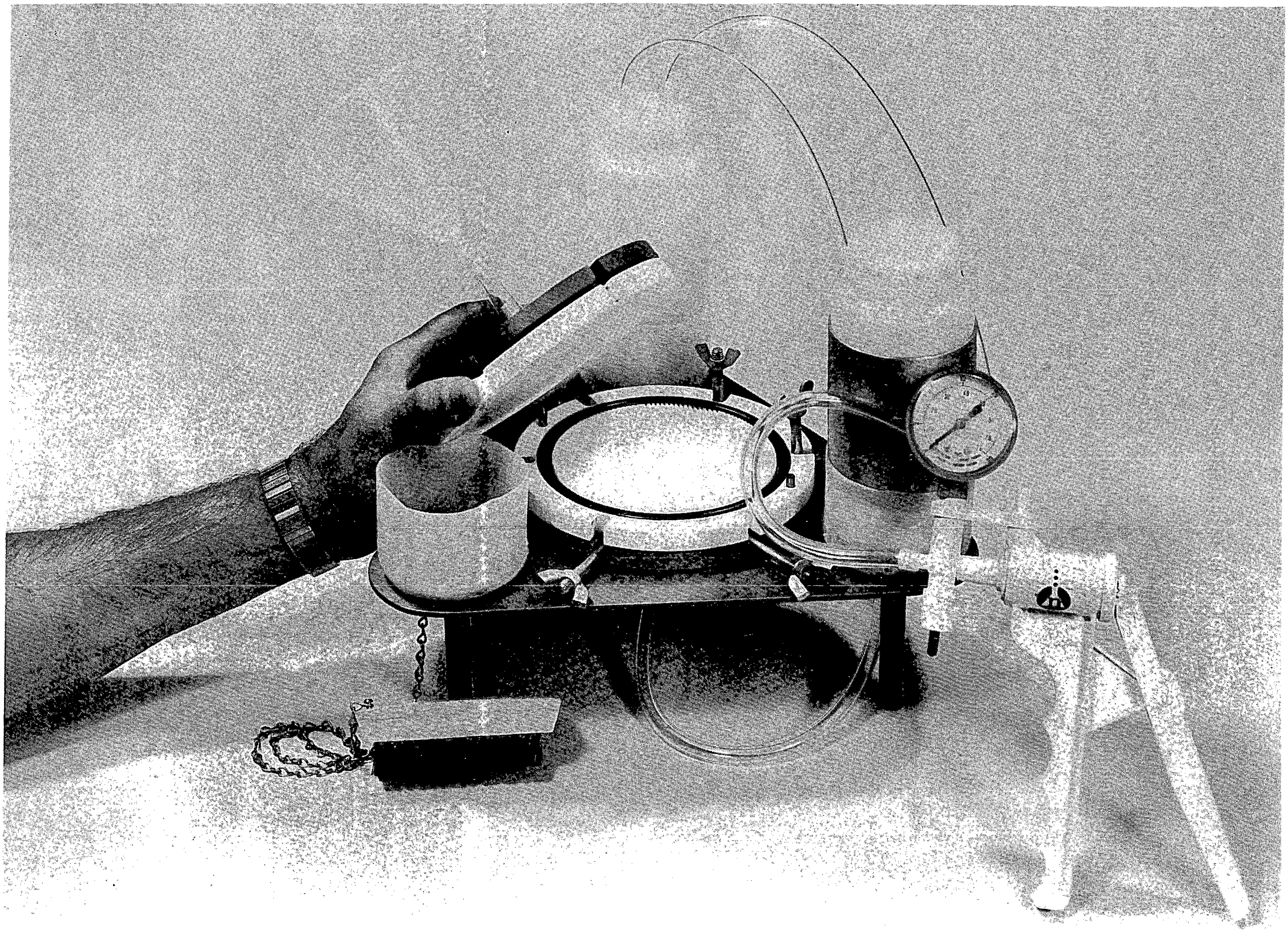


Fig. 2. Portable filtering apparatus with hand-operated vacuum pump. CBB 7410-7354

At each spring a drop of water was evaporated onto a lexan disc with a fixing solution. These discs were later analyzed in the laboratory by XRF for the major elemental abundances. Evaporation in the field is shown in Fig. 3, and the resulting lexan disc is shown in Fig. 4.

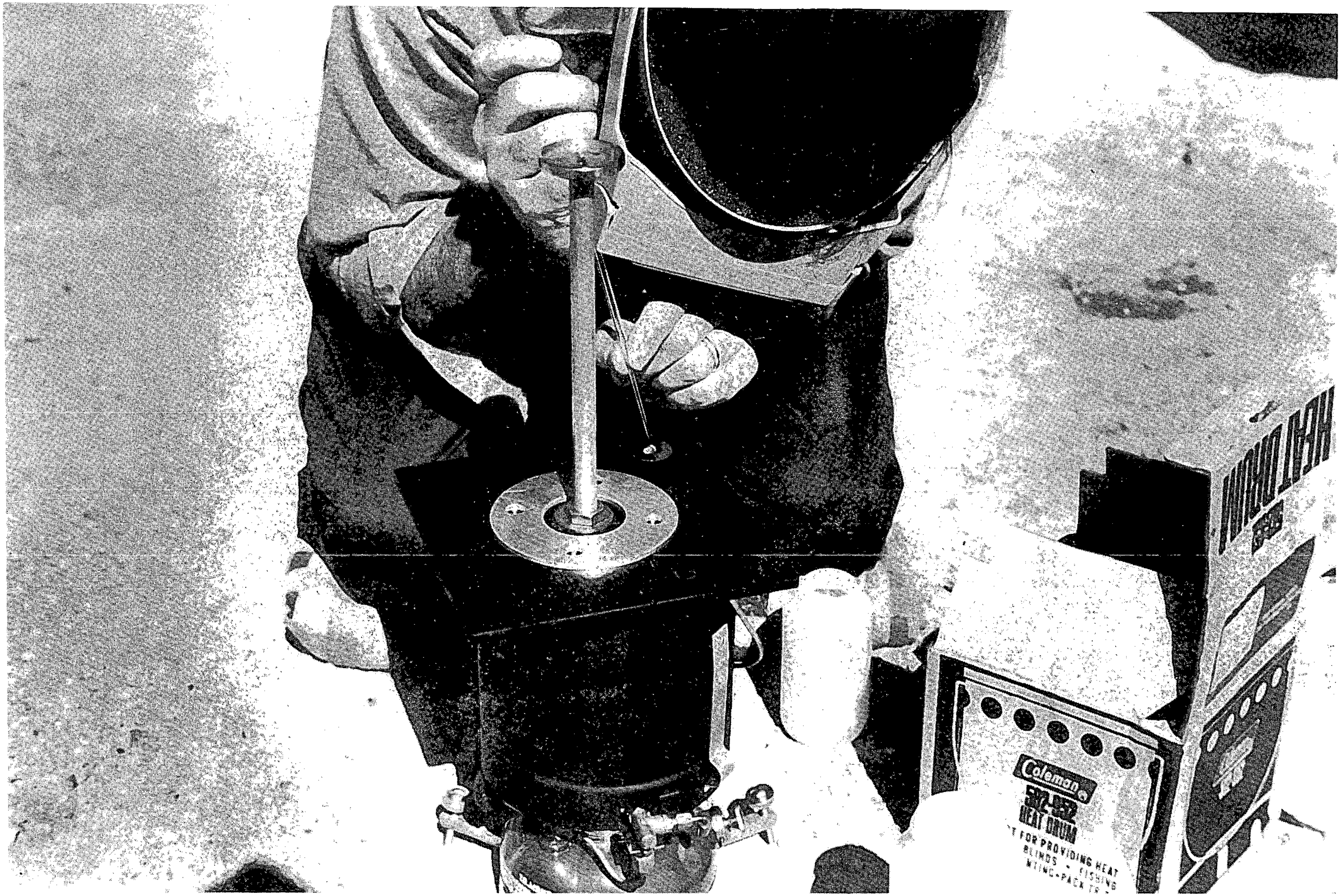
Hydrogen sulfide tests were made by placing a silver disc into a bottle of unfiltered water at each spring. The silver discs were later analyzed for sulfur using XRF (in the lab). The sulfur x-ray data were compared with that from discs placed in standard solutions of H_2S.

1. Neutron Activation Analysis

The neutron activation technique developed for analysis of pottery (Perlman and Asaro, 1969) was used in these measurements. Evaporates from water samples and powders from crushed rock samples were made into pellets and irradiated, along with a composite standard pellet, in the TRIGA Research Reactor at the University of California, Berkeley. Nearly all elements in the samples have their counterparts in the standard, and the abundances are determined by comparing the gamma rays emitted from the unknowns with the gamma-ray spectra of the standards. This method is capable of quantitatively analyzing nearly 50 elements in a sample. In rock samples, more than two dozen elements can be determined with precisions of less than 5%, and a number of these are determined to better than 1% (Bowman, Asaro, and Perlman, 1973).

2. X-Ray Fluorescence Analysis

The XRF method of analysis used in this study was developed by Hebert and Street (1974). In this method the powdered rock samples are mixed with $LiBO_2$ and fused into glass discs. The major elemental



CBB 7510-7937

Fig. 3. Evaporating a 50 μl aliquot of a water sample onto a lexan disk in the field.

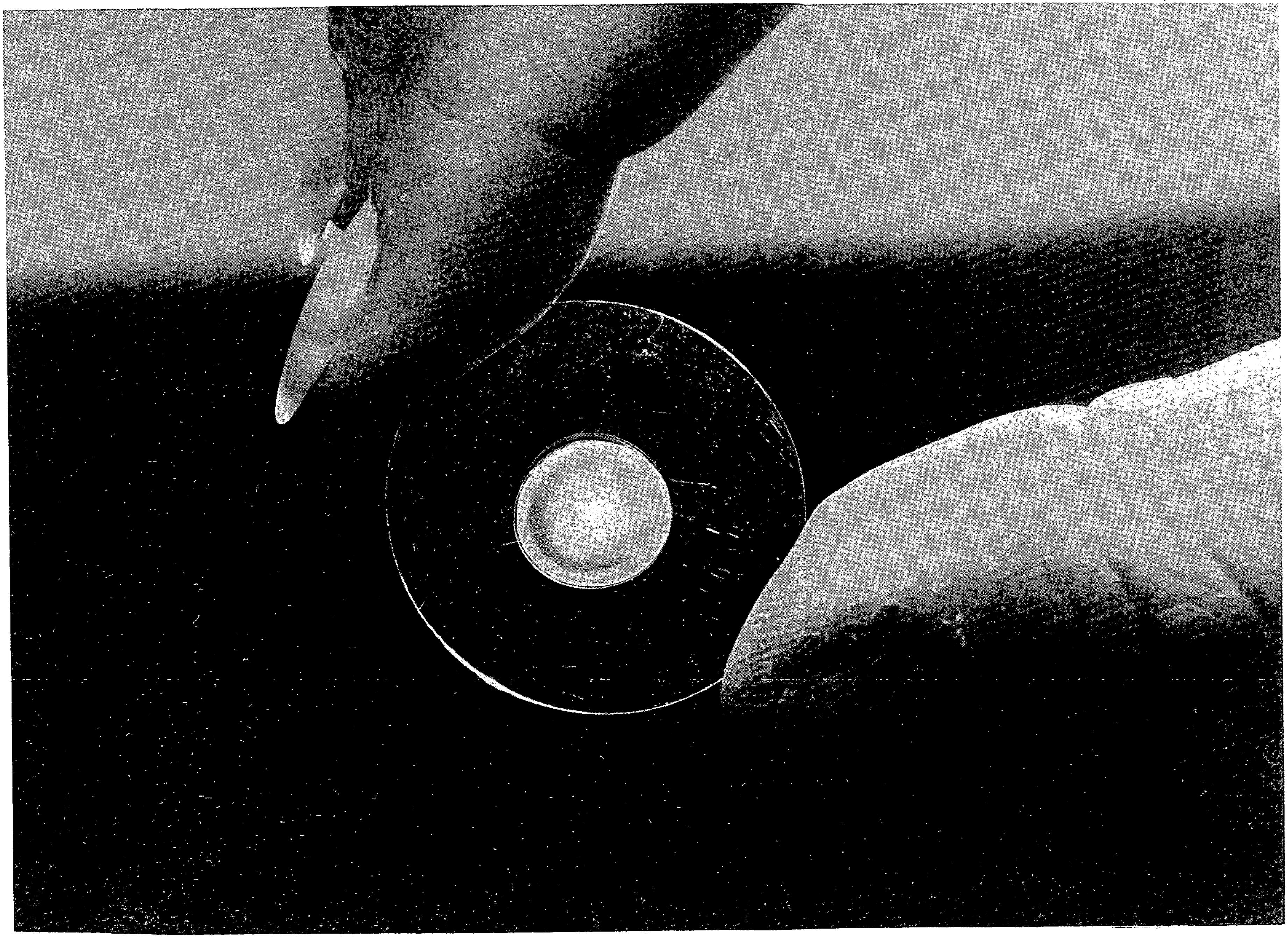


Fig. 4. Lexan disk with evaporated sample affixed. The sample spot is ~0.7 cm in area and 2 to 5 microns thick.

XBB 745-3565

abundances are determined by comparing these samples (indirectly) with USGS standard rocks G-2, BCR, DTS, PCC and AGV.

A variation of this technique was used for the water evaporate analysis. In this case DTS standard rock was spiked with MgO, NaCl, $CaSO_4$ and K_2CO_3 and used as a standard.

The lexan discs with samples of single drops of water were analyzed using XRF by comparing the water drops with standard solutions made in the laboratory.

3. Radioelements

Prior to sampling, a gamma survey of the spring area was conducted using a portable NaI(Tℓ) detector. Samples for laboratory radiometry were usually collected by scooping the spring water directly from the pools into Nalgene bottles. This minimized radon loss which might occur if the water were drawn through the filter system. Bottle lids were immediately taped, and samples transported to the laboratory for gamma-ray pulse-height analyses. The time of sampling was carefully noted to account for the radioactive decay of ^{222}Rn (3.8-day half-life) between sampling and gamma counting. With a reasonably short interval between sampling and counting, the sensitivity of this method is of the order of a few tens of pCi per liter of ^{222}Rn. Along with spring waters, spring wall sinter, tufa, and muck were also collected for subsequent laboratory gamma-ray analyses. This provided comparison of the contents of radium and other radioelements with the ^{222}Rn content of the water.

A sampling system for radon emanating in and around a spring system utilized alpha-track detectors. This method integrated radon emanation over a long time period, and minimized short term fluctuations due to changes in atmospheric conditions. The detectors were inverted plastic cups with specially treated, dielectric alpha-sensitive plastic wafers attached inside. Each was placed, in an approximately 0.5 meter deep hole and then covered. After several weeks' exposure, the cups were retrieved, detectors removed, and etched, the tracks counted, and normalized track densities calculated. This service, used primarily by the uranium industry, was provided by Terradex Company in Walnut Creek, California.

III. RESULTS

In this section we present geochemical data on the waters, spring deposits, and rocks of the hydrologic regions surrounding the four hot spring areas. Water sample locations in the region studied in northern Nevada are shown on Fig. 5; rock sample locations on Fig. 6.

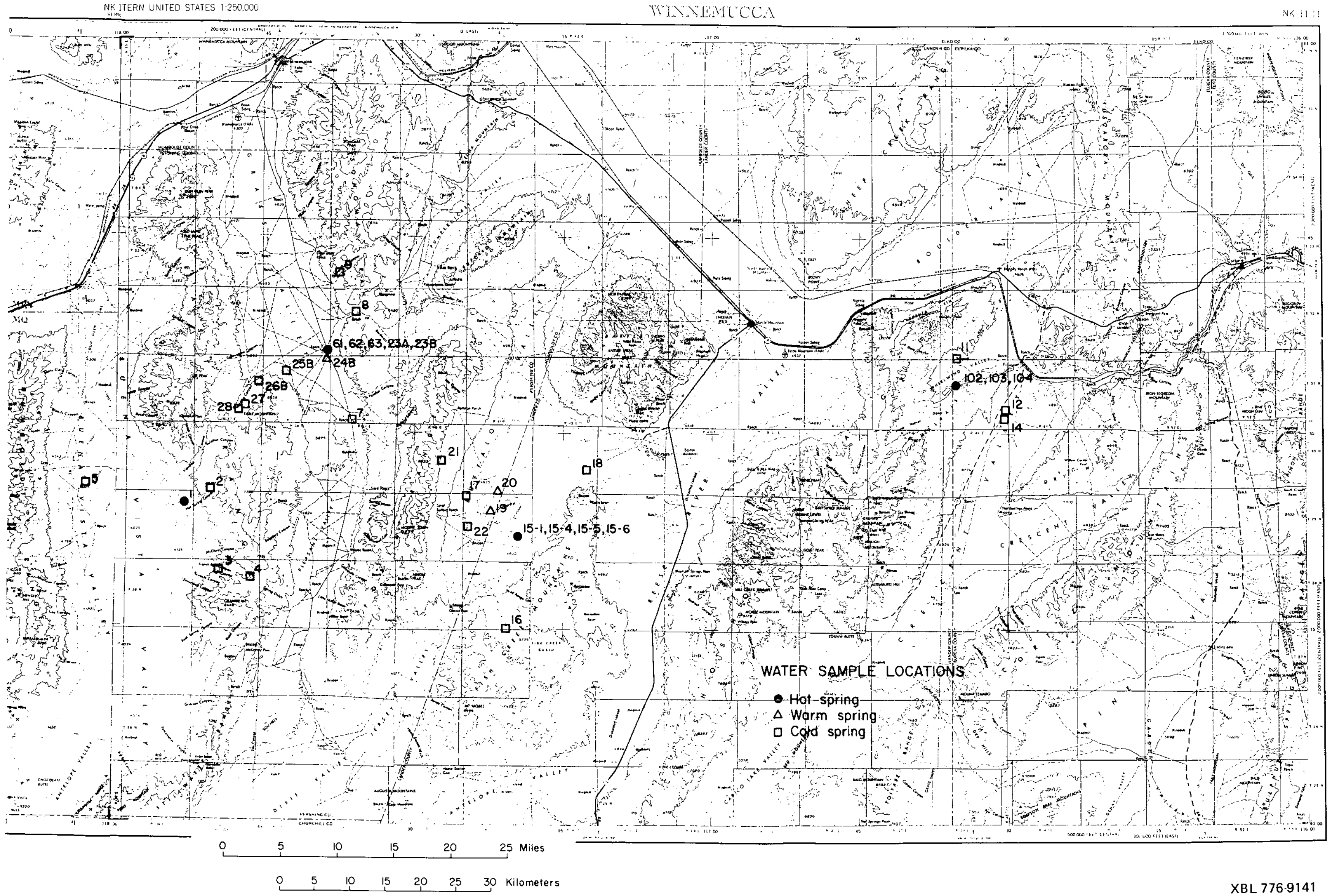
A. Buena Vista Valley

A warm pool and spring deposits at Kyle Hot Springs were sampled, as well as cold springs and country rocks in the surrounding hydrologic region. Earlier surveys at Kyle Hot Springs by USGS personnel (Mariner et al., 1974) indicated a surface spring flow of 20 l/min and spring temperature of 77°C. They estimated that temperatures at depth within the spring system were within the range 170 to 190°C, based on silica and alkali element geothermometers. The springs are presently depositing $CaCO_3$, though older spring deposits nearby contain abundant silica.

1. Waters and Spring Deposits

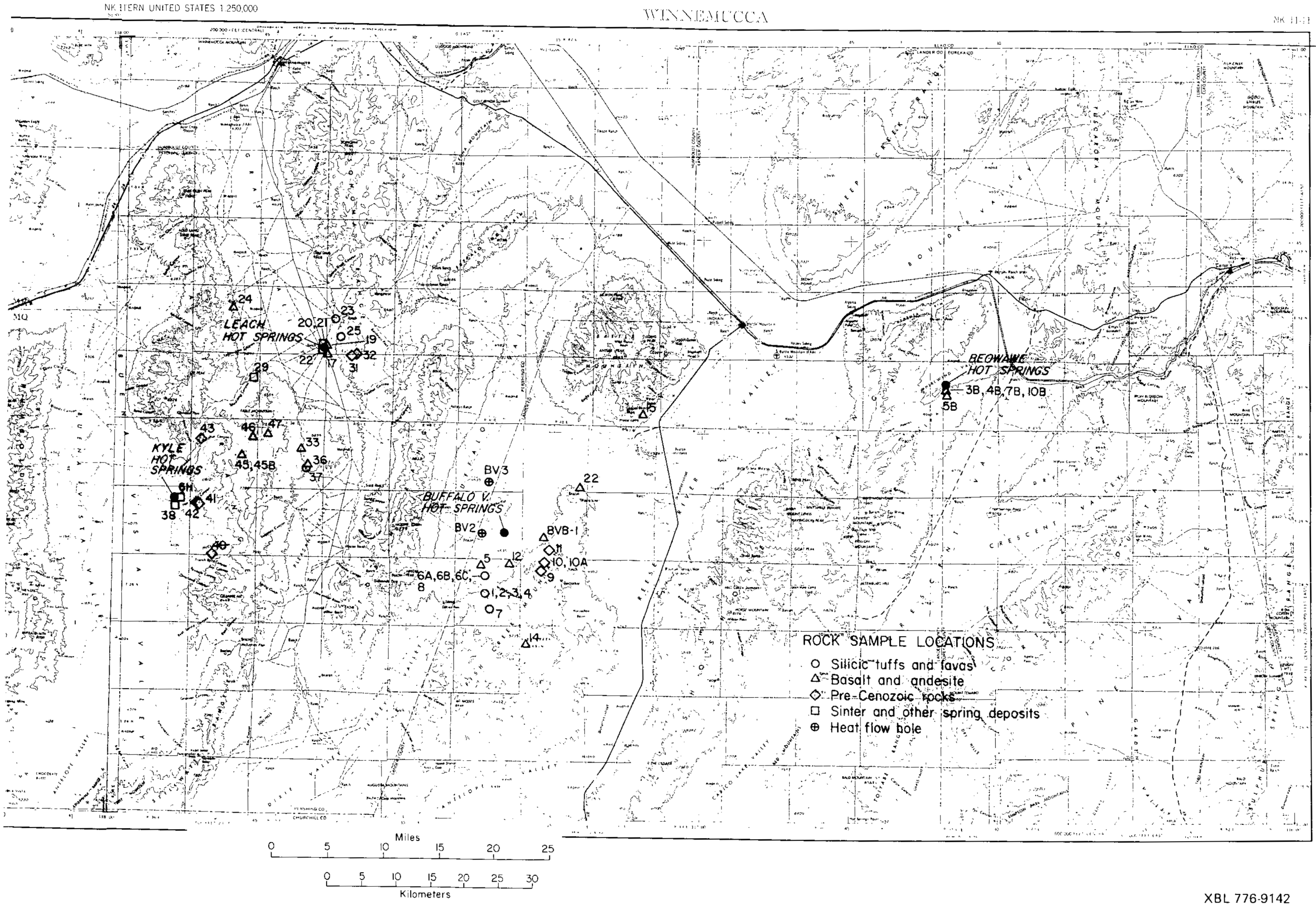
Major and trace-element data for a pool at Kyle Hot Springs and cold springs near and away from Kyle are listed on Table 1. The silica content of the hot water was determined by XRF after fusing the water evaporate with lithium borate; silica contents of the cold springs were determined by the less-reliable single-drop method. Other elements were determined by neutron-activation analyses.

Comparison of chemistries of cold-springs and Kyle Hot Spring waters indicates that most of the elements listed are in appreciably greater abundance (in several cases one or more orders of magnitude) in the hot spring. Exceptions are higher contents of U and Mo in the cold springs.



XBL 776-9141

Fig. 5. Location map, water sample sites in north-central Nevada.



XBL 776-9142

Fig. 6. Location map, rock sample sites in north-central Nevada.

Table 1. KYLE WATER SAMPLES

	—Hot—	Cold Springs			
Sample	1	2	3	4	5
Temp (°C)	59°	12°	cool	cool	cool
			mg/liter		
SiO_2	155	20	5	20	5
Na	535	80	41	100	7
Cl	730	82	31	86	8
K	77	4	2	< 8	< 1
Ca	87	60	35	75	43
			µg/liter		
U	< 0.7	3.1	5.2	3.1	2.6
Ba	565	90	53	82	45
W	82	< 1	< 0.5	< 10	< 0.2
Br	720	134	51	96	19
Sb	8	< 0.2	< 0.3	< 0.5	< 0.4
Mo	< 2	2	17	6	2.5
Rb	760	< 1	< 0.5	< 1	< 0.7
Cs	340	< 0.01	< 0.01	< 0.1	< 0.1
As	< 20	< 7	< 3	14	4
Fe	290	< 25	40	< 17	40
Sc	< 0.04	< 0.02	< 0.02	< 0.02	< 0.02
Mn	< 50	< 2	5	120	2

Samples:

1 Kyle Hot Spring, from Spring House, Sec. 32, T29N, R36E.

2 Cool seep, ~4 l/min, ~3.5 mile east of Kyle Hot Springs in Hot Springs Canyon, NE1/4, Sec. 32, T30N, R37E.

3 Say Creek, road crossing above corral and shack, Sec. 4, T28N, R37E.

4 French Boy Creek, no apparent surface flow at source, Sec. 12, T28N, R37E.

5 Buena Vista Valley, cold spring ~500 meters west of Harrison Springs (now dry), < 0.4 l/min flow, SE1/4, Sec. 33, T30N, R35E. (Not on map.)

As with other hot springs where $CaCO_3$ is the predominant deposit, Kyle Hot Springs are relatively high in radioactivity compared with springs where SiO_2 is being deposited (Wollenberg, 1974). The radon-222 content of a sample of the hot spring waters, collected in 1974, was 587 pCi/ℓ. Field measurements over the surface away from the hot pools at Kyle indicated γ-ray exposure-rate background values of 12.5 to 25 μR/h, while readings over the pools ranged from 250 to 500 μR/h. Material presently being deposited on the walls of the hot spring is also relatively high in radio-element content compared to older travertine away from the spring, as shown in Table 2.

2. Rocks

Analyses of major oxides in samples of unaltered and altered rocks from the Kyle Hot Springs area are listed on Table 3. Samples from the East Range, east of the hot springs, included Tertiary basalt, greenstone and semischist of the Valmy Formation, and limestone of indefinite age. Samples also included calcareous spring deposit material from Kyle Hot Springs, and siliceous sinter from an old "fossil" hot spring deposit southwest of Kyle. Samples of the Valmy Formation, basalt, and limestone are probably representative of rock types in the hydrologic recharge area for the hot springs.

B. Grass Valley

At Leach Hot Springs, five warm pools and eight cold springs were sampled, along with country rock and spring deposit material.

Total surface flow from the Leach Hot Springs system has been measured at 130 ℓ/min (Olmstead, et al., 1975). Surface temperatures of the springs reach 95°C, boiling at their altitude, and water

Table 2. Radioelement content of Kyle Hot Spring deposit materials.

	Th (ppm)	Equivalent U (ppm)	K (%)	Ra* (pCig^{-1})
Calcareous Muck from Spring Walls	11.6	76.3	0.16	27
Travertine Away from Active Spring	0.2	4.1	0.09	1.5

*Calculated from activities ratio ^{226}Ra/^{238}U.

Table 3. KYLE AREA ROCK SAMPLES

	Unaltered					Altered			
Sample	40	46	45	41	45B	43	6H	42	38
SiO_2	57.4	56.4	52.2	50.8	49.3	43.1	20.2	1.6	90.6
Al_2O_3	16.6	17.0	17.4	11.1	16.6	16.4	0.7	0.2	0.5
ΣFeO	6.1	7.7	9.2	9.1	10.0	11.3	0.1	--	0.5
MgO	3.4	3.7	5.5	12.3	6.7	4.8	0.0	0.3	0.3
CaO	6.1	7.0	8.2	10.0	9.5	5.9	41.5	43.9	0.2
Na_2O	3.7	3.3	3.5	2.4	2.9	1.0	0.1	--	0.2
K_2O	2.8	2.3	1.4	0.2	1.0	2.7	0.1	.1	0.2
TiO_2	0.8	1.3	1.4	0.9	1.5	3.9	0.0	--	--
MnO	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	--
Total %	97.0	98.9	99.0	97.0	97.7	89.2	62.8	46.2	92.5

<u>Samples</u>:

40 Basalt (greenstone) of Leach Fm., mouth of French Boy Canyon, NE1/4, NW1/4, Sec. 4, T28N, R37E.

46 Basalt, East Range, SW1/4, NW1/4, SE1/4, Sec. 12, T30N, R37E.

45 Basalt, capping East Range, almost entirely crystalline, NE1/4, SW1/4, NE1/4, Sec. 23, T30N, R37E.

41 Basalt (greenstone) of Leach Fm., mouth of unnamed canyon, NE1/4, SE1/4, Sec. 7, R37E, T29N (unsurveyed).

45B Basalt, glassy from margin of feeder dike, East Range NE1/4, SW1/4, NE1/4, Sec. 23, T30N, R37E.

43 Green, calcareous semischist of Leach Fm., NW1/4, SW1/4, SW1/4, Sec. 8, R37E, T30N.

6H Travertine, Kyle Hot Spring area, T29N, R36E.

42 Limestone, white, coarsely crystalline Jurassic or Triassic stream bed, NW1/4, SE1/4, Sec. 7, R37E, T29N.

38 Glassy opaline sinter, black, contains organic material, extinct spring SW of Kyle Hot Spring, T29N, R36E.

temperatures at depth are estimated to be 155 to 170°C, based on silica and alkali-element geothermometers (Mariner et al., 1974). Silica is the predominant material being deposited presently, as well as in the past.

1. Waters and Spring Deposits

Major- and trace-element abundances of the warm pools at Leach and the nearby cold springs are listed on Table 4. Of the major elements Ca and Cl are more abundant in the cold springs than in the hot pools, as are the trace elements U and Br. There is considerable variation in trace-element contents between the hot pools. The two hotter pools at Leach are lower in Na, Cl, W, and Br than their cooler counterparts. Cesium, rubidium, and chloride contents of the hot pools are plotted against Na in Fig. 7. Chloride correlates well with Na, and positive correlations are observed in the plots of Cs and Rb versus Na. The inverse correlation between Na and Cl with pool surface temperature is also shown on Fig. 7. The pool numbered 62 on Table 4 has little or no apparent outflow; surface evaporation probably contributes considerably to its observed high salinity and may also be responsible for its relatively high Rb, W, Cs, and As contents. Therefore, variations observed in chemistries of the pools at Leach Hot Springs may be more influenced by variations in flow and evaporation than by mixing of near-surface cold waters.

Field radioactivity and radioelement contents of water and spring-deposit material were measured at Leach Hot Springs (Wollenberg, 1974a). As with other spring systems dominated by SiO_2, field gamma radioactivity was low, ranging from 5 to 7.5 μR/h over the spring area. This was

Table 4. Leach Area Water Samples

	Hot Springs					Cold Springs							
Sample	23B	63	61	23A	62	13	17	7	8	9	15	19	20
Temp (°C)	95°	94°	79°	75°	34°	--	--	--	--	12.5°	--	--	--
mg/liter													
SiO_2	183	--	99	89	175	85	60	20	10	30	30	45	20
Na	89	80	164	154	181	140	95	32	29	13	95	70	50
Cl	14	12	27	26	30	25	215	55	56	16	155	105	60
K	7	4	9	8	11	10	3	5	5	3	3	4	2
Ca	7	8	7	10	3	8	310	62	65	35	110	80	75
µg/liter													
U	<0.2	<0.3	<0.1	<0.02	<0.08			1.6	0.4	1.9			
Ba	130	190	170	190	70			107	75	46			
W	25	80	125	85	132			1	1.1	<0.7			
Br	30	35	60	75	70			110	118	44			
Sb	140	180	10	9	14			0.1	<0.2	<0.5			
Mo	13	13	1.5	1	3			1.3	<1	3			
Rb	120	40	105	98	125			<1	4	1.3			
Cs	115	65	110	102	122			0.02	0.02	0.5			

Table 4. Continued

	Hot Springs					Cold Springs							
Sample	23B	63	61	23A	62	17	17	7	8	9	15	19	20
Temp (°C)	95°	94°	79°	75°	34°	--	--	--	--	12.5°	30	45	20
As	12	<5	<4	3	16			30	<3	9			
Fe	<25	950	<55	<75	<52			<30	150	<20			
Sc	<0.03	0.16	<0.02	<0.02	<0.02			<0.02	<0.02	<0.02			
Mn	55	12	60	55	60			10	3	<0.4			

Samples:

23B, 63, 61, 23A, 62 from pools of varying temperature at Leach Hot Springs, Sec 36, T32N, R38E.

7 Mud Springs, seep, muddy, Sec. 33, T31N, R39E.

8 Sheep Ranch Springs, ~4 l/hr, from iron pipe, Sec. 16, T32N, R39E.

9 Grand Truck Springs, ~60 l/hr, SE1/4, Sec. 30, T33N, R38E.

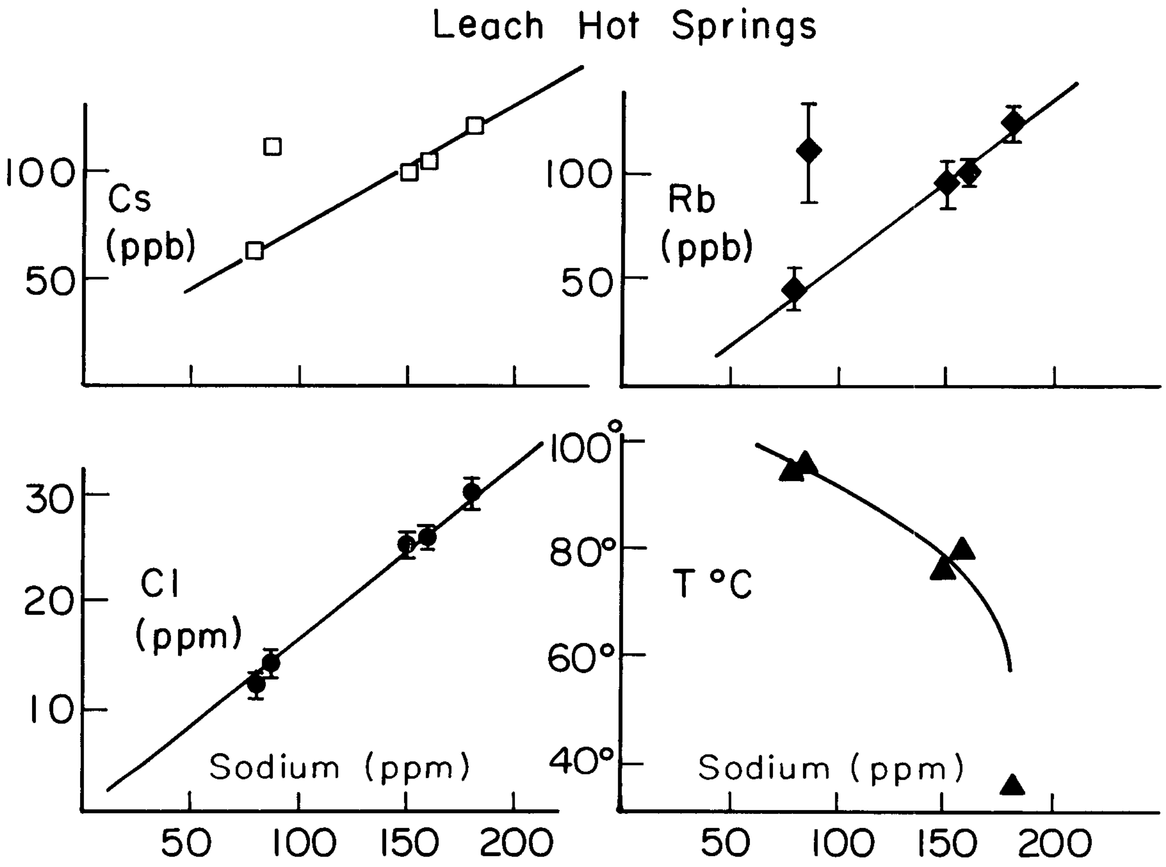
13 Spring SW of Leach Hot Springs Sec. 26, T31N, R38E.

25 West side of Grass Valley near entrance Spaulding Canyon, Sec. 16, T31N, R38E.

26 NE end of Spaulding Canyon, Sec. 13, T31N, R37E.

27 Marble Spring, south side of Spaulding Canyon, Sec. 26, T31N, R37E.

28 Dead Cow Springs, Spaulding Canyon, Sec. 27, T31N, R37E.



XBL776-1292

Fig. 7. Cesium, rubidium, chloride and temperature _versus_ sodium in the pools at Leach Hot Springs.

corroborated by the low radioelement content of the sinter: Thorium 1.08 ppm, equivalent uranium 0.72 ppm, and 0.35% potassium. Leach Hot Spring water had contents of radon-222 and uranium-238 below detectability limits. This is in contrast to spring systems dominated by $CaCO_3$ such as at Kyle and Buffalo Valley hot springs, where relatively high radioactivities and uranium-daughter radioelement contents were observed.

2. Rocks

Major-element contents of samples of altered and unaltered rocks and spring deposits in the Leach Hot Springs region are listed on Table 5. Rock types sampled included Tertiary felsic tuffs, Tertiary basalt, Paleozoic quartzite and greenstone, and Quaternary sinter and calcareous spring deposit material. The basalts and rhyolites are the principal rock types in the groundwater recharge area on the west side of southern Grass Valley, while Paleozoic rocks predominate in the Tobin Range bounding the valley to the east. Zeolitized water-laid tuffs along with freshwater limestone and clastics comprise a sequence of Tertiary sedimentary rocks occupying the lower eastern slopes of Grass Valley. The structural setting of the area suggests that most recharge to Leach Hot Springs is probably from the east. Therefore, the chemistry of the hot spring waters might be most influenced by that of the Paleozoic and Tertiary sedimentary rocks, represented by samples 31, 32, and 23.

Age dates of Tertiary volcanic units in this area, listed on Table 6, were obtained by the potassium-argon method (Archibald, private comm.).

Table 5. LEACH AREA ROCK SAMPLES

	Unaltered							Altered							
Sample	37	25	24	47	36	19	17	32	21	22	23	20	33	31	29
SiO_2	72.8	71.2	56.3	52.9	52.5	52.5	52.2	99.0	90.9	86.5	63.0	52.0	49.8	44.9	3.8
Al_2O_3	12.2	12.4	17.1	17.7	17.3	15.5	15.5	0.7	4.2	2.2	12.2	11.1	17.2	15.2	3.4
ΣFeO	0.9	1.4	6.4	9.4	10.1	10.2	9.8	0.1	0.7	0.4	0.7	4.6	11.0	10.6	0.3
MgO	0.2	0.3	3.2	5.4	5.6	5.2	5.1	0.2	0.3	0.2	1.1	2.1	5.7	7.1	0.6
CaO	1.2	3.5	6.2	8.1	8.4	8.3	8.0	0.1	0.1	0.6	0.6	9.3	8.6	8.5	28.4
Na_2O	3.2	1.0	2.8	3.3	3.6	3.0	3.3	--	--	0.8	4.4	1.2	3.5	1.0	--
K_2O	5.2	6.6	2.6	1.8	1.3	1.3	1.3	0.2	1.9	0.4	3.0	2.9	1.0	1.0	1.0
TiO_2	--	0.2	1.1	1.5	1.4	1.7	1.7	--	0.3	0.1	0.1	0.6	1.7	1.4	--
MnO	--	--	0.1	0.2	0.2	0.2	0.2	--	--	--	--	0.1	0.2	0.2	0.2
Total	95.7	96.6	95.8	100.3	100.4	97.9	97.1	100.3	98.4	91.2	85.1	83.9	98.7	89.9	37.7

Samples:

37 Rhyolite vitriphyre, dense with some vesiculation, east margin of dome, SW1/4, NW1/4, NE1/4, Sec. 26, R38E, T30N.

25 Welded rhyolitic tuff, few sanidine and quartz phenocryst, east of Leach Hot Spring, NW1/4, NE1/4, SW1/4, Sec. 29, R39E, T32N.

24 Basalt, north trending dike, west side of Grass Valley SE 1/4, SW1/4, SE1/4, Sec. 10, T32N, R37E.

47 Basalt, young, black, glassy, SW1/4, SW1/4, Sec. 8, T30N, R38E.

36 Basalt, dike cutting devitrified rhyolite, west side of dome, Goldbanks Hills Center, NE1/4, Sec. 26, R38E, T30N.

19 Basalt, dike SE of Leach Hot Spring, NW1/4, NE1/4, SW1/4, Sec. 31, T32N, R39E.

Table 5. Continued.
Leach Area Rock Samples — Locations

17 Basalt, southern end of dike, SE of Leach Hot Spring, SE1/4, NW1/4, NW1/4, Sec. 6, T31N, R39E.

32 Quartzite, Halvallan Fm., NE1/4, NE1/4, Sec. 4, T31N, R39E (unsurveyed).

21 Massive microcrystalline sinter, from stream cut exposure of sinter ledge, NE of Leach Hot Spring.

22 Layered opal sinter, east side of road cut SW of Leach Hot Spring.

23 Zeolitized airfall tuff, silicic; from road cut ~200' east of SW corner of Sec. 17, T32N, R39E.

20 Brick-red altered rock just SE of sinter ledge, NE of Leach Hot Spring.

33 Basalt remnant, lower more crystalline part of unit, Goldbanks hills, SW1/4, NW1/4, SW1/4, Sec. 14, T30N, R38E.

31 Greenstone (Pumpernickel Fm.) NW1/4, Sec. 4, T31N, R39E (unsurveyed).

29 White friable spring deposit, east side of Spaulding Canyon, NE1/4, NW1/4, NE1/4, Sec. 13, T31N, R37E.

Table 6. Potassium-argon ages of Tertiary volcanic rocks in the Leach Hot Springs area.

Description	Age (million years)
Basalt, capping the East Range (whole rock)	12.6 ± 0.3
Basalt, vicinity of Leach Hot Springs (whole rock)	14.2 ± 9.5
Basalt, Goldbanks Hills (plagioclase)	15.0 ± 0.9
Rhyolitic tuff, south flank, Goldbanks Hills (sanidine)	14.5 ± 0.2
Rhyolite, dome in southern Goldbanks Hills (whole rock)	11.8 ± 0.2

C. Buffalo Valley

Several hot pools and spring deposits at Buffalo Valley Hot Springs, cold and possible warm springs, as well as country rocks in the surrounding hydrologic region, and material from heat flow holes were sampled and analyzed. Mariner et al. (1974) observed a surface spring flow of ~10-l/min, though Olmsted et al. (1975) estimated that a considerably greater amount of water may be leaving the spring system by evapo-transpiration and subsurface leakage. Estimated subsurface water temperature, based on the silica conductive geothermometer (Mariner et al., 1974) is 125° C. Present-day and old spring deposits are predominantly $CaCO_3$.

1. Waters and spring deposits

Major and trace-element chemistries of four pools at Buffalo Valley Hot Springs are listed on Table 7, along with similar data for warm and cold springs elsewhere in and around Buffalo Valley. In contrast to Leach Hot Springs, there is little variation in element abundances between the pools at Buffalo. Though they are a considerable distance from the hot springs, springs 18, 19, and 20 (Table 7) have distinctive chemistries which are suggestive of a warm water component. Their silica contents are high compared to the cold springs in the region, as are Na, Cl and Br contents of springs 18 and 20. Airborne thermal infrared surveys in pre-dawn hours indicated that spring 19 was relatively warm compared to the other cool springs. Their positions in the Buffalo Valley playa, their salinity, and the apparent warmth of spring 19 distinguish this group of springs from the other cool springs sampled.

Table 7. BUFFALO VALLEY WATER

	Hot Springs					Warm and Cold Springs							
	15-6	15-1	15-4	15-5	Average	20	18	19	16	17	21	22	
Temp °C	72°	72°	65°	68°		cool	17°	cool	19°	15°	10°	14°	Temp °C
						mg/liter							
SiO_2	75	64	81	84	76 ± 9	80	60	60	20	10	< 2	< 2	SiO_2
Na	268	269	277	280	274 ± 6	320	130	80	50	20	6	15	Na
Cl	28	28	26	25	26.8 ± 1.5	250	100	17	46	21	4	23	Cl
K	29	27	27	36	30 ± 4	9	15	8	1	0.5	4	3	K
Ca	24	25	28	20	24 ± 3	2	47	7	31	48	28	37	Ca
						μg/liter							
U	< 0.08	< 0.16	< 0.16	< 0.14		0.5	3.5	1.0	0.15	2.0	0.35	0.55	U
Ba	160	150	140	135	146 ± 11	50	70	100	50	200	60	180	Ba
W	28	30	33	24	29 ± 4	25	2	7	1	3	< 0.2	< 0.3	W
Br	62	65	70	70	67 ± 4	250	210	40	85	30	8	30	Br
Sb	37	57	35	22	38 ± 14	0.3	0.4	0.5	< 0.1	0.5	0.3	< 0.2	Sb
Mo	4	< 1	< 1	< 1		55	5	15	12	2.5	0.5	0.5	Mo
Rb	124	133	130	135	131 ± 5	10	40	15	10	< 0.3	2	< 0.8	Rb
Cs	150	155	160	160	156 ± 5	0.4	0.1	0.1	4	0.05	0.06	0.04	Cs
As	< 10	< 10	< 10	25		85	< 7	30	4	18	2	< 2	As
Fe	< 100	< 100	< 250	< 100		120	< 25	< 25	130	40	< 16	< 10	Fe
Sc	< 0.02	< 0.02	< 0.02	< 0.02		0.05	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	Sc
Mn	30	30	40	10		< 6	< 3	< 5	270	3	< 6	< 4	Mn

Sample Locations:

15-6, 1, 4, 5 Buffalo Valley Hot Springs, Sec. 6, T29N, R41E.

20 Buffalo Valley flat warm spring, ~4.3 miles NW of Buffalo Valley Hot Springs.

18 Pickett's Well, Buffalo Valley windmill SW1/4, Sec. 23/24, T30N, R42E.

19 Buffalo Valley flat warm spring, ~3.3 miles NW of Buffalo Valley Hot Springs.

16 Daisy Creek Spring, Daisy Creek Road, Sec. 32, T28N, R41E.

17 Cool spring, west side of Buffalo Valley at BM4643, slow-flowing spring (~1 gal/min), NW1/4, Sec. 6, T29N, R41E.

21 Spring on west side of Buffalo Valley, 4.5 miles north of Saval Buffalo Ranch, T29N, R40E.

22 Marked spring, west side of Buffalo Valley, SE1/4, SE1/4, SW1/4, Sec. 29, R41E, T30N.

As with the Kyle and Leach hot spring regions, uranium contents of Buffalo Valley hot springs are near or below detectability limits, while cold springs have appreciable abundances of this element. There is a similar contrast in molybdenum abundances between cold and hot springs at Kyle and Buffalo Valley. Conversely, K, W, Sb, Rb, Cs and Mn are of considerably higher concentration in the hot springs than in the cold springs.

Similar to Kyle Hot Springs where $CaCO_3$ is also being deposited, Buffalo Valley Hot Springs are radioactive (Wollenberg, 1974). General gamma-ray background near the spring area is 6.25 μR/hr, while exposure rates of 30-38 μR/hr were measured over some of the springs. This is due partially to relatively high Rn-222 contents of the water, 73pCi/l, and to radioactive calcareous spring deposits. The radioelement contents are listed on Table 8.

2. Rocks

Buffalo Valley Hot Springs are located near to or within the zone of northeast-trending faults bordering the east side of Buffalo Valley. Therefore, the principal recharge area for the springs is the Fish Creek Mountains; rock sampling was concentrated in that area. The chemistries of the hot-spring waters may reflect the chemical compositions of late-Tertiary basalts, siliceous ash flow tuffs, and Triassic carbonate rocks.

Samples were collected primarily from the Tertiary volcanic rocks which border and underlie the eastern and southern portions of Buffalo Valley. Several samples were obtained from the Fish Creek Mountains tuff, a sequence of rhyolitic ash-flows erupted in the Miocene from

Table 8. Radioelement Contents of Buffalo Valley Spring Deposits

	Th (ppm)	Equivalent U (ppm)	K (%)	Ra* (pCi/g)
Calcareous muck from small mound	45.9	25.5	0.21	9.2
Tufa	6.2	65.7	0.35	23.7

*Calculated from activities ratio $^{226}Ra/^{238}U$.

a center 16 km. south of Buffalo Valley Hot Springs (McKee, 1970). The tuffs were uplifted during Basin and Range faulting, affording good exposures by stream erosion in Daisy Canyon, and permitting sampling of the tuff units upward from the bottom contact. The chemical compositions of several of the tuff layers are listed on Table 9 (samples 1 through 7), with data from the upper units on the left. Successively lower units are listed from left to right. Phenocrysts make up less than 1% of the lower layers of the tuff sequence, and their abundance increases to over 30% in the upper layers.

Basalt flows and cinder cones occupy a northeast-trending belt along the west flank of the Fish Creek Mountains. The basalts are of Pliocene age; whole-rock specimens were dated by the potassium- argon method at 2.6 to 3 m.y. (E. H. McKee and D. Archibald, private communications). Chemical compositions of samples of the basalt are also listed on Table 9 (samples 12, B22 and 11).

The high radioelement content of the Fish Creek Mountains Tuff may be partly responsible for the relatively high concentration of uranium daughters and thorium at Buffalo Valley Hot Springs (Table 8). Compared with the tuff and pre-Tertiary quartz monzonite, the Triassic limestones of the northern Fish Creek Mountains are relatively low in radioelements, as shown on Table 10.

3. Heat Flow Holes

Three heat flow holes were drilled in alluvium of Buffalo Valley near and away from the hot springs (Sass et al, 1975). Samples of drill cuttings were taken every 10 feet from two of the holes, BVHF-2 and BVHF-3 (locations are shown on the map, Fig. 5). They were analyzed for major

Table 9. BUFFALO VALLEY ROCKS

	7	4	3	2	1	6A	6B	6C	9	8	12	B22	11	
SiO_2	75.08	74.00	71.23	74.70	73.74				67.6	60.6	44.5	47.7	48.1	SiO_2
Al_2O_3	13.0	13.2	13.4	12.5	12.4				13.5	17.5	15.3	17.0	17.6	Al_2O_3
ΣFeO	0.51 ± 0.01	0.28	0.87	0.64	0.65	1.34	0.121	1.28	2.6	5.0	8.5	10.7	9.4	ΣFeO
MgO	0.03	0.12	0.26	0.20	0.13				0.7	1.0	5.5	6.2	5.4	MgO
CaO	0.80	0.57	1.86	0.47	0.47				1.8	4.8	12.9	9.8	9.4	CaO
Na_2O	3.38 ± 0.03	4.20	4.06	4.42	2.84	2.60	2.79	2.61	3.0	3.5	3.0	3.3	4.0	Na_2O
K_2O	5.40	5.09	4.59	4.58	6.18	6.0	6.0	5.9	4.7	4.0	2.0	1.2	1.3	K_2O
TiO_2	0.20	0.11	0.19	0.06	0.05	0.11	0.11	0.11	0.7	0.9	2.0	2.0	2.6	TiO_2
MnO	0.004	0.006	0.019	0.015	0.019	0.024	0.025	0.024	0.042	0.077	0.172	0.179	0.169	MnO
Total %	98.40	97.53	96.48	97.54	96.50				94.6	97.3	93.9	98.1	98.0	Total %
							(ppm)							
U	6.70 ± 0.05	11.3	13.0	16.1	23.4	20.8	22.2	21.3	15.6	6.5	2.3	0.8	1.5	U
Th	30.5 ± 0.2	66.8	74.5	113.5	116.3	84.2	84.7	83.3	54	21	4.0	2.5	3.8	Th
Ta	2.01 ± 0.01	4.49	4.80	6.42	5.49	5.58	5.46	5.54	4.2	1.0	2.9	1.9	3.4	Ta
Hf	5.6 ± 0.1	10.5	10.0	10.3	9.9	10.1	9.7	10.1	8.8	6.8	4.5	5.6	5.3	Hf
La	97 ± 1	70	59	23	27	26	29	27	31.4	56	35	24	36	La
Ce	180 ± 1	137	120	50	72	66	68	67	72	89	69	54	73	Ce
Nd	65 ± 2	61	60	38	51	54	66	53	42	49	31	31	37	Nd
Sm	9.88 ± 0.02	11.6	12.4	10.6	16.2	17.4	18.3	17.4	12.7	10.0	5.9	6.6	6.5	Sm
Eu	0.35 ± 0.02	0.18	0.29	< 0.01	< 0.01	0.09	0.06	0.05	0.6	1.8	1.8	2.2	2.1	Eu
Tb	0.84 ± 0.04	1.6	2.0	2.2	3.4	3.1	3.1	3.1	2.3	1.20	0.85	1.00	0.80	Tb
Dy	5.1 ± 0.1	9.8	12.1	13.6	21.3	21.8	22.8	21.7	14.8	7.0	4.8	7.0	5.1	Dy
Yb	2.54 ± 0.04	5.0	6.2	6.2	8.9	9.0	9.1	9.0	6.7	3.3	2.6	4.1	2.7	Yb
Lu	0.30 ± 0.02	0.68	0.76	0.80	1.12	1.08	1.17	1.12	0.92	0.39	0.39	0.57	0.40	Lu
Rb	180 ± 4	498	495	685	884	476	481	489	403	183	13	10	30	Rb
Cs	4.2 ± 0.1	19	25	32	30	20	20	20	21	11	0.9	0.4	0.6	Cs
W	2.9 ± 0.3	3.3	3.5	3.8	4.3	4.6	4.4	4.2	3.2	2.4	2.7	0.5	1.0	W
Ba	423 ± 20	201	330	31	105	< 30	< 30	< 30	568	1700	840	285	541	Ba
Sb	0.2 ± 0.1	1.0	1.7	1.6	1.7	0.85	0.75	1.06	1.2	0.8	0.5	0.3	0.2	Sb
Mo	< 0.7	< 0.5	< 0.5	1.2	3.2	7.2	7.7	5.6	1.4	1.9	3.7	1.7	3.6	Mo
Sc	3.2 ± 0.1	1.8	3.7	1.7	1.0	1.9	1.4	1.8	4.8	10.8	20.7	31.2	23.2	Sc
Co	0.21 ± 0.04	0.4	1.0	0.3	0.7	0.3	0.2	0.3	3.8	7.9	33	40	36	Co
Zn	34 ± 5	100	200	140	137	130	115	80	140	130	100	120	110	Zn
Cr	< 9	< 10	< 10	< 10	< 10	< 7	< 7	< 7	< 10	15	40	100	20	Cr
Ni	< 10	< 10	< 10	< 10	< 10	< 7	< 7	< 7	< 10	< 10	< 10	90	< 10	Ni

Table 9. Continued.

Buffalo Valley Rocks — Locations

1	Dense, hydrated, glassy pumice fragment, very phenocryst-poor to phenocryst-free; lower part of the Fish Creek Mt. Tuff; at the mouth of Dacies Canyon, Center; NW1/4, SW1/4, NW1/4, Sec. 22, T28N, R41E.
2	Dense, devitrified pumice fragment, ~5% phenocryst, same location as sample #1.
3	Whole-rock specimen of welded tuff, ~10% phenocrysts, same location as sample #1.
4	Dense and devitrified fragment, ~25% phenocryst, upper part of cliff at same location as samples #1, 2, and 3.
6A,B,C	Separate samples of phenocryst-poor, glassy, hydrated pumice fragments from the lower nonwelded part of the Fish Creek Mt. Tuff; 1/4 mile NW of locations 1, 2, 3, and 4.
7	Whole-rock specimen of welded tuff, 30-40% phenocrysts; Daisy Canyon Road, ~1/2 mile SE of locations 1, 2, 3, and 4, T28N, R41E.
8	Dacite breccia fragments, Fish Creek Mt. Tuff, Sec. 9, T28N, R41E.
9	Rhyolitic fragments, Fish Creek Mt. Tuff mudflow, Sec. 9, T28N, R41E.
11	Olivine basalt, Sec. 28, T29N, R42E.
12	Olivine basalt, Sec. 1, T28N, R41E.
B22	Quaternary olivine basalt, north end of Fish Creek Mts. (near micro-wave station), Sec. 36, T30N, R42E.

Table 10. Radioelement contents of some pre-Tertiary rocks of the northern Fish Creek Mountains.

Location No.	Description	Th (ppm)	U (ppm)	K (%)
9	Quartz Monzonite	21.7	5.1	3.3
10	Limestone	0.10	2.6	0.01
10A	Limestone	0.04	1.4	0.05
11	Bluish Limestone	0.04	2.05	0.06

elements. Results are expressed as oxides on Table 11; their silica contents are plotted with temperature profiles on Fig. 8.

Cuttings from Hole BVHF-2, drilled ~2.5 km. west of the hot springs, have rather uniform contents over the total depth of 373 ft. The relatively high silica and alkali-element contents of this material indicate that the alluvium at this location was derived mainly from the Fish Creek Mountains tuff, with perhaps minor contribution from the basalts.

Silica and alkali contents are considerably lower and CaO is higher in Hole BVHF-3, drilled on the west side of Buffalo Valley playa, approximately 7 km. NNW of the hot springs. As shown on Fig. 8, SiO_2 is more variable in BVHF-3 with a small "high" at ~100 ft. (corresponds roughly to a zone of lower geothermal gradient) and a low silica content at the bottom of the hole. The general basic composition of material from this hole indicates that alluvium at BVHF-3 was derived from greenstones in the Paleozoic eugeosynclinal rocks of the Tobin Range on the west side of Buffalo Valley.

4. Radon Emanation Survey

The applicability of alpha-track detectors to discern radon emanation, which in turn might disclose fault zones, was studied in Buffalo Valley (Wollenberg, 1974b). An array of detectors provided by Terradex Corporation and General Electric Company, were placed in the ground near and away from radio-active warm pools in Buffalo Valley. Subsequent etching of the detectors revealed high track densities at locations near the pools (Fig. 9) and a tenfold decrease in track densities in detectors

Table 11.

BUFFALO VALLEY HEAT FLOW HOLE #2

	$\frac{0}{13}$	$\frac{13}{23}$	$\frac{23}{33}$	$\frac{33}{43}$	$\frac{53}{63}$	$\frac{73}{83}$	$\frac{83}{93}$	$\frac{93}{103}$	$\frac{103}{113}$	$\frac{113}{123}$	$\frac{153}{163}$	$\frac{183}{193}$	$\frac{243}{253}$	$\frac{276}{286}$	$\frac{293}{303}$	$\frac{303}{313}$	$\frac{313}{323}$	$\frac{323}{333}$	$\frac{333}{343}$	$\frac{343}{353}$	$\frac{353}{363}$	$\frac{363}{373}$	
SiO_2	71.4	72.4	73.9	75.4	73.4	71.8	71.3	74.0	72.3	74.6	71.6	73.0	75.6	73.9	73.6	74.6	73.1	74.2	73.2	74.7	73.7	73.4	SiO_2
AL_2O_3	11.7	11.4	12.4	11.8	12.2	12.6	12.8	11.4	11.6	11.9	12.2	11.9	12.4	12.6	12.6	12.2	12.6	12.2	12.5	12.1	11.7	12.7	AL_2O_3
Σ FeO	1.2	1.2	1.2	1.2	1.5	2.3	1.9	1.4	1.5	1.4	1.5	1.5	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.2	1.5	1.2	ΣFeO
MgO	.5	.6	.5	.5	.6	1.3	.8	.6	.6	.6	.7	.6	.5	.9	.5	.4	.5	.4	.6	.4	.8	.5	MgO
CaO	1.3	1.1	1.9	1.3	1.2	2.5	2.2	1.2	1.6	1.6	1.7	1.7	1.5	2.1	2.0	2.1	2.2	1.7	1.8	1.8	1.9	1.8	CaO
Na_2O	1.3	2.4	1.7	2.3	2.7	1.0	1.7	1.7	2.5	2.6	2.6	2.7	2.7	1.5	2.6	2.6	2.3	2.6	2.5	2.8	2.3	2.5	Na_2O
K_2O	4.7	4.3	4.5	4.3	4.5	4.0	4.5	4.6	4.5	4.3	4.2	4.5	4.5	4.5	4.5	4.4	4.5	4.6	4.5	4.6	4.5	4.7	K_2O
TiO_2	.2	.2	.2	.2	.3	.5	.3	-	-	.2	.2	.3	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	TiO_2
MnO	.02	.03	.02	.01	.03	.04	.04	.13	.13	.01	.04	.02	.02	.04	.03	.03	.02	.02	.04	.01	.04	.02	MnO
Total	92.3	93.6	96.3	97.0	96.4	96.0	95.5	95.0	94.7	97.2	94.7	96.2	98.7	97.1	97.2	97.7	96.7	97.1	96.6	97.8	96.6	97.0	Total

BUFFALO VALLEY HEAT FLOW HOLE #3

	$\frac{0}{23}$	$\frac{23}{43}$	$\frac{43}{53}$	$\frac{53}{63}$	$\frac{63}{73}$	$\frac{73}{83}$	$\frac{83}{93}$	$\frac{93}{103}$	$\frac{103}{113}$	$\frac{113}{123}$	$\frac{123}{133}$	$\frac{133}{143}$	$\frac{143}{153}$	$\frac{153}{163}$	
SiO_2	47.0	53.1	51.3	51.2	49.4	51.7	52.7	60.0	51.8	52.7	51.1	51.0	52.6	52.1	SiO_2
ALO_3	11.7	11.1	10.8	13.3	13.3	13.6	13.9	13.0	13.1	13.7	13.5	13.7	14.1	14.0	ALO_3
ΣFeO	4.4	6.3	8.3	6.1	5.9	6.0	6.0	8.6	6.4	7.0	7.2	6.5	6.5	6.7	ΣFeO
MgO	5.1	3.3	3.2	3.9	3.9	4.2	4.0	4.0	4.1	3.9	4.0	4.0	4.0	4.0	MgO
CaO	12.8	3.8	9.6	7.4	7.3	7.4	7.1	7.4	6.9	7.4	7.3	7.2	7.1	7.9	CaO
Na_2O	1.4	1.0	1.4	3.0	2.5	2.9	2.8	2.5	2.8	2.9	2.7	2.8	2.7	2.6	Na_2O
K_2O	2.7	3.2	2.8	3.4	3.2	3.4	3.2	3.2	3.3	3.2	3.3	3.2	3.3	3.4	X_2O
TiO_2	.5	.4	.4	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.1	TiO_2
MnO	.12	.10	.11	.13	.08	.10	.11	.11	.11	.13	.13	.12	.13	.13	MnO
Total	85.7	82.3	87.9	89.5	86.6	90.4	90.9	99.9	89.6	92.0	90.3	89.6	91.4	91.9	Total

BUFFALO VALLEY HEAT FLOW HOLE #3 (continued)

	$\frac{163}{173}$	$\frac{173}{183}$	$\frac{202}{212}$	$\frac{212}{222}$	$\frac{232}{242}$	$\frac{242}{252}$	$\frac{252}{262}$	$\frac{262}{272}$	$\frac{272}{282}$	$\frac{282}{292}$	$\frac{292}{302}$	$\frac{302}{305}$	$\frac{305}{312}$	
SiO_2	52.2	50.7	54.9	57.3	56.8	54.4	58.0	60.9	57.3	53.2	54.4	56.1	44.5	SiO_2
AL_2O_3	14.0	12.4	11.1	10.7	10.6	10.3	10.1	9.6	10.3	10.2	10.7	10.4	8.4	AL_2O_3
ΣFeO	6.7	6.6	4.3	4.6	4.7	4.7	4.4	3.9	4.5	4.2	5.1	4.5	3.0	ΣFeO
MgO	4.1	3.7	4.0	3.7	3.9	3.8	3.7	3.7	4.0	3.9	4.1	4.1	4.7	MgO
CaO	7.5	7.0	7.6	7.2	7.9	7.9	7.9	7.7	8.5	9.1	8.0	7.6	17.5	CaO
Na_2O	2.8	2.5	1.4	1.5	1.6	1.7	1.2	1.3	1.6	1.5	-	-	-	Na_2O
K_2O	3.4	3.0	2.7	2.7	2.7	2.5	2.5	2.4	2.6	2.4	2.5	2.7	1.7	K_2O
TiO_2	1.1	.9	.6	.7	.6	.6	.5	.5	.6	.6	.7	.7	.3	TiO_2
MnO	.13	.10	.09	.08	.08	.08	.08	.11	.09	.11	.14	.10	.11	MnO
Total	91.9	86.9	86.7	88.5	88.9	86.0	88.4	90.1	89.5	85.2	85.6	86.2	80.2	Total

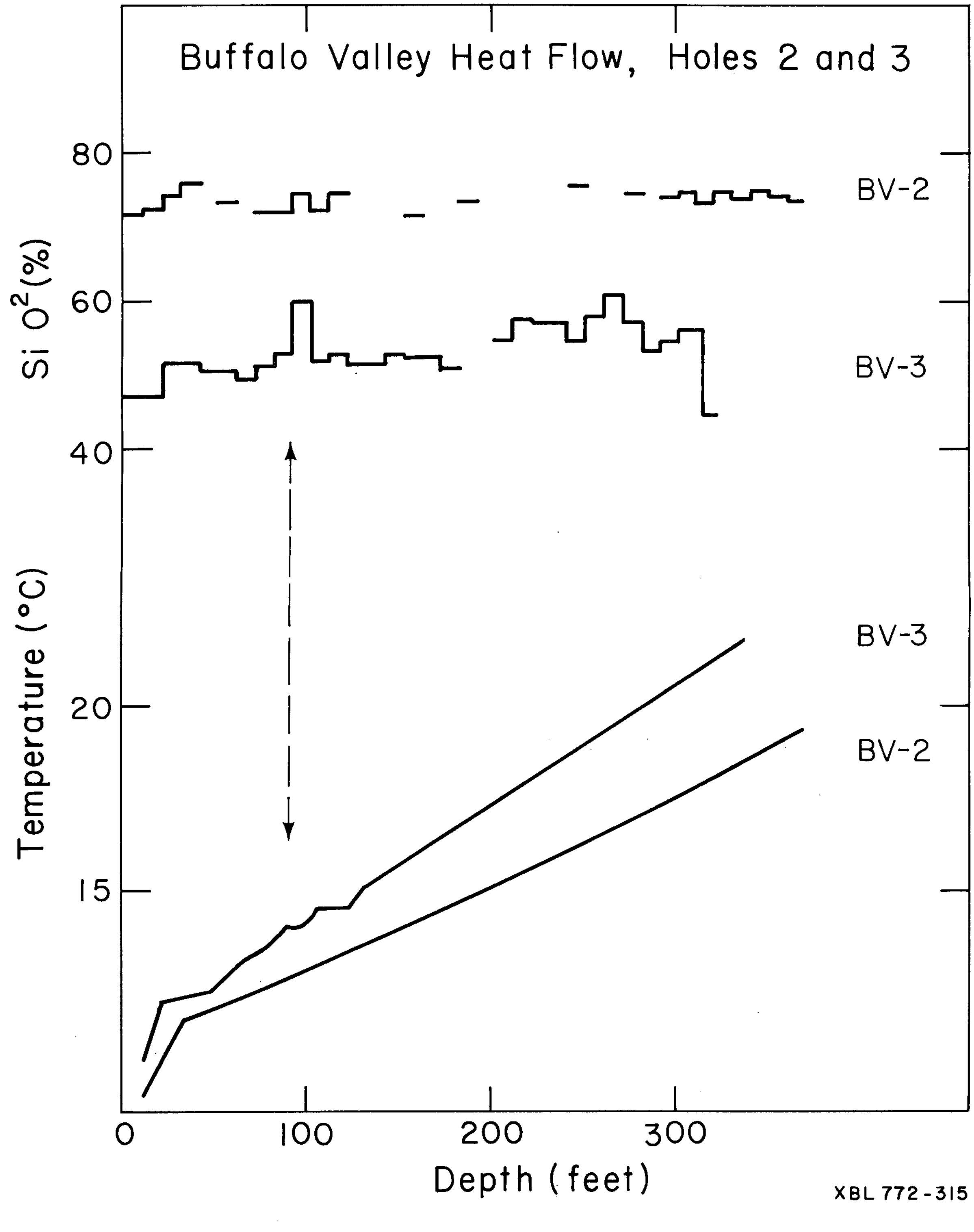


Fig. 8. Silica content of cuttings, and temperatue *versus* depth in Buffalo Valley heat flow holes 2 and 3.

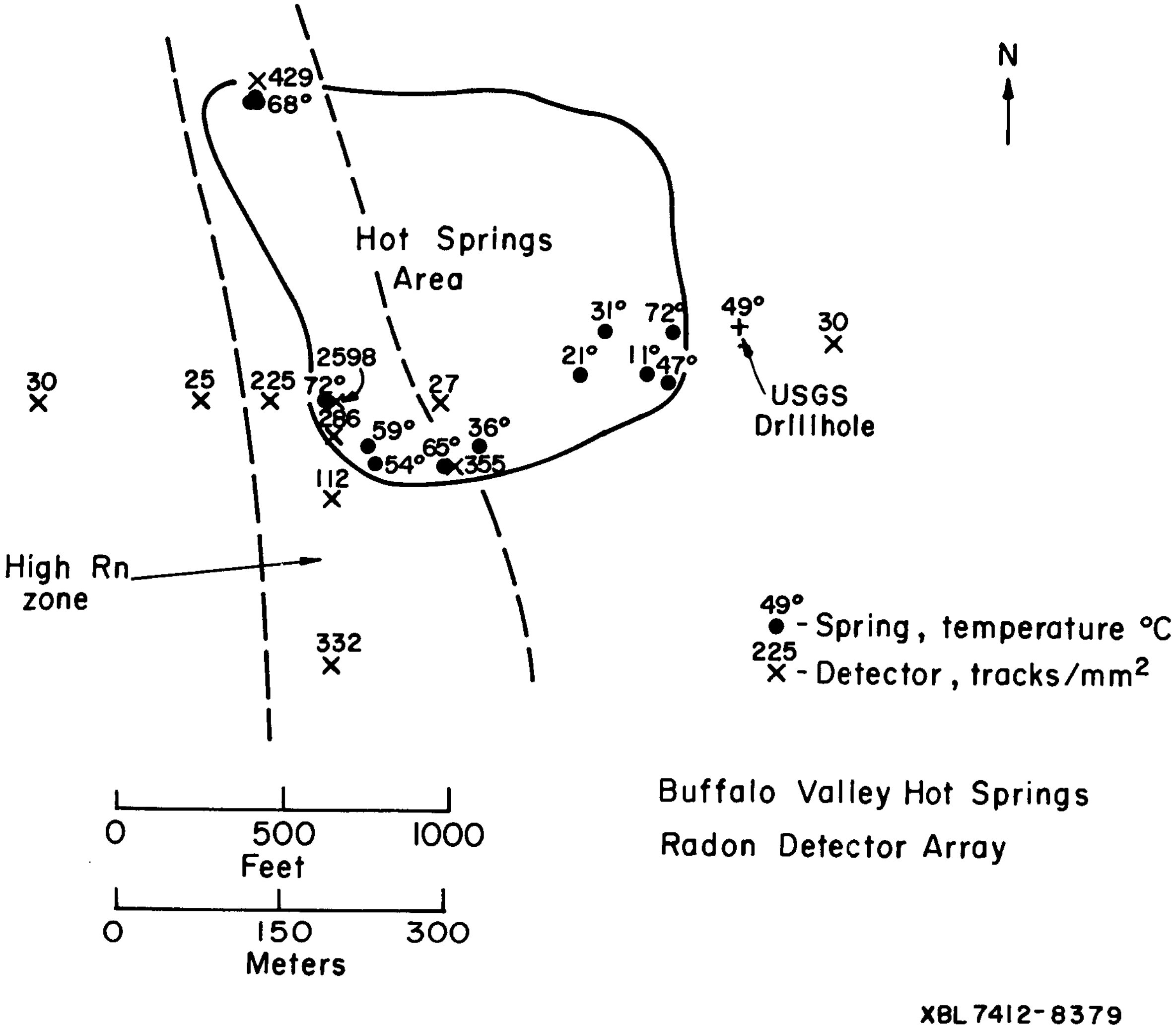


Fig. 9. Map of Buffalo Valley Hot Springs area, showing locations of the warm pools, temperatures, and alpha-track densities.

away from the pools. In the southern part of Buffalo Valley, relatively high track densities reflected the proximity of the detectors to the comparatively high-radioactive Fish Creek Mountain tuffs which underlie valley alluvium and are the source of most of the alluvial material. With the exception of the hot springs area and a single site northwest of the springs, the contoured radon track density field (Fig. 10) is fairly featureless in the region surveyed.

Track densities and the uranium content of near-surface soil were compared. Samples of soil from the track-detector holes were collected and analyzed for radioelement contents by gamma spectrometry. Results showed some correlation between equivalent uranium (due primarily to radium-226) and alpha-track density in the hot springs area. In the array of detector holes away from the springs, there was no apparent correlation between soil uranium contents and track densities, indicating that a substantial portion of the radon measured comes from sources deeper than the soil surrounding the detectors. Slightly elevated U values at the southerly locations probably reflect the influence of the Fish Creek Mountain tuffs on the composition of the alluvium.

D. Whirlwind Valley Area

Sampling sites in the Whirlwind Valley area included a blowing well and hot pools at Beowawe Hot Springs, a cold well in Whirlwind Valley, cold springs in Crescent Valley, and volcanic outcrops in the Beowawe area. Mariner et al. (1974) estimated that the reservoir temperature at Beowawe was near or exceeded 200^{o}C, based on silica geothermometry of fluid from the blowing well and hot pools. Chemical geothermometer temperatures were substantiated by measurements in

Fig. 10. Contours of radon alpha-track density (in tracks/mm^2, normalized to a 30-day exposure) in Buffalo Valley. Dotted numbers are station locations.

CBB 7412-8765

test wells by Magma Power Co. Flow from the hot springs is ~ 100 l/min. Silica is being deposited by the blowing wells and springs, forming a large sinter apron at the base of the Malpais escarpment.

1. Waters and spring deposit

Trace- and major-element compositions of hot and cold waters are listed on Table 12. The hot waters are represented by samples from one of the blowing wells, a nearby small acidic pool (pH 3), and a hot pool in the valley below the sinter apron. The only cold ground water accessible in the upper part of Whirlwind Valley was from a cattle well (location 11); the high Fe and Mn contents of this water are probably from the well liner. Supplementary samples of cold-spring waters were obtained from sites in northern Crescent Valley.

In keeping with the relatively high reservoir temperature, silica contents of the Beowawe blowing well and hot-spring water are the highest of the spring systems examined in northern Nevada. With the exceptions of U and Ba, trace-element contents of the hot waters are considerably higher than those of the cold waters. Comparatively high concentrations of W, Br, Sb, Mo, Rb, and As were measured in the hot waters.

The Whirlwind Valley cold-well water and rock samples from Beowawe have high contents of barium, compared to the other hydrologic regions studied. Of the hot springs, the barium to calcium ratio is highest by far at Beowawe, 53.9; compared with 6.1 at Buffalo Valley, 21.4 at Leach, and 6.5 at Kyle. The Beowawe-Whirlwind Valley area lies within a barium-rich region; several barite deposits are presently being mined.

Table 12. BEOWAWE WATER SAMPLES

	Hot Springs			Cold Springs		
Sample	102	104	103	11	12	14
Temp (°C)	steam	88°	78°	cool	cool	cool
			mg/liter			
SiO_2	490	330	300	30	--	--
Na	280	210	250	32	190	66
Cl	67	56	42	20	120	30
K	40	8	31	12	100	18
Ca	1.5	1.0	3	55	60	40
			µg/liter			
U	< 0.07	< 0.2	0.5	< 0.1	1.5	0.14
Ba	50	50	190	260	80	70
W	135	150	12	< 0.7	3	< 0.5
Br	145	135	120	80	40	130
Sb	11	13	5	< 0.3	1	< 0.3
Mo	11	19	3	1	4	1
Rb	320	145	215	< 7	100	30
Cs	220	200	115	1	1.1	1.1
As	33	40	< 15	< 4	30	< 5
Fe	< 90	< 70	670	40000	< 40	60
Sc	< 0.02	< 0.02	0.7	10	< 0.02	< 0.02
Mn	< 3	< 3	115	100	50	20

Samples:

102 Beowawe Steam well, from most northern blowing well, Sec. 17, T31N, R48E.

104 Beowawe Hot Spring, below the blowing well.

103 Beowawe Acidic Spring, ~50 meters north of blowing wells.

11 Whirlwind Valley windmill, Sec. 32, T32N, R48E.

12 Cattle pool, north end of Crescent Valley, SE of Beowawe Steam wells, Sec. 25, T31N, R48E.

14 Seep, north end of Crescent Valley, SE of Beowawe Steam wells, Sec. 36, T31N, R48E.

Characteristic of hot-spring areas where silica is the principal deposit (Wollenberg, 1974), hot waters at Beowawe are essentially devoid of radioactivity; radon contents are below the detection limit (~10 pCi/l). This was reflected in the low gamma radioactivity measured over the springs and sinter deposit, 2-2.5 R/h, compared to 14-18 R/h, measured over the andesite of the Malpais escarpment. As at Leach Hot Springs, the radio-element content of the sinter at Beowawe is relatively low: Th 0.9ppm, U 0.4ppm, K 0.4%.

2. Rocks

Results of major-and trace-element analyses of rock samples are listed on Table 13. Tertiary volcanics of the Malpais escarpment and rim, southeast of Beowawe Hot Springs, were sampled. (Unfortunately, samples were not obtained of the Valmy formation which underlies the volcanics). Rock types include andesite of the escarpment, and volcani-clastics and basalt of the rim area. The andesites are unusual in that their abundances of alkalies, U, Th, and rare-earth elements are high compared to silica. This, together with the noteworthy high abundances of barium in all of the rock samples, suggests the presence of hydrothermal mineralization.

Table 13. BEOWAWE ROCK SAMPLES

Sample	10B	4B	3B	7B	5B
SiO_2	67.9	60.3	56.0	51.3	49.1
Al_2O_3	13.8	14.3	13.5	11.4	16.2
ΣFeO*	5.8	6.9	3.8	3.0	11.1
MgO	0.3	0.8	3.1	1.3	7.5
CaO	2.2	4.1	6.7	12.1	9.5
Na_2O*	3.21	3.24	2.02	1.90	2.67
K_2O	4.8	4.1	2.4	3.1	0.9
TiO_2*	0.8	0.9	0.7	0.5	1.5
MnO*	0.052	0.135	0.081	0.068	0.191
Total %	98.9	94.8	88.3	84.7	98.7
		(ppm)			
U	3.34	4.25	1.75	2.03	0.57
Th	17.6	12.7	8.6	2.3	2.6
Ta	1.34	1.78	0.71	0.65	1.3
Hf	10.6	11.7	5.6	4.7	4.3
La	63	67	295	28	30
Ce	124	140	618	52	64
Nd	55	66	245	22	33
Sm	10.7	12.4	5.3	4.80	7.1
Eu	1.9	2.8	1.2	1.2	2.0
Tb	1.30	1.7	0.75	0.64	1.0
Dy	7.9	10.6	4.5	3.6	6.3
Yb	4.8	6.6	2.75	1.9	3.6
Lu	0.66	0.90	0.38	0.27	0.53
Rb	165	130	105	100	< 15
Cs	3.2	5.8	7.7	7.5	< 0.3
W	1	1.6	< 1	1.9	1
Ba	1700	1900	2100	1530	1340
Sb	< 0.1	0.2	0.2	0.8	< 0.2
As	25	5	5	45	< 10
Mo	4.3	5.5	1.6	13	< 1
Sc	10.0	1.65	1.20	6.02	3.04

Table 13. Continued.

Co	5.8	6.8	7.0	5.0	41
Zn	130	170	85	73	160
Cr	< 3	< 3	15	< 15	175
Ni	< 20	< 20	< 20	< 20	115
Cl	< 500	700	3200	< 500	1100
V	< 25	50	60	< 25	280

Samples:

10B	Andesite.
4B	Scoriaceous andesite.
3B	Mudflow breccia.
7B	Buff tuff.
5B	Massive basalt.

IV. DISCUSSION

Specific items resulting from the sampling and analytical program are reviewed in this section. Included are brief discussions of the concordance between USGS and LBL analytical results, mixing calculations, possible trace-element geothermometers, and concentration of uranium in hydrothermal systems.

A. Concordance of USGS and LBL Results

Comparison of major-element abundances determined by the USGS (Mariner et al., 1974) and by LBL (this report) in hot waters of Kyle, Leach, Buffalo Valley, and Beowawe hot springs shows good agreement. Fair concordance exists between USGS (Mariner et al., 1975) and LBL trace-element determinations, where Br, Rb, Cs, Fe, and Mn results can be compared.

B. Analytical Methods

1. Rocks

Both the NAA and XRF analysis methods were originally designed for rock analysis and many of the precisions, accuracies and pit-falls are known. The NAA precisions (mainly the counting statistics) are demonstrated in column #1 on Table 9 (Buffalo Valley Rocks). The error values for other entries in Table 9 have been omitted to save space. To convert these precisions to accuracies one has to fold in the accuracies of the standard (Perlman and Asaro, 1969). In the upper part of Table 9 we show the major elemental oxide abundances of the Buffalo Valley rock samples. Most of these entries were obtained by XRF analysis; the Na and Fe were taken from NAA. The precision for the XRF data has been omitted since it is not as well understood.

The overall accuracy depends indirectly on the USGS rock standards' accuracy. This method uses four of the USGS standards to calibrate a secondary standard material so that the overall accuracies involve the accuracies of standard rocks BCR-1, AGV-1, DTS-1, PCC-1 and G-2.

2. Water Evaporates

Any transfer of solutions from the collecting bottles to other containers can lead to fractionation losses. Evaporation from open dishes can lead to material losses. Fractionation can even occur within the collection bottle during evaporation. In our method we: (1) evaporate the solution in the collecting bottle, (2) cut the bottles in half, (3) remove the evaporate from inside surfaces, and (4) use this material to scrub off the wall of the top section. Step (4) is optional when the residue is less than 50 mg. The evaporates are remixed and stored in air tight containers. The reproducibilities of this method with artificial samples can approach 1%. With field-collected samples the uncertainties are probably greater. The four separate analyses for Buffalo Valley Hot Springs (Table 7) demonstrate this reproducibility quite well. In Table 7 we have given averages and RMS deviations for each element measured in the hot spring waters. The one-sigma deviations for Na, Rb, and Cs are 2.2%, 3.8% and 3.2% respectively. A plot of Cs vs. Na (Fig. 11) for all of the hot water samples suggests that even this small variation at Buffalo Valley hot springs may be real and not statistical.

3. Single Water Drops

The XRF analyses of single drops of spring waters pipetted onto lexan discs gave good results for the elements Ca and K, but rather poor results

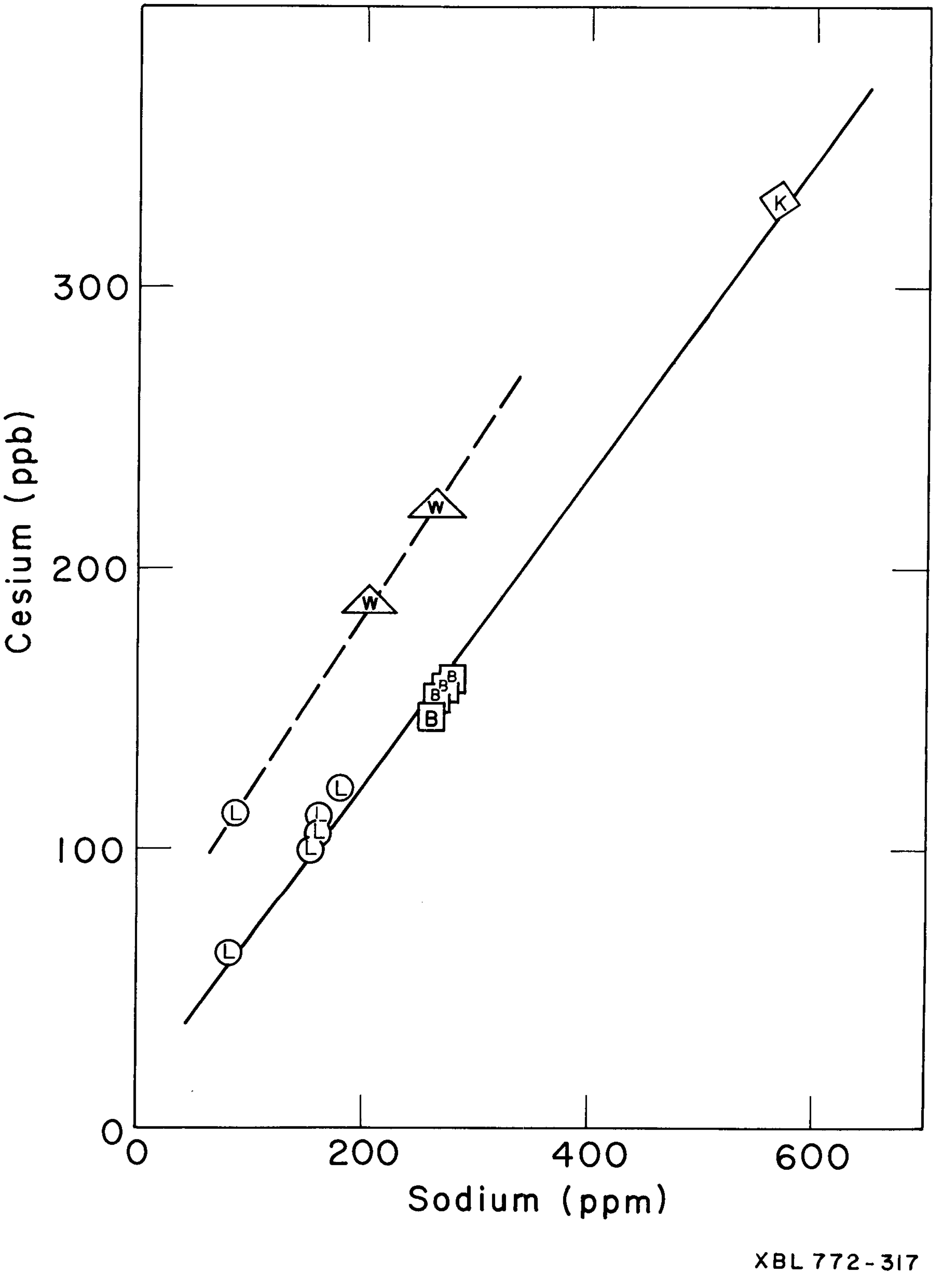


Fig. 11. Cesium *versus* sodium in hot waters from Beowawe (W), Buffalo Valley (B), Leach (L), and Kyle (K) hot springs.

for Na and SiO_2 (10-20% errors). The Na variations were probably related to variations in x-ray absorption in the sample, and the SiO_2 difficulties were related to the SiO_2 background in the lexan. Analyzing multiple samples of the same waters reduced these variations considerably.

In general we avoided using single-drop data in the tables of this report, except for some of the cold spring waters where the residues were small and multiple runs could be made. This method is presently being reexamined to see if we can obtain higher precisions. One of our new approaches is to use freeze-dried water-drops on pure copper foils.

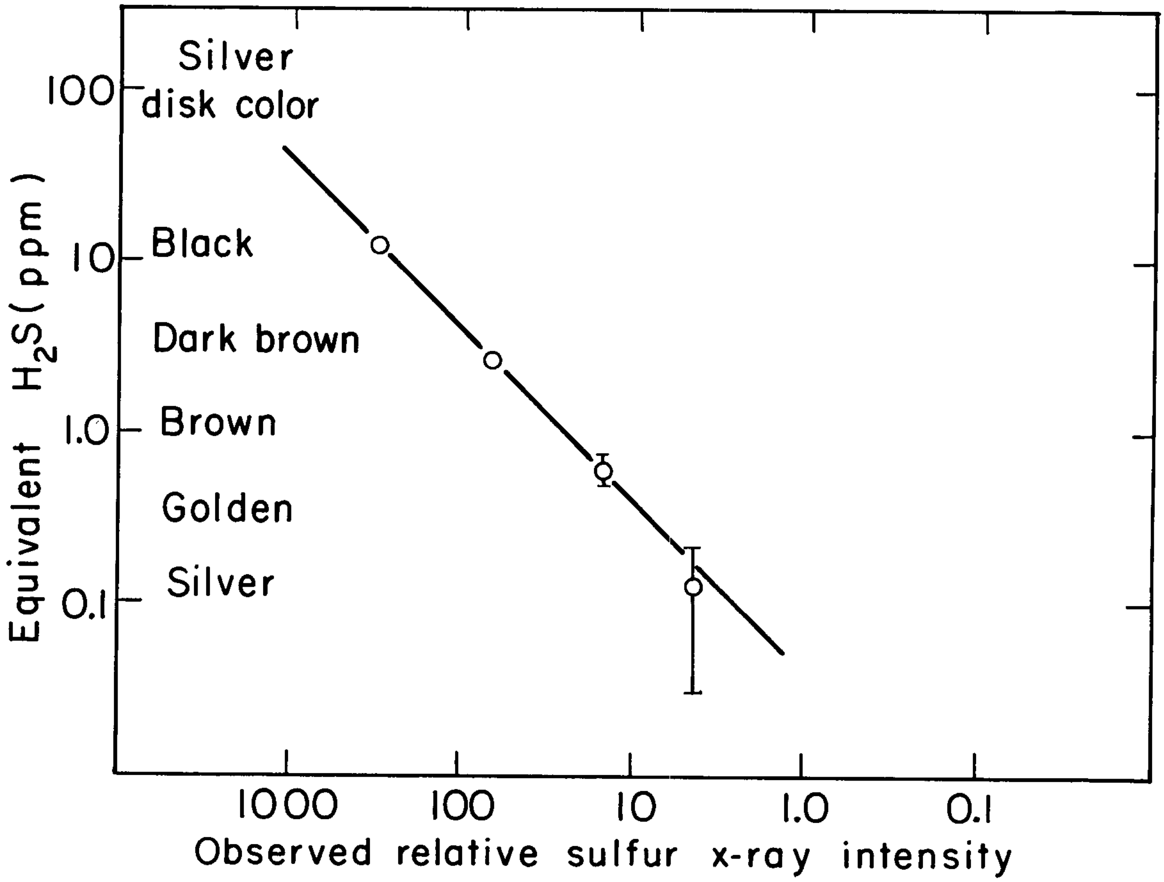
4. Relative Sufide Measurement (H_2S)

This method (Hebert, 1976) gives good reproducibility for the sulfide taken out of solution by placing a silver-plated disc into a bottle of spring water. Later, the sulfur abundance of the discs is analyzed by XRF in the laboratory. Calibration discs are obtained by spiking distilled water samples with aliquots of a saturated solution of hydrogen sulfide and introducing a silver disc for one day.

A typical calibration curve is shown in Fig. 12. In Fig. 13 we show the relative sulfide abundance measured in the four hot springs areas plotted against the reciprocal chemical geothermometer temperatures. It may be possible to develop a color tone comparison procedure to test for relative sulfide in the field (Hebert, 1976).

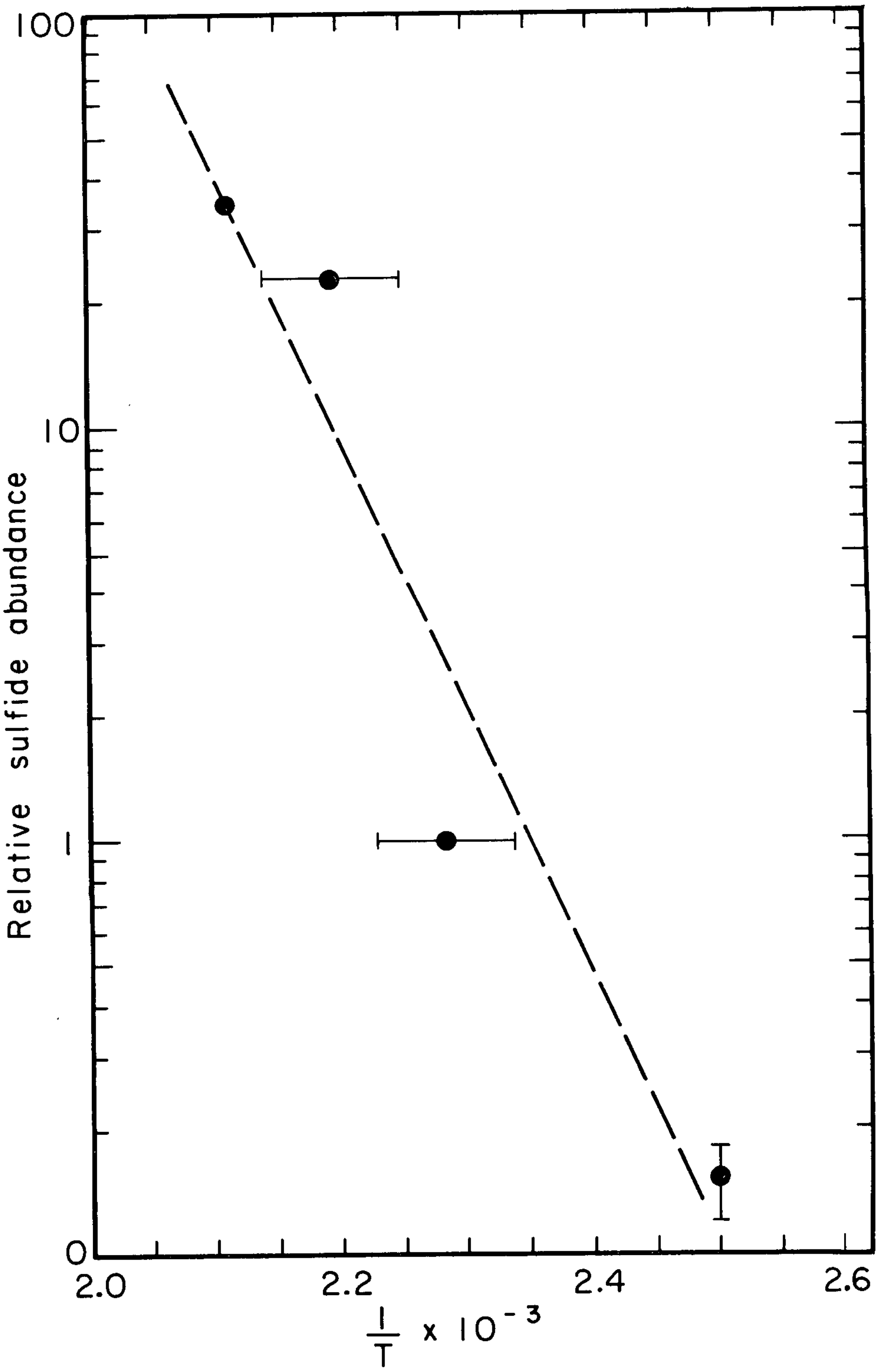
C. Mixing Calculations

We estimated the subsurface temperatures of unmixed hot water and fractions of mixed cold water at Kyle, Leach, and Buffalo hot springs, using the method of Fournier and Truesdell (1974). We assumed that the temperature and chemistry of cold spring waters in the



XBL776-1291

Fig. 12. Calibration curve for silver disc XRF method of H_2S determination.



XBL776-1293

Fig. 13. Relative sulfide abundance in the four hot springs *versus* estimated subsurface reservoir temperatures, based on the Na/K/Ca geothermometer of Fournier and Truesdell (1973).

hydrologic regions surrounding the hot springs represented the temperature and chemistry of cold water which might be mixing with hot water at depth in the hydrothermal systems. The graphical method of Fournier and Truesdell was used, resulting in the temperatures and fractions listed on Table 14. The temperatures calculated by this method for unmixed hot water at Kyle and Leach hot springs (275 and 250°C respectively) are probably too high, given their estimated chemical geothermometer temperatures, and most likely represent an upper limit to the possible hot water temperatures. On the other hand, the 180°C calculated for unmixed hot water at Buffalo Valley appears more in keeping with the temperature estimated for that system by chemical geothermometry.

Application of the same mixing model to conditions at Beowawe did not result in a unique solution; the curves for silica and enthalpy failed to intersect at a discrete temperature and cold-water fraction. According to Fournier and Truesdell (1974), this may be the case if steam escapes from the hot water before mixing, or if excess silica is dissolved by the warm spring water. Therefore, the temperature and cold-water fractions were recalculated, using Fournier and Truesdell's model #2. Resulting temperature and cold-water fraction are listed on Table 14. The temperature calculated in this manner (200°C) agrees closely with that estimated by chemical geothermometry and measured in the nearby wells, suggesting that, at Beowawe, very little cold water mixes near the surface with hot water.

Table 14. Parameters for and results of mixing calculations for the hot springs.

Location	Cold Water		Hot Spring Water		Estimated*	
	Temp. (°C)	SiO_2 (ppm)	Temp. (°C)	SiO_2 (ppm)	Temp. of Unmixed Hot Water (°C)	Fraction of Cold water (%)
Kyle Hot Springs	12	20	77	155	275	77
Leach Hot Springs	12.5	20	75	136.5	250	75
Buffalo V. Hot Sprs.	15	18	69	76	180	68
Beowawe Hot Sprs.	12	30	83	315	200	8.4

*Estimates for Kyle, Leach, and Buffalo Valley based on Fournier and Truesdell's (1974) mixing model #1; Beowawe estimates are based on model #2.

D. Possible Tungsten Geothermometers

Examination of the tables of trace-element contents in warm and cold waters indicates that a correlation exists between the tungsten contents of hot-spring waters and their subsurface temperatures, estimated by silica and alkali-element geothermometers (Mariner et al., 1974). However, there are appreciable variations in W content of individual pools at Leach Hot Springs. At that site W averages 89 ± 43 ppm, with relatively low values in the pools where some boiling occurs (95°C); the warm, non-boiling pools have considerably higher W values. In contrast, at Buffalo Valley where pool temperatures are all below boiling and are fairly uniform, W contents are also fairly uniform and average 29 ± 4 ppm.

Tungsten contents are plotted vs estimated reservoir temperature, together with a linear least-squares fitted line, on Fig. 14. The standard deviations of W at Leach, Buffalo Valley and Beowawe are shown by the horizontal error bars; the vertical bars for Leach and Kyle illustrate the range in estimated temperatures for those spring systems. Based on the observation that most of the cold springs have small but detectable W contents, one suspects that an exponential curve may better fit the data.

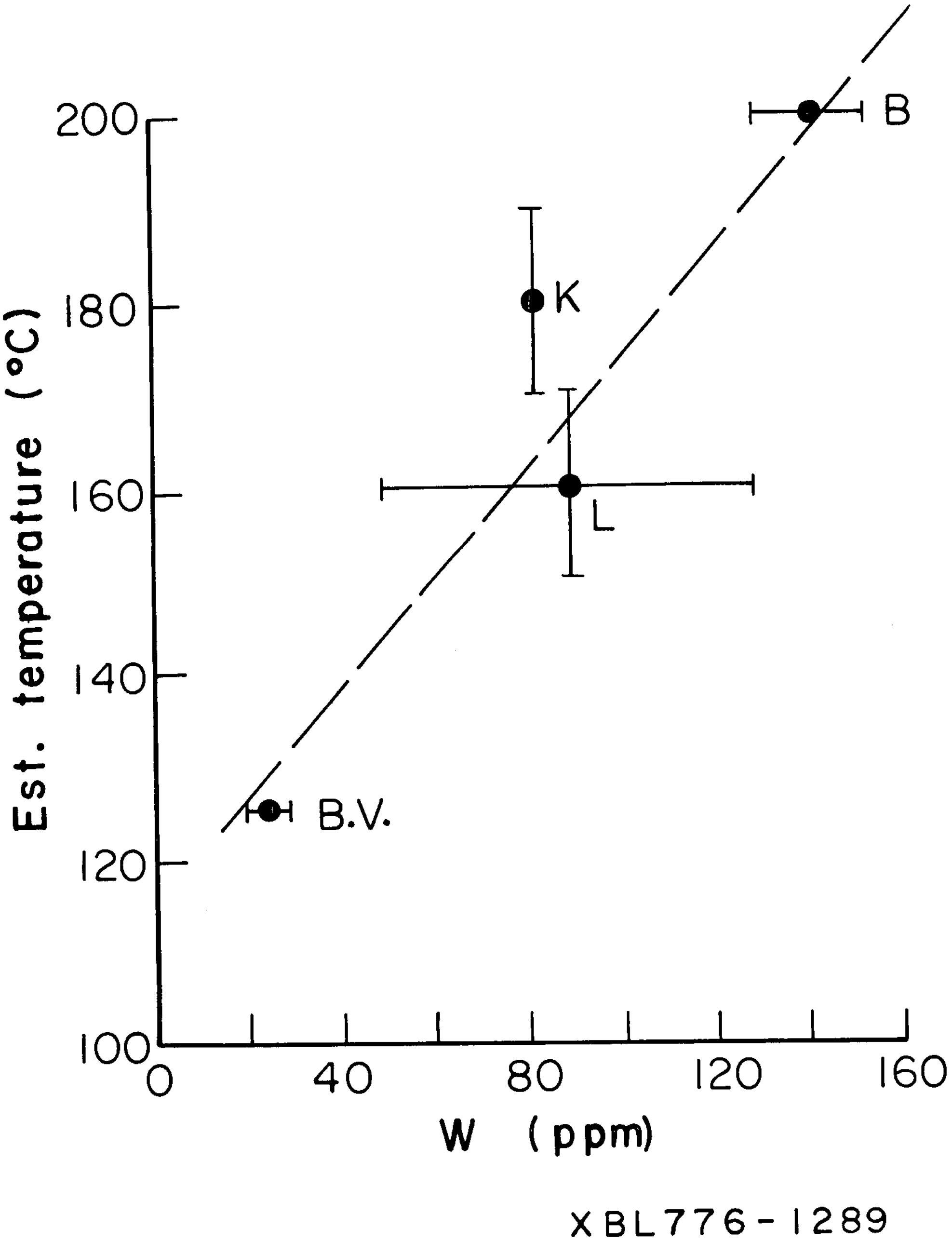


Fig. 14. Variation of tungsten content with estimated reservoir temperatures at the four hot springs.

E. Radioelement Considerations

1. Apparent Concentration of Uranium

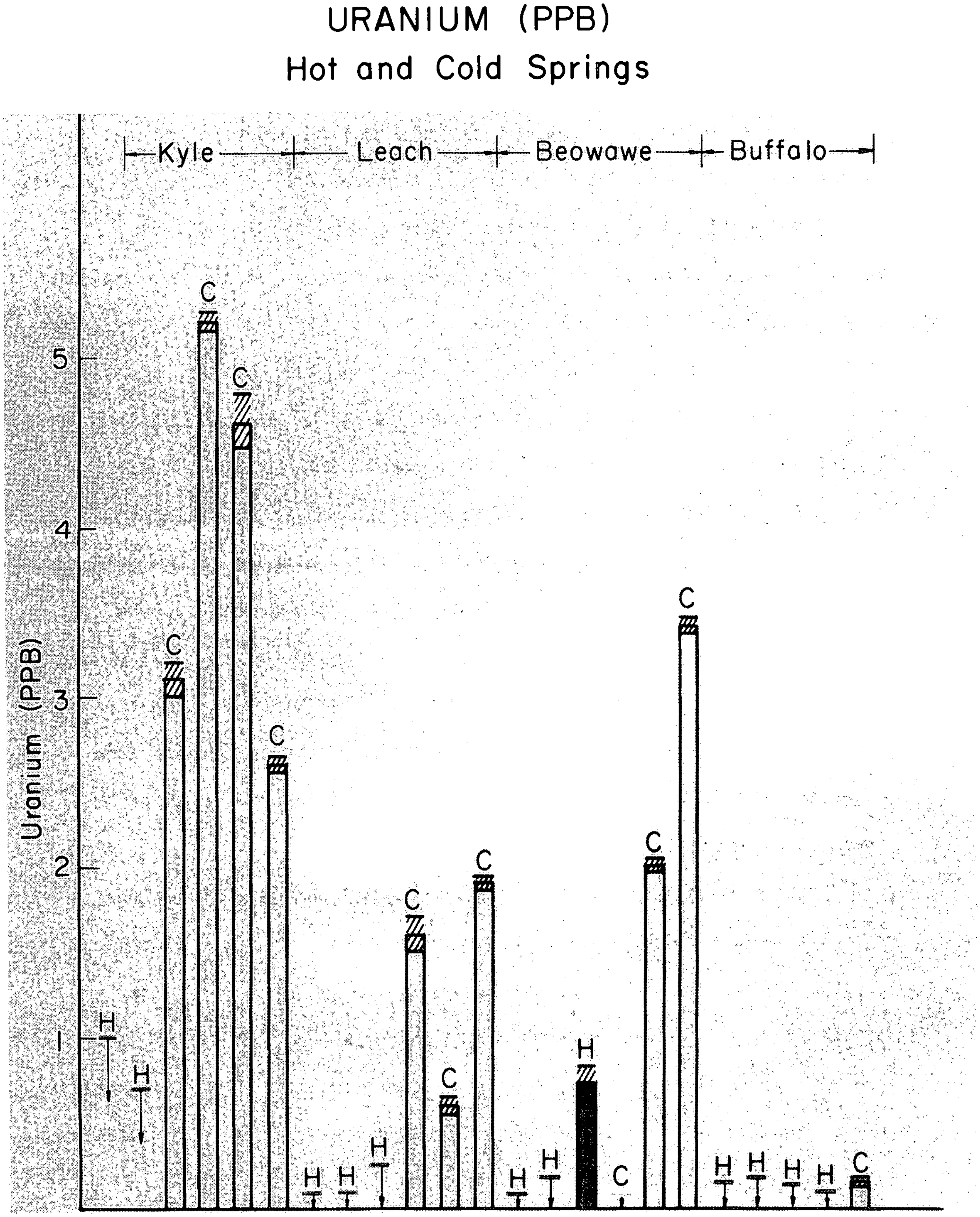
Examination of the trace-element contents of hot- and cold-spring waters sampled in this study indicates that the hot waters are essentially devoid of uranium,* while the cold waters contain appreciable U. Yet, the hot waters, especially at Kyle and Buffalo Valley hot springs, contain uranium daughter elements. The bar-chart, Fig. 15, illustrates the ranges of uranium concentration in hot and cold springs.

The amount of U which may be concentrating at depth within the individual hot spring systems is the product of the flow rate times the difference between hot- and cold-spring U contents. This calculation is based on the assumptions that the U content of the cold springs represents the U content of the cold ground water recharging the convecting geothermal systems, and that the spring systems' flow rates are constant. From the tabulated trace-element data for the country rocks we see that U contents of bedrock terranes range from a few to over 10 ppm, sufficient to provide the few ppb measured in the cold waters.

Average cold-spring U contents are listed on Table 15 together with flow rates and calculated deposition rates. With the exception of the acid pool at Beowawe, hot-spring U contents are below the detection limits of the neutron-activation system. Therefore, for the purpose of U-deposition calculations, U contents of the hot springs are estimated to be at the detection limits. Given the above assumptions,

---

*This may not always be the case: O'Connell and Kaufmann (1976) have detected both ^{234}U and ^{238}U in warm-spring waters of the western U.S.



CBB 747-4760

Fig. 15. Uranium abundances (ppb) in hot and cold springs at the four geothermal areas in north-central Nevada. C - cold springs, H - hot springs; tails of vertical arrows indicate detection limits.

Table 15. Estimation of uranium deposition rates of the hot-spring systems.

Location	Mean U in Cold Water (ppb)	Est. U in Hot Water (ppb)	Flow Rate[a] (ml/yr)	U Deposition (g/yr)
Kyle Hot Springs	3.5	0.7	1.05×10^{10}	2.9×10^{1}
Leach Hot Springs	1.3	0.1	4.8×10^{11}	5.8×10^{2}
Buffalo Valley	1.15	0.1	1.1×10^{11}	2.4×10^{2}
Beowawe[b]	0.8	0.3	5.3×10^{10}	2.6×10^{1}

[a] From Olmsted et al., (1975) for Buffalo Valley and Leach; Mariner et al., (1974) for Kyle and Beowawe.

[b] Cold spring U based on Crescent Valley spring data.

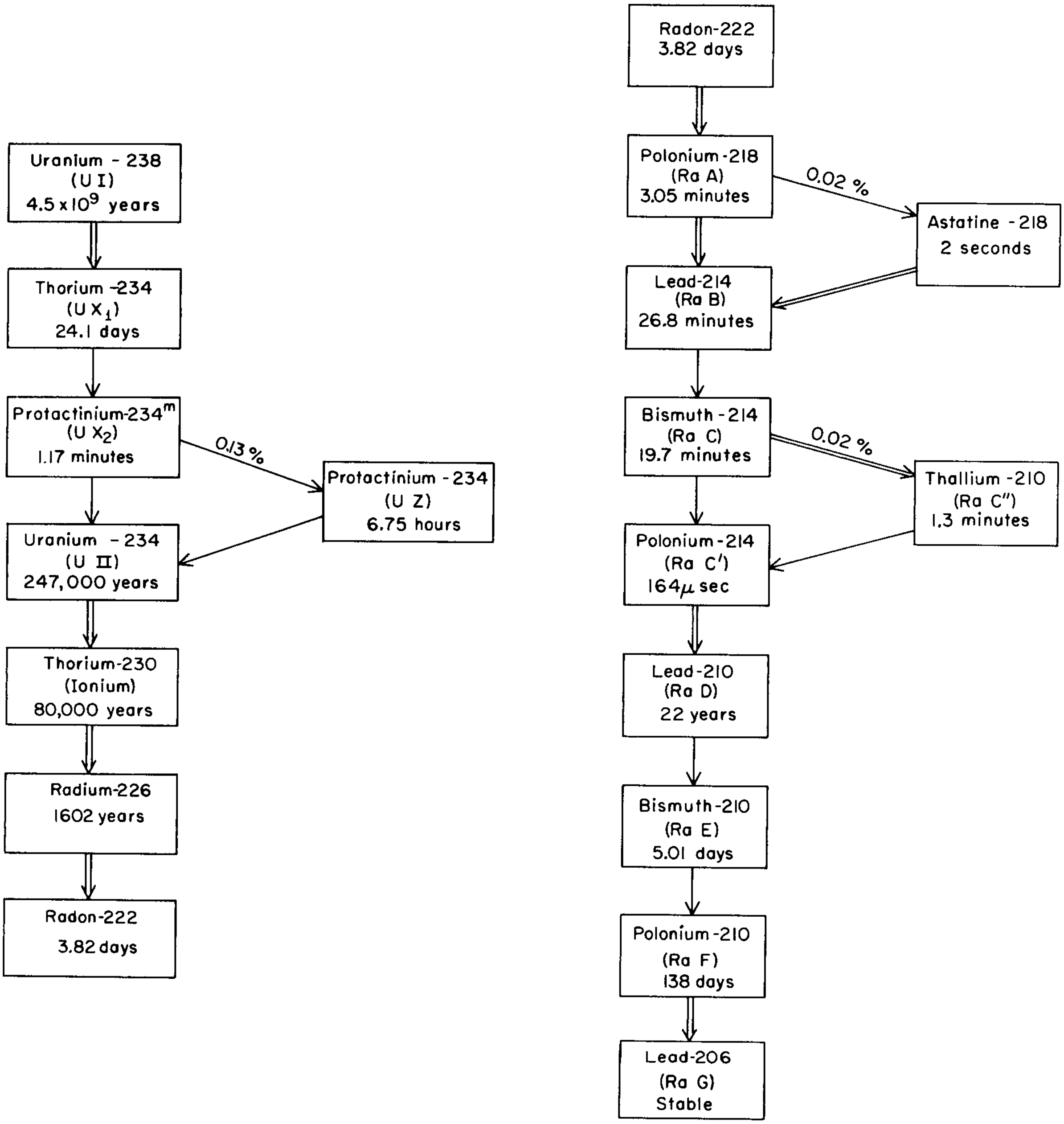
we see that several tens to several hundred grams of uranium may be deposited per year in the hot spring systems.

The mechanism of concentration may be twofold. Uranium, as the uranyl (U^{+6}) ion, is fairly mobile in an oxidizing environment. Uranyl carbonate may be transported in groundwater into a geothermal system where it is reduced to U^{+4} in a reducing environment afforded in large part by H_2S, a ubiquitous component of hot springs. Uranyl carbonate, as is the case with most carbonates, has retrograde solubility; it precipitates at high temperature (Blake et al., 1956). Thus, the presence of a high-temperature, reducing environment favors concentration of U, as it is reduced from U^{+6} to U^{+4}, and the carbonate is precipitated.

2. Age of the Hot Spring Systems

Based on the evidence that uranium is concentrating in the hot spring systems, knowledge of the U content of the cold-spring waters and of the radium-226 content of the hot spring waters permits one to estimate the age of a hot-spring system. (For guidance, the uranium decay series is shown on Fig. 16.) However, it must be assumed that:

1) the flow of the spring system and its uranium abundance has been constant.
2) the radium content of the cold water is negligible,
3) uranium is in secular equilibrium with its other daughter elements,
4) the uranium content of the hot water is negligible,
5) all the radium observed in the hot spring waters is from radioactive decay of the uranium deposited at depth, and represents all of the Ra produced,



XBL741-2101

Fig. 16. The uranium decay series, indicating half lives.

6) there has been no near-surface contamination or dilution of the hot spring water,

7) ^{234}Th and ^{230}Th are quantitatively removed from the hot water at depth.

The age of the system can then be calculated from the equation

$$T = \frac{Ra}{U\lambda_{Ra}} \tag{1}$$

where: T is the apparent age of the system, Ra is the radium content observed in the hot spring waters, U is the difference between uranium measured in the cold water and that estimated in the hot water (Table 15), and λ_{Ra} is the radioactive decay constant of radium-226.

Results of such calculations for Kyle and Buffalo Valley hot springs are listed on Table 16. The radium content of the hot waters was determined radiochemically, incorporating precipitation by barium sulfate. To simplify the calculations, the radium content was converted to equivalent uranium, as indicated on Table 16.

If Th is depleted in the cold or hot waters, there will be significant departures from Eq. (1). If ^{230}Th is depleted in the cold water but all other conditions (1-7) are the same, the age can be obtained from the equation:

$$Tu/T_{Io} = 1-f(1-e^{-\lambda_{Io}T_{Io}})/(\lambda_{Io}T_{Io}) \tag{2}$$

where Tu is the age calculated from Eq. (1), f is the fraction of the uranium in the cold water which is not in equilibrium with

Table 16. Estimated minimum ages of the hot spring systems.

Location	Difference Between U in Cold Water and Hot Water (ppb)	Ra Content of Hot Water (pCi/l)	Ra (Equiv. U) in Hot Water (ppb)	Age of Spring System (Years) a	b
Kyle Hot Springs	2.8	8.9	25	20600	78000
Leach Hot Springs	1.2	< 1.4	< 4	(see text)	
Buffalo V. Hot Sprs.	1.05	7.9	22	48400	126000

[a] Age assuming ^{230}Th is in equilibrium with ^{238}U in the cold water.

[b] Age using Fig. 17, assuming cold water has essentially no ^{230}Th.

^{230}Th(I_O), λ_{I_O} is the decay constant of ^{230}Th expressed in reciprocal years, and T_{I_O} is the age of the geothermal system. The ratio T_{I_O}/Tu is given in Fig. 17 as a function of Tu and f. Large increases in the calculated age occur for younger systems with cold water depleted in ^{230}Th. The three areas studied all have very large depletions of ^{232}Th in the cold water, and presumably have nearly comparable depletions of ^{230}Th.

If condition 7 is not met and ^{230}Th is present in the hot water, then it will contribute a component to the age which is given by Eq. (1) with ^{230}Th values substituted for those of ^{226}Ra. Thus, without data on ^{230}Th, the calculated ages are lower limits. If condition 5 is not met and some ^{226}Ra remains at depth, then it will contribute a component to the age which is also given by Eq. (1) with ^{222}Rn values substituted for those of ^{226}Ra. In addition, if ^{230}Th is depleted in the cold water, then an equation in the form of Eq. (2) must be used for the radon component.

The situation at Leach Hot Springs warrants some brief discussion. As shown on Table 16 radium contents at Leach are below detection limits, yet the cold waters contain appreciable uranium. Thus, U which is leached from the rocks by cold water is probably deposited in the geothermal system. The radioactivity of ^{234}U may be enhanced with respect to its parent, ^{238}U, but ^{234}U has not been measured in the cold waters. In Table 16 the ^{226}Ra content of the hot water at Leach is given as less than 1.4 pCi/l. If there were no ^{230}Th or ^{226}Rn in the hot water, the calculated age would be less than 7200 y. This value, however, would be effected by Th depletion in the cold

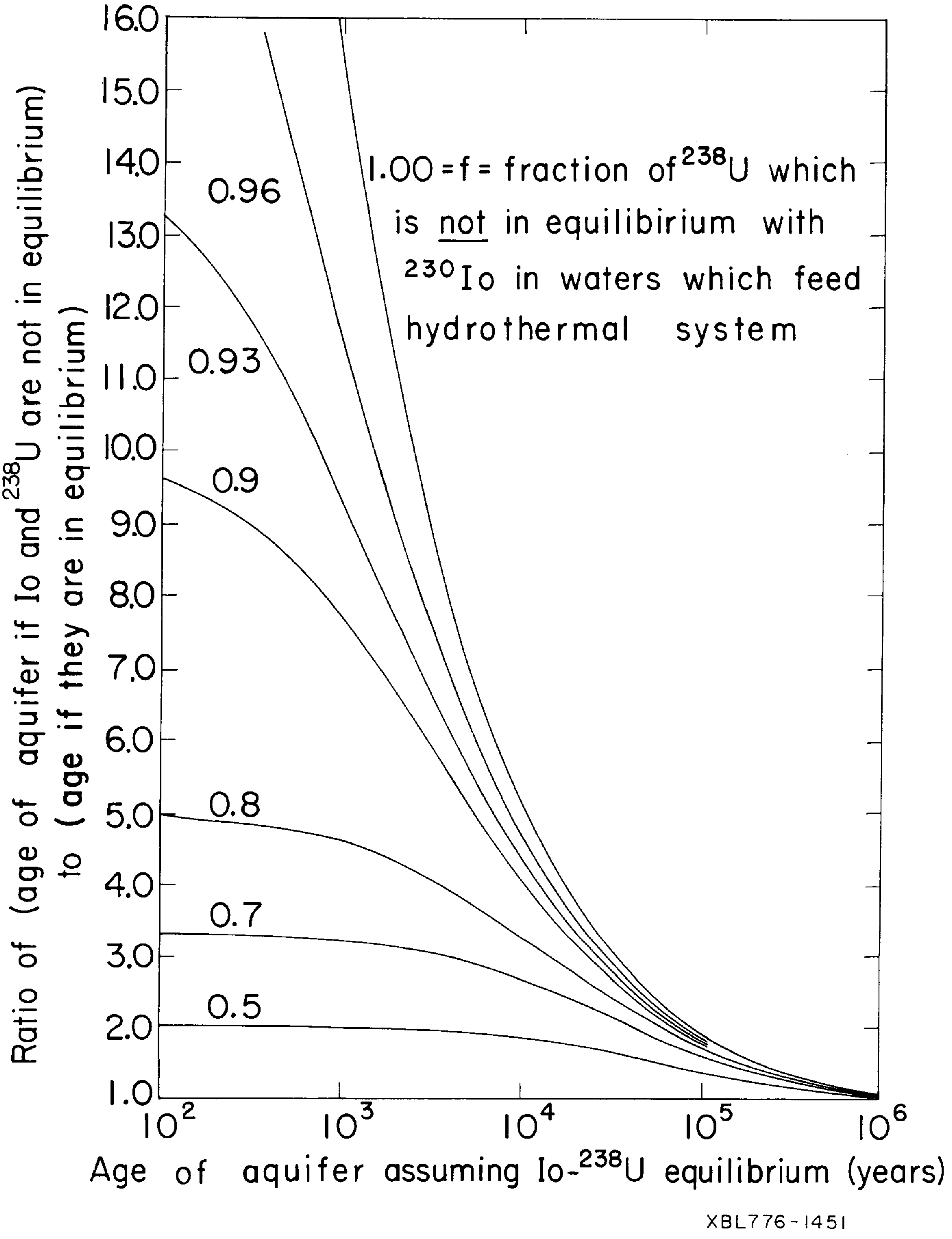


Fig. 17. T_{Io}/Tu as a function of Tu and f.

water. Fortunately, some detailed data on the radioactivities of Leach Hot Spring water was reported by O'Connell and Kaufmann (1976): ^{230}Th 0.97 ± 0.34 pCi/l, ^{226}Ra 0.33 ± 0.14 pCi/l, and ^{222}Rn 41 ± 17 pCi/l. From these values the relative contributions of ^{230}Th, ^{226}Ra, and ^{222}Rn, expressed as pCi/l, are 7.8×10^4, 5.3×10^2, and 0.43, respectively. Only ^{230}Th is significant, and the age of the spring system, using a form of Eq. (1), is 3.1×10^5 y. If ^{234}Th is rapidly removed from the uranium at depth by the hot water and transported to the surface, the age of the system could be much greater than this value.

CONCLUSIONS

Though this report is essentially a presentation and discussion of analytical data, some conclusions can be drawn. They are briefly listed:

1. Sampling methods, combined with neutron-activation and non-dispersive XRF analyses, give accurate trace- and major-element abundances in rocks and waters.
2. Uranium and molybdenum appear to be in greater concentration in cold springs than in hot springs, while other trace elements are generally more abundant in the hot springs. The springs depositing $CaCO_3$, Kyle and Buffalo Valley, are considerably more radioactive than the silica-dominated springs of Beowawe and Leach. The relatively high concentration of barium in the Beowawe region is reflected in the chemistries of the hot and cold waters of Whirlwind Valley.
3. Mixing model calculations estimated temperatures well in excess of 200°C for unmixed water at Leach and Kyle. These are probably too high, in light of spring water chemistries. The model-calculated temperature, 200°C, of unmixed hot water at Beowawe is close to that determined by alkali-element geothermometry, indicating little near-surface mixing of hot and cold water. The 180°C calculated for unmixed hot water at Buffalo Valley is within the range estimated by alkali-element geothermometers (Mariner et al., 1974).
4. Contents of tungsten and dissolved H_2S in hot-spring waters may be indicative of subsurface temperature.

5. Uranium is probably concentrating in hot spring systems, on the order of tens of grams per year. If appropriate assumptions are met, a knowledge of uranium parent and daughter isotope abundances may provide sufficient data to estimate the age of the systems.

ACKNOWLEDGMENTS

The reactor irradiations were done at the U. C. Berkeley Triga Reactor. Most of the x-ray fluorescence analyses were made by Alvin Hebert, and many of the radiometric measurements were performed by Alan Smith. We gratefully acknowledge the help of Don Noble, Gail Mahood, Helen Michel, and Silvia Stevenson. We wish to thank Robert O. Fournier and Alfred Truesdell of U.S.G.S. for providing some of the water samples that were used in our early test experiments.

REFERENCES

Beyer, J.H., A. Dey, A. Liaw, E. Majer, T.V. Mc Evilly, H.F. Morrison, and H.A. Wollenberg, 1976, Preliminary open file report, Geological and geophysical studies in Grass Valley, Nevada, Lawrence Berkeley Lab. Rept., LBL-5262.

Blake, C.A., C.F. Coleman, K.B. Brown, D.G. Hill, R.S. Lowrie, and and J.M. Schmidt, 1956, Studies in the carbonate-uranium system; Jour. Amer. Chem Soc., v. 78, p. 5978.

Bowman, H., A. Hebert, H. Wollenberg, and F. Asaro, 1976, Trace, minor, and major elements in geothermal waters and associated rock formations (north-central Nevada), Proc. Second U.N. Symposium on the development and use of geothermal resources, San Francisco.

Bowman, H.R., H.A. Wollenberg, F. Asaro, and A. Hebert, 1977, Sampling and analysis of hot and cold spring waters and associated rock and soil samples from potential geothermal resource areas in north-central Nevada, Proc. Second U.S. EPA Workshop on sampling and analysis of geothermal effluents, Las Vegas.

Fournier, R.O., and A.H. Truesdell, 1974, Geochemical indicators of subsurface temperature, U.S. Geol. Surv. Jour. of Research, v.2, no. 3.

Fournier, R.O., and A.H. Truesdell, 1973, An empirical Na-K-Ca geothermometer for natural waters, Geoch. et Cosmoch. Acta, v. 37, p. 1255.

Goldstein, N.E., H. Beyer, R. Corwin, D.E. di Somma, E. Majer, T.V. Mc Evilly, H.F. Morrison, and H.A. Wollenberg, 1976, Open file report, geoscience studies in Buena Vista Valley, Nevada, Lawrence Berkeley Lab. Rept., LBL-5913.

Hebert, A., and H. Bowman, 1976, Non-dispersive soft X-ray fluorescence analyses of rocks and waters, Proc. Second U.N. Symposium on the development and use of geothermal resources, San Francisco.

Hebert, A., 1976, Sulfide levels in natural waters; a possible new geothermometer, Lawrence Berkeley Lab. Report., LBL-5259.

Hose, R.K., and B.E. Taylor, 1974, Geothermal systems of northern Nevada, U.S. Geol. Surv. open file rept. 74-271.

Mariner, R.H., J. B. Rapp, L.M. Willey, and T.S. Presser, 1974. The chemical composition and estimated minimim thermal reservoir temperatures of the principal hot springs of northern and central Nevada, U.S. Geol. Surv. open file rept., 1974.

Mariner, R.H., T.S. Presser, J.B. Rapp, and L.M. Willey, 1975, The minor and trace elements, gas and isotope compositions of the principal hot springs of Nevada and Oregon, U.S. Geol. Surv. open file rept., 1975.

McKee, E.H., 1970, Fish Creek Mountains tuff and volcanic center, Lander County, Nevada. U.S. Geol. Surv. Prof. Paper 681.

O'Connell, M.F., and R.F. Kaufmann, 1976, Radioactivity associated with geothermal waters in the western United States; basic data, U.S.E.P.A. Tech. Note ORP/LV-75-8A.

Olmstead, F.H., P.A. Glancy, J.R. Harrill, F.E. Rush, and A.S. Van Denburgh, 1975, Preliminary hydrologic appraisal of selected hydrothermal systems in northern and central Nevada, U.S. Geol. Surv. open file report. 75-56.

Perlman, I., and F. Asaro, 1969, Pottery analysis by neutron activation, Archaeometry, v. 11, p. 21-52.

Sass, J.H., A.H. Lachenbruch, R.G. Munroe, G.W. Greene, and T.H. Moses, Jr., Heat flow in the western United States, J. Geophys. Res., v. 76, p. 6376.

Sass, J.H., F.H. Olmsted, M.L. Sorey, H.A. Wollenberg, A.H. Lachenbruch, R.J. Munroe, and S.P. Galanis, Jr., Geothermal data from test wells drilled in Grass Valley and Buffalo Valley, Nevada, U.S. Geol. Surv. open file report. 76-85, and Lawrence Berkeley Lab. Rept. LBL-4489.

Wollenberg, H.A., 1974a, Radioactivity of Nevada hot spring systems, Geophys. Res. Let., v. 1, p. 359.

Wollenberg, H.A., 1974b, Radon alpha-track survey of a potential geothermal resource area, Lawrence Berkeley Lab. Rept. LBL-3225.

Wollenberg, H.A., 1975, Sampling hot springs for radioactive and trace elements, Proc. U.S. EPA Workshop on sampling geothermal effluents, Las Vegas.

Wollenberg, H.A., F. Asaro, H. Bowman, T. V. McEvilly, H.F. Morrison and P. Witherspoon, 1975, Geothermal energy resource assessment, Lawrence Berkeley Lab. Rept. UCID-3762.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720