Geochemical Baselines of Stream and Spring Waters and Rankings of the Potential Release of Total Dissolved Solids and Resistance to Introduced Acidity from Watersheds Underlain by Four Rock Compositional Types from the Humboldt River Basin, Nevada

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Open-File Report 00-161

2000

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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Introduction

When precipitation, as rain and snow, falls within a watershed, water comes into contact with rock minerals and chemical weathering is initiated. These processes release elements to the natural waters of a watershed. Therefore the chemical composition of natural waters that evolve within a watershed, in the absence anthropogenic input, is determined mostly by the chemical composition of rocks within the basin. Biota activity in the soil zone concentrates CO_2, and biota may concentrate elements (or species). Other factors such as rates of mechanical erosion, grain size and crystallinity of the rock minerals, amount and distribution of precipitation, temperature, and type and amount of vegetation influence mainly the rates of the water-rock reactions, but the chemical composition of the rocks is the fundamental factor which determines the type of waters which evolve within a headwater watershed (Miller, 1999). This natural baseline geochemistry of the natural waters of a watershed can be modified by input from anthropogenic processes such as nuclear fallout, atmospheric emission, or mining wastes. There is probably no place in the world in which the background composition of waters of an area has not been modified to some extent by anthropogenic processes; the effects of these processes are always superimposed on the background geochemistry. But areas, particularly headwater areas within public lands, can be selected which are only minimally affected by anthropogenic input. The distribution of water available in streams and springs in these headwater watersheds is uneven throughout the year with high flows during the spring runoff and after summer thunderstorms. In the winter, water available in streams and springs reaches a minimum when element concentrations are high but mass flux is low. At this time, runoff is fed mainly by the recession of the groundwater reservoir. Geochemical baselines, at a particular point in time, can be determined for stream and spring waters in these headwater watersheds, and may approximate the background geochemistry. This information is useful for an understanding of the processes responsible for the chemical composition of waters of a watershed and because water geochemistry is sensitive to changes in the environment, by monitoring water geochemistry in these watersheds and comparing the results to the earlier geochemical baseline data, changes within the watershed can be detected. This geochemical baseline is an approximation of the background and if remediation is needed in the future because of anthropogenic contamination, this baseline is the ideal goal. Note that it is not feasible to require chemical quality standards lower than this natural baseline, as a lower quality standard than the natural baseline would be difficult to impossible to achieve.

The purpose of this study is to determine the range of elements (or species) and other geochemical parameters in order to characterize the baseline geochemistry of stream and spring waters evolving within headwater watersheds for several of the major rock compositional types in the Humboldt River Basin, Nevada (referred to as the Humboldt Basin in the remaining text). Limited time for field collection allowed the characterization of waters from four rock compositional types. Only watersheds that have not been impacted significantly by anthropogenic processes such as mining were selected for sampling. Processes responsible for the control and mobility of the elements in the natural waters were also investigated. Geochemical baselines of waters from the four rock types demonstrate the importance of rock composition in determining the types of waters evolving in these headwater watersheds.

In late Spring, 1998, 37 water samples were collected from streams and springs mostly in the Humboldt Basin but also in a few sites in watersheds adjacent to the Humboldt Basin. A limitation of the investigation is that only four rock compositional types, which make up no more than 20 % of the rock compositional types in the Humboldt Basin, were adequately characterize.

Study Area

The study area is located in north-central Nevada (fig. 1). The Humboldt Basin occurs within the Great Basin region of the Basin and Range physiographic province (Hunt, 1974) and is characterized by long narrow mountain ranges separated by broad flat valleys. The mountain ranges and intermountain basins generally trend north-south. The Humboldt Basin is a closed basin that drains to the Humboldt Sink in the western part of the basin. Dendritic drainage patterns are well developed and most of the sampled watersheds are of moderate to high relief. Altitudes range between 3900 to 11,800 feet above sea level. Annual precipitation ranges from as little as 4 to 8 inches in a few watersheds to 8-16 inches in most of the area (Houghton and others, 1975). Some of the higher mountain ranges receive greater than 16 inches, mainly as snow during the winter.

Because of the large differences in altitude, the climate varies from sub-humid continental with moderate precipitation and cold winters in the higher elevations to semi-arid mid-latitude steppe with cold winters and hot summers in the lower elevations. The natural vegetation in the study area is strongly zoned by altitude. The mountain ranges consist of ponderosa or limber pine and the basins, in order of abundance, sagebrush, wheatgrass, greasewood, shadscale, or salt flats with no vegetation (Kuchler, 1964).

Geology

The complex geologic history of the Humboldt Basin consists of episodes of sedimentation, igneous activity, orogenic deformation, and continental rifting. Detailed descriptions of the geology and geologic history of the Humboldt Basin can be found in Roberts and others (1967), Stewart and McKee (1977), Stewart (1980), and Coats (1987). Based on these references, a brief summary follows. Ages of rocks in the Humboldt Basin range from late Proterozoic to Holocene. Paleozoic formations were laid down in a broad geosyncline and later folded in late Devonian and Mississippian time. The oceanic siliceous and volcanic assemblage rocks were moved eastward into juxtaposition with the eastern shelf carbonate assemblage rocks along the Roberts Mountain thrust. The sea retreated and plutonic and volcanic activity began in Mesozoic time. Plutonic rocks are felsic to intermediate in composition and range from Jurassic to late Tertiary in age. Eocene to Miocene time was dominated by voluminous eruptions of ignimbrites, less voluminous exogenous domes of silicic rocks, and intermediate and mafic flows and pyroclastic deposits. Quaternary alluvium partly fills the valleys and extends up the flanks of mountain ranges. Basin and Range structure of block-faulted mountain ranges characterizes the present-day physiography.

Methods

Generally small streams were sampled, usually with a watershed area of around several square miles, although some watersheds are larger. Springs within the watershed were also sampled. Both stream and spring sites were chosen to represent each of the four major rock composition types.

Samples of water were collected from 23 streams and 14 spring sites within the study area during May 21 to May 26, 1998. The waters were collected after peak runoff had occurred but prior to the streams reaching base flow or in some cases, drying up completely. Except for the first day, during the time of sampling, the weather was stable and no precipitation occurred. Samples were collected by width and depth integration (Edwards and Glysson, 1988) or from a point source for springs. Temperature, pH, and conductivity were measured at the site. pH was measured using an Orion model 250 pH meter with an Orion Ross Sure-Flow electrode. Temperature was measured with a temperture

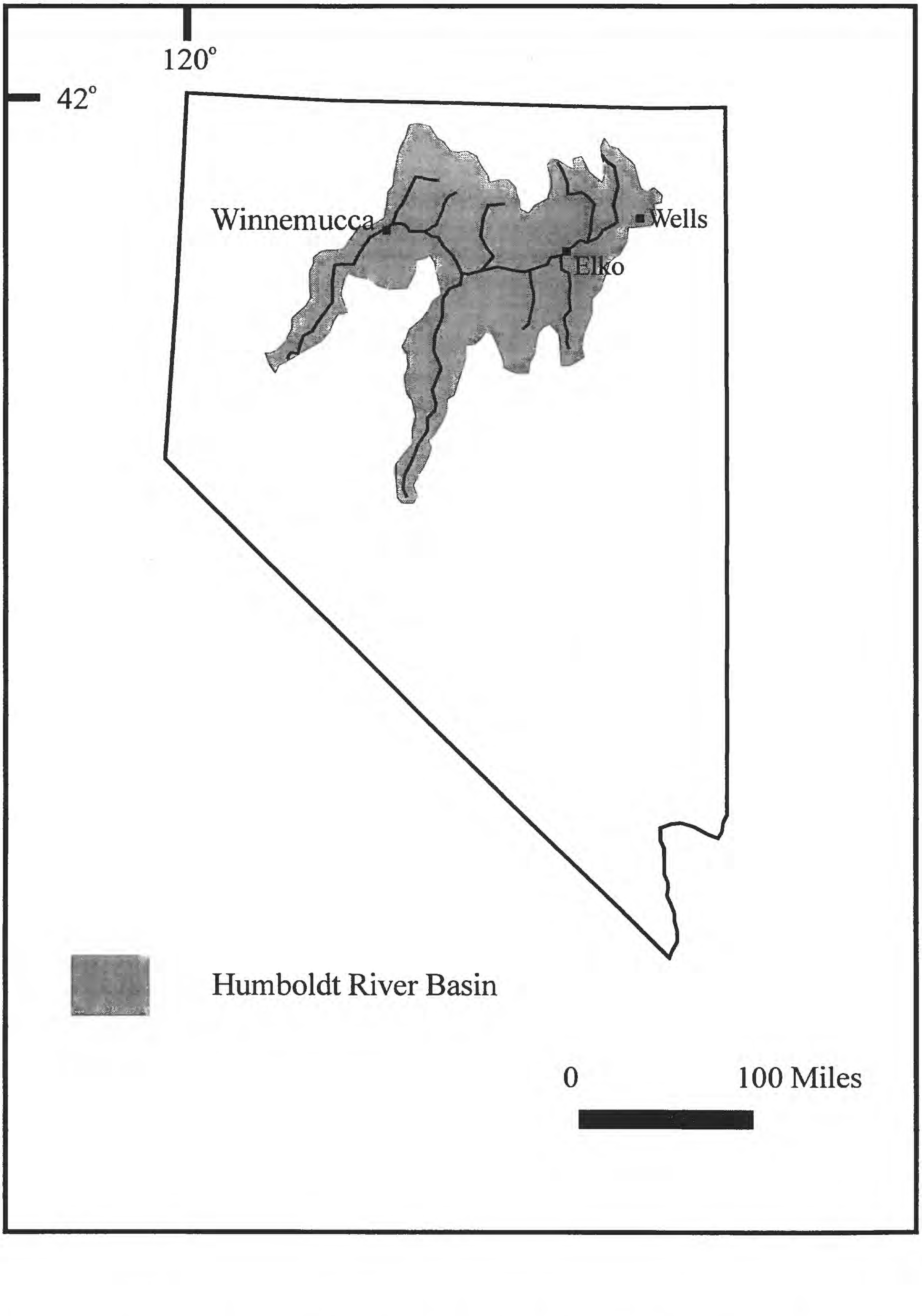

Figure 1. Map showing location of the Humboldt River Basin, Nevada.

probe. The conductivity was measured using an Orion model 120 conductivity meter. Samples were collected into high-density polyethylene bottles. For the dissolved cation analyses, a sample was filtered at the site through a 0.45 μm-membrane filter and acidified with ultrapure reagent-grade Ultrex nitric acid to $pH < 2$. Another sample was filtered but not acidified for anion analyses and an unfiltered, unacidified sample was collected for alkalinity measurement. The samples were stored in an ice chest and later in a refrigerator and kept cool until analyzed.

Upon return to the laboratory, alkalinity as HCO_3^-, was determined by titration with H_2SO_4 using Gran's plot technique (Orion Research, Inc.,1978). Sulfate, chloride, nitrate, and fluoride concentrations were determined by ion chromatography (IC) (Fishman and Pyen, 1979). Cations were analyzed by inductively coupled plasma - atomic emission spectrometry (ICP-AES) or inductively coupled plasma - mass spectromentry (ICP-MS). IC, ICP-AES, and alkalinity analyses were performed by Murdock Environmental Laboratory, University of Montana, Missoula, The ICP-MS analyses were performed by ACTLABS, Wheatridge, CO. Duplicate water samples, blank samples, and USGS Water Resource Division standard reference waters were analyzed with each data set. The chemical analyses with dates of collection, location, rock type of basin, water type, flow data, and comments are shown for all sites in appendix 1.

Results

Water samples were collected from springs and small streams from watersheds that were within, or at a few sites adjacent to the Humboldt Basin. The watersheds are headwaters that are not impacted by mining. Sample sites were selected from watersheds underlain by the four major rock compositional types. These four rock compositional types are Tertiary felsic ash-flow tuff, Tertiary basalt and basaltic andesite, Mississippian Chainman Shale, and Paleozoic and Mesozoic siliceous and volcanic assemblage rocks (Table 1). One sample each was collected from watersheds underlain by quartz monzonite and predominately siltstone. Because of the limited samples, these rock types are not included in the following discussion, but the chemical analyses can be found in appendix 1. Samples of spring and stream waters were collected from 35 sites from watersheds underlain by the four rock compositional types. A summary of the mean geochemical data of waters collected within each of the four major rock compositional types is shown in Table 2.

Felsic ash-flow tuffs

Water samples were collected from two springs and one stream in an area underlain by Caetano Tuff along the western flank of the Toiyabe Range west of Mount Callaghan (fig. 2) and two springs in an area underlain by Bates Mountain Tuff along the western flank of the Shoshone Range west of Horse Mountain (fig. 3). The Caetano Tuff (Gilluly and Masursky, 1965) is mostly a rhyolitic crystal-rich welded ash-flow tuff of Oligocene age. The Bates Mountain Tuff (Stewart and McKee, 1968) is a widespread nonwelded to welded crystal-poor ash flow of quartz-latite composition of Miocene age (Stewart and McKee, 1977). The ranges and means of selected species in the waters are shown in Table 3. Four of the waters are Ca^{2+}- HCO_3^- type waters and one is a Na^+-Cl^- type water with slightly alkaline to moderately alkaline pH values and moderately high conductivity values. Mean value of pH is 7.50 and mean conductivity is 622 μS/cm. SiO_2 concentrations ranged from 9.2 to 27 mg/l with a mean of 17 μg/l. This mean SiO_2 value is slightly higher than average fresh water (Table 4) and are probably because of the felsic rock composition and the fine-grain size of the minerals which compose the rocks are more susceptible to weathering. Alkalinity values ranged from 89 to 276 mg/l as HCO_3^- with a mean of 183 mg/l. This moderately high mean value may be due to the longer contact time of the water and

Table 1. Four rock compositonal types in the Humboldt Basin, Nevada

Reference in manuscript	Age	Dominant Rock Composition Type	Setting
Felsic ash-flow tuff	Tertiary	rhyolitic and quartz latitic ash flow tuff	Toiyabe Range, Shoshone Range
Basalt and basaltic andesite	Tertiary	olivine basalt and basaltic andesite	Sheep Creek Range
Chainman Shale	Mississippian	black shale and siltstone, minor sandstone and conglomerate	Pinion Range
Siliceous and volcanic rocks	Mesozoic and Paleozoic	chert, argillite, shale, greenstone, quartzite, minor limestone, siltstone, siltstone, and conglomerate	Battle Mountain, Shoshone Range

Table 2. Summary of means of chemical data of each rock compositional type. All means are geometric means except pH which is arith

Dominant rock composition	n	pH	Conductivity	TDS[1]	Ca	Mg	Na	K	SiO_2	Alkalinity	SO_4
Felsic ash-flow tuff	5	7.50	622	314.9	53	11	34	5	17	183	41
Basalt and basaltic andesite	6	7.60	216	120.4	14	3.2	20	3.4	18	81	11
Chainman Shale	17	8.35	280	151.7	21	6.4	19	2.5	12	91	24
Siliceous and volcanic rock	7	8.39	333	173.7	31	7.2	22	1.9	12	105	30

[1] Total Dissolved Solids

etic.

Dominant rock composition	Cl	F	Nitrate	Al	Fe	Mn	Ba	Be	Li	Mo	Sr
Felsic ash-flow tuff	35	0.31	0.27	4.6	14	<0.3	66	<0.05	23	2.8	274
Basalt and basaltic andesite	7.5	0.28	0.3	179	126	3.3	54	<0.05	5.2	<1	120
Chainman Shale	9.5	0.22	0.29	42	52	3.3	128	<0.05	8.7	1.8	127
Siliceous and volcanic rock	14	0.24	<0.25	18	23	0.9	44	<0.05	4.8	3	146

Dominant rock composition	Ti	V	Zn	Sc	Cr	Co	Ni	Cu	Ga	Ge	As
Felsic ash-flow tuff	<2	3.9	0.28	7.1	4.7	0.1	1.6	0.2	<0.01	0.03	5.2
Basalt and basaltic andesite	4.9	3.1	0.34	6.9	1.2	0.1	0.75	0.69	0.03	0.02	1.9
Chainman Shale	2	5	0.33	4.1	1.3	0.1	1.7	1.2	0.02	<0.01	3.9
Siliceous and volcanic rock	<2	<2	0.33	4.4	2.5	0.1	1.1	0.84	<0.01	<0.01	6.8

Dominant rock composition	Se	Br	Rb	Y	Zr	Nb	Cd	In	Sn	Sb	I
Felsic ash-flow tuff	1.6	97	6.6	0.03	0.05	0.02	0.02	0.011	0.09	0.25	8.2
Basalt and basaltic andesite	0.33	31	1.8	0.16	0.39	0.03	0.02	<0.001	<0.05	0.15	4.4
Chainman Shale	1.5	45	0.68	0.09	0.22	0.02	0.04	<0.001	<0.05	0.3	5.5
Siliceous and volcanic rock	1.5	41	0.9	0.03	0.06	0.01	0.05	<0.001	<0.05	0.79	5.3

Dominant rock composition	Cs	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
Felsic ash-flow tuff	0.29	0.006	0.006	0.003	0.005	0.004	0.022	0.004	0.002	0.003	0.001
Basalt and basaltic andesite	0.021	0.126	0.281	0.033	0.147	0.032	0.019	0.04	0.004	0.03	0.004
Chainman Shale	0.012	0.058	0.112	0.017	0.069	0.019	0.039	0.019	0.003	0.016	0.003
Siliceous and volcanic rock	0.02	0.016	0.041	0.004	0.02	0.004	0.013	0.006	<0.001	0.003	<0.001

Dominant rock composition	Er	Tm	Yb	Lu	Hf	W	Re	Tl	Pb	Bi	Th	U
Felsic ash-flow tuff	0.002	0.001	0.003	0.002	0.016	0.25	0.011	0.008	0.11	0.21	0.12	3.1
Basalt and basaltic andesite	0.016	0.002	0.02	0.003	0.012	0.11	0.001	<0.01	0.11	0.15	0.081	0.2
Chainman Shale	0.009	0.001	0.009	0.001	0.014	0.1	0.006	<0.01	<0.1	0.04	0.085	0.45
Siliceous and volcanic rock	0.002	<0.001	0.002	<0.001	0.004	0.13	0.01	<0.01	<0.1	0.05	0.038	0.8

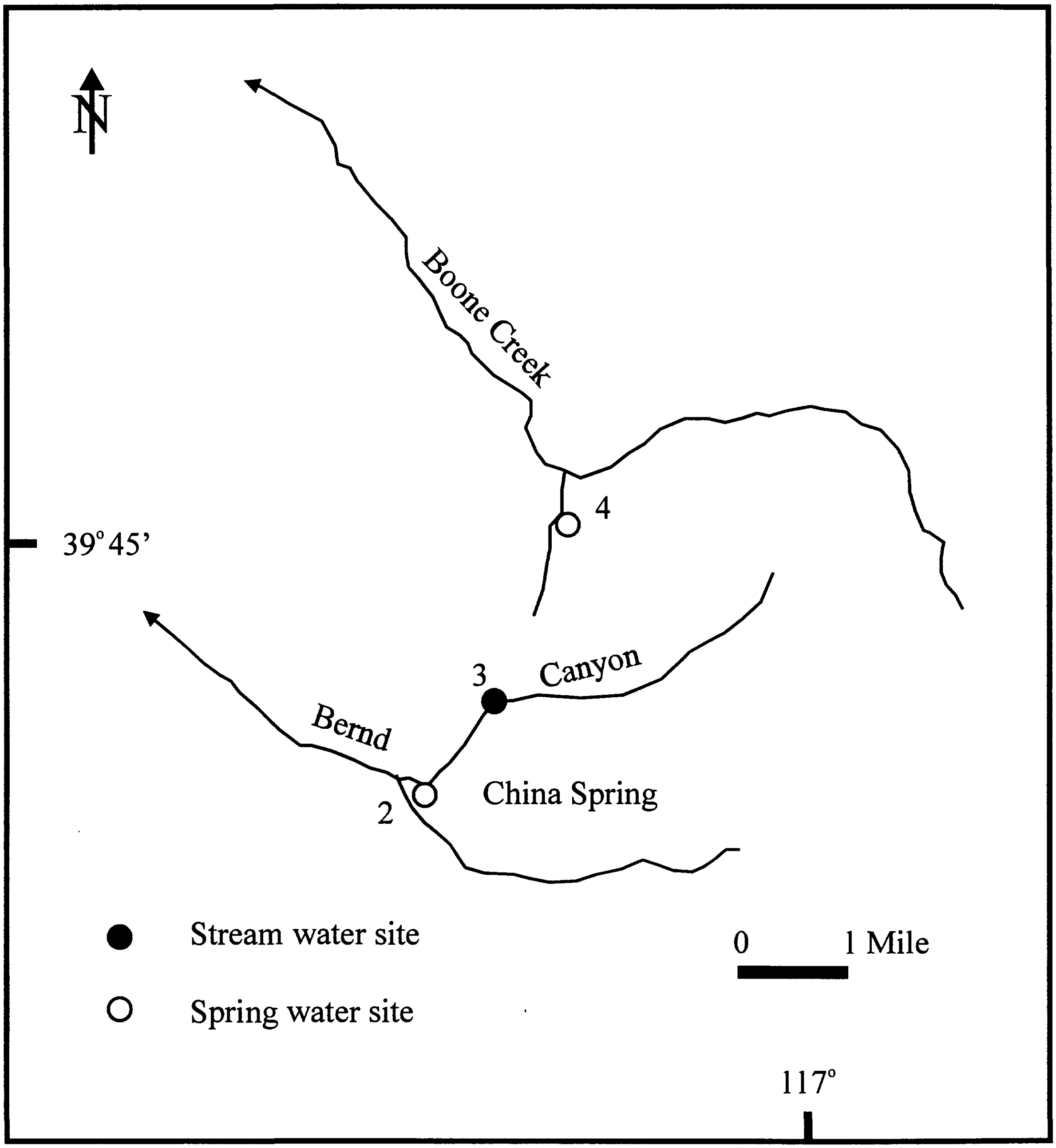

Figure 2. Site locations of stream and spring water samples (prefixed HB) from areas underlain by Oligocene rhyolitic ash-flow tuff.

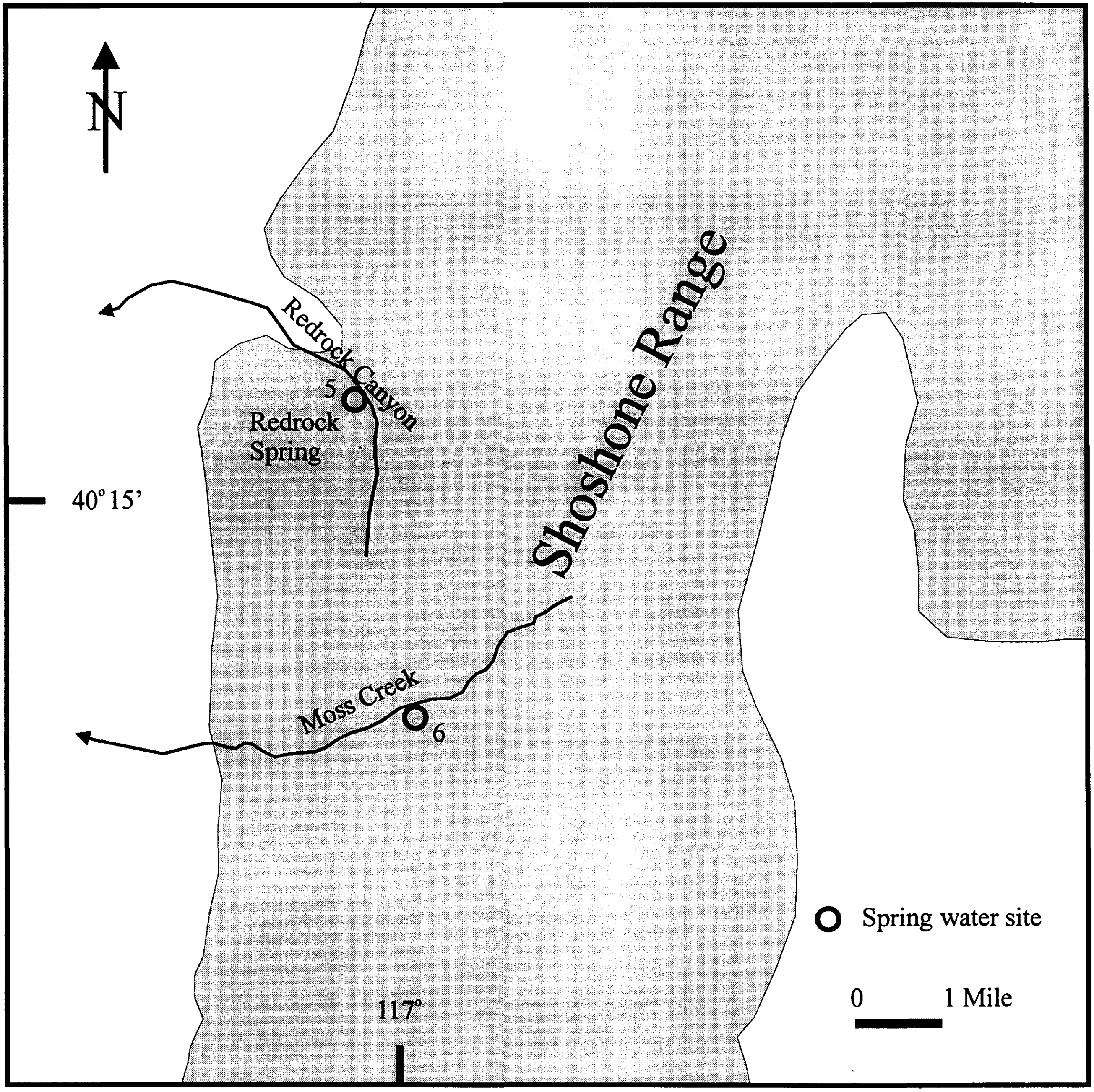

Figure 3. Site locations of spring water samples (prefixed HB) from areas underlain by Miocene quartz latite ash-flow tuff.

Table 3. Waters from four springs and and one stream from watersheds underlain by felsic ash-flow tuff

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	396	1155	622
pH	7.17	7.68	7.50
Ca	26.5	89	53
Mg	6.7	17.8	11
Na	19.9	126	34
K	2.2	9.4	5
SiO_2	9.2	27	17
Alkalinity	89	276	183
SO_4	23	134	41
Cl	14	161	35
F	0.17	1	0.31
Nitrate	<0.25	0.47	0.27
Al	<3	89	4.6
Fe	<5	60	14
Mn	<0.3	3	<0.3
Cu	<0.1	0.6	0.2
Zn	<0.2	1	0.28
Pb	<0.1	3.3	0.11
Mo	2	10	2.8
Sb	0.05	0.73	0.25
As	1.4	24	5.2
Cr	1.5	7.8	4.7
Ni	0.8	2.1	1.6
U	0.7	7.2	3.1
Li	7.2	81	23
Se	0.6	7.5	1.6
Br	52	351	97
Ba	32	109	66
Sr	153	367	274
V	<2	14	3.9
Rb	1	14.7	6.6

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, F and nitrate in mg/l, alkalinity in mg/l HCO_3^-, conductivity in µS/cm, remaining elements in µg/l

[2] All variables are geometric means except for pH which is arithmetic mean.

Table 4. Background of trace metals in freshwater and chemical analyses of mean river water

Background of trace metals (µg/l) in freshwater	
Element	Data after Forstner and Wittmann (1979)
Al	<30
Fe	<30
Mn	<5
Cu	1.8
Zn	10
As	2
Mo	1
Pb	0.2
Sb	0.1
Cr	0.5
Ni	0.3
Li	1
Se	0.1
U	0.5

Chemical analyses (mg/l) of mean river water	
Element in mg/l	Data from Livingstone (1963)
Ca	15
Mg	4.1
Na	6.3
K	2.3
SiO_2	13.1
SO_4	11.2
HCO_3	58.4
Cl	7.8

rock. Mean Cl content is 35 mg/l, which is high compared to the input of Cl in precipitation to the basin of less than 1 mg/l in rainfall (Junge and Werby, 1958). The high mean Cl value is probable due to the long residence time of the water in contact with the rocks and evaporation effects. Mean sulfate value of 41 mg/l is also elevated compared to average fresh water (Table 4). Mean concentrations of Mo, As, Cr, Ni, Li, Se, and U are 2.8, 5.2, 4.7, 1.6, 23, 1.6, and 3.1 µg/l, respectively, and are elevated compared to average fresh water (Table 4). Mean values of Zn and Cu are 0.28 and 0.2 µg/l, respectively, and are low compared to average fresh water. Site HB 05, Red Rock Spring, contains the most concentrated waters and is the only Na^+-Cl^- type water of this area. The high concentrations of Na and Cl may be due to input from thermal water in the subsurface. The concentrations of Fe, Li, Mo, As, SO_4, Br, and Se are also elevated compared to the other four samples. The longer contact time of the water and rock and evaporation processes favor moderately high alkalinity values. Waters from these areas underlain by felsic ash-flow tuffs, are of acceptable chemical quality.

Basalt and basaltic andesite

Water samples were collected from four springs in an area underlain by basaltic andesite and one spring and one stream from an area underlain by olivine basalt on the top and along the southern flank of Sheep Creek Range (fig.4). The top of Sheep Creek Range, just north of the town of Battle Mountain, is made up mostly of flows consisting of a lower unit of basaltic andesite of Miocene age and a upper unit of olivine basalt of Pliocene age (Stewart and McKee, 1977). The two units do not appear to be related and differ somewhat in chemical composition. Because of the close proximity of the two units, they are treated as one rock compositional type. The ranges and means of selected species in the waters are shown in Table 5. All the waters are Na^+- HCO_3^- type waters with slightly acidic to alkaline pH values and moderately low conductivity values. Mean value of pH is 7.60 and mean conductivity is 216 µS/cm. SiO_2 concentrations ranged from13 to 22 mg/l with a mean of 18 µg/l, which is higher than the average for fresh water (Table 4) and probably due to the fine-grained nature of the rocks which are more susceptible to weathering. Alkalinity values ranged from 67 to 96 mg/l as HCO_3^- with a mean of 81 mg/l. This moderately low mean value may be due to the shorter contact time of the water and rock along the top of Sheep Creek Range. Mean Cl content is 7.5 mg/l, which is low compared to the other waters from the study area and is probably due to the shorter residence time of the water in contact with the rocks and lower evaporation rates. Mean trace metal concentrations are low compared to average fresh water (Table 4), except for Cr, Ni, Li, and Se, which are 1.2, 0.75, 5.2, and 0.33 µg/l, respectively. Mean Zn, Cu, Mo, and As are 0.34, 0.69 , <1, and 1.9 µg/l, respectively. The concentrations of Fe and Al are high compared to average fresh water at 126 and 179 µg/l, respectively (Table 4). The shorter contact time of the water and rock favor moderately low alkalinity values compared to waters from the other rock types. Waters from this area, underlain by Tertiary basalt and basaltic andesite, are of acceptable chemical quality.

Chainman Shale

Water samples were collected from three springs and 8 streams in watersheds underlain predominantly by Mississippian Chainman Shale along Ferdelford Creek (fig.5) and two springs and four streams along the southwest flank of Grindstone Mountain, both in the Pinion Range (figs. 6). The watersheds are underlain by rocks of the Chainman Shale and minor Webb Formation and Diamond Peak Formation. These rocks are part of the Mississippian terrigeneous detrital province in a foreland basin (Coats, 1987). The Chainman Shale (Nolan and others, 1956) consists of pyritiferous marine black shales and siltstone with minor beds of sandstone and conglomerate. Based on fossils, the age is

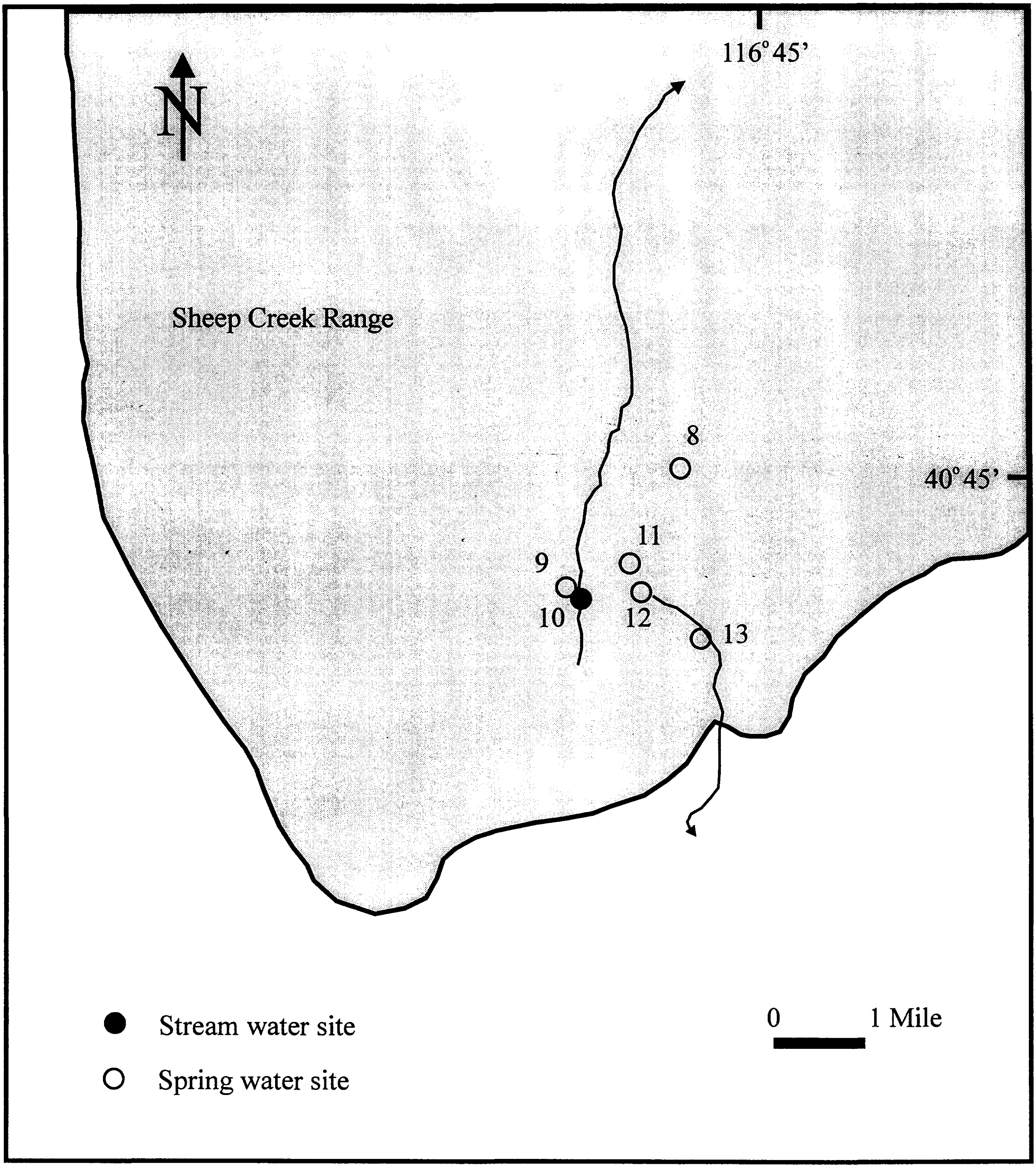

Figure 4. Site locations of steam and spring water samples from areas underlain by Pliocene olivine basalt and Miocene basaltic andesite.

Table 5. Waters from five springs and and one stream from watersheds underlain by basalt and basaltic andesite

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	165	327	216
pH	6.82	8.25	7.60
Ca	10.6	23.8	14
Mg	2.6	4.8	3.2
Na	15	26	20
K	1.8	6.8	3.4
SiO_2	13.1	22	18
Alkalinity	67	96	81
SO_4	7.8	25	11
Cl	5	21	7.5
F	0.19	0.52	0.28
Nitrate	<0.25	0.73	0.3
Al	59	1175	179
Fe	42	616	126
Mn	1.1	16.4	3.3
Cu	0.3	1.7	0.69
Zn	<0.2	11	0.34
Pb	<0.1	0.2	0.11
Mo	<1	2	<1
Sb	0.09	0.2	0.15
As	1.1	4.7	1.9
Cr	0.7	2.5	1.2
Ni	0.6	1.4	0.75
U	0.1	0.7	0.2
Li	2.8	12	5.2
Se	0.2	0.7	0.33
Br	20	69	31
Ba	37	72	54
Sr	98	150	120
V	<2	8	3.1
Rb	1.1	4.5	1.8

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, F and nitrate in mg/l, alkalinity in mg/l HCO_3^-, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

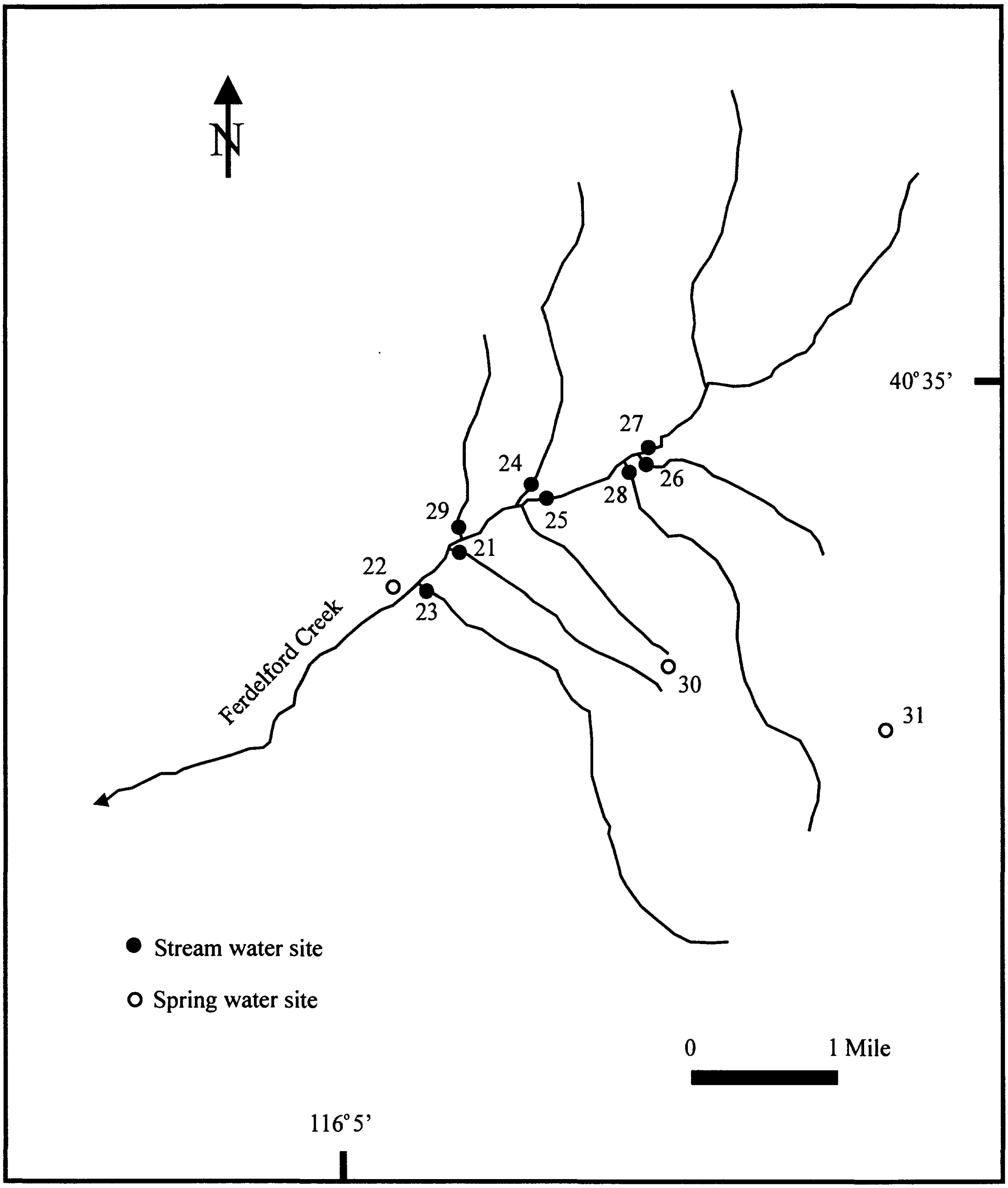

Figure 5. Site locations of steam and spring waters (prefixed HB) of areas underlain by Mississippian Chainman Shale and minor Webb and Diamond Peak Formations of mostly shale, but also minor sandstone, limestone, and conglomerate.

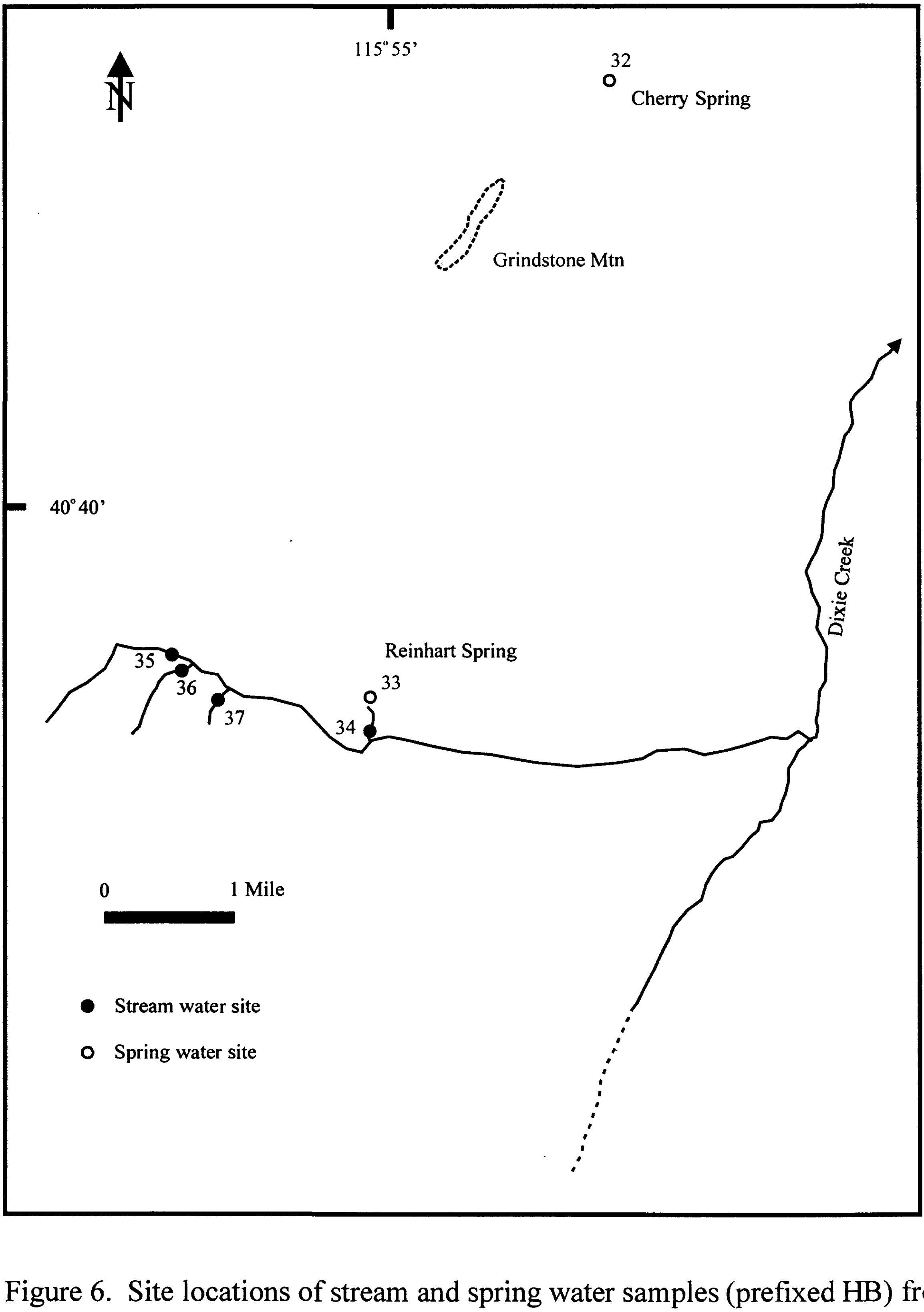

Figure 6. Site locations of stream and spring water samples (prefixed HB) from areas underlain by Mississippian Chainman Shale of mostly shale but also minor sandstone and locally calcareous zones.

probably Late Mississippian (Nolan and others, 1956). The Late Mississippian or possibly Pennsylvanian Diamond Peak Formation consists of siltstone, sandstone and conglomerate and conformably overlies and interfingers with the Chainman Shale (Nolan and others, 1956 and Brew, 1961). The Webb Formation (Smith and Ketner, 1968 and 1975) consists of mudstone and claystone with thin layers of sandstone and limestone. The formation is Early Mississippian in age and may be equivalent to the lowest part of the Chainman Formation (Smith and Ketner, 1968 and 1975). Both units represents only minor occurrences in the watersheds. The ranges and means of selected species in the waters are shown in Table 6. Eight of the waters are Ca^{2+}-HCO_3^- and nine are Na^+- HCO_3^- type waters with slightly alkaline to alkaline pH values and moderate to moderately high conductivity values. Mean value of pH is 8.35 and mean conductivity is 280 µS/cm. SiO_2 concentrations ranged from 7.3 to 19 mg/l with a mean of 12 µg/l, which is slightly lower in concentration than the average fresh water (Table 4). Sulfate concentrations ranged from 9.9 to 89 mg/l with a mean of 24 mg/l, which is elevated compared to fresh water (Table 4), probably because of the weathering pyrite present in the marine shale. Alkalinity values ranged from 37 to 209 mg/l as HCO_3^- with a mean of 91 mg/l. This moderately low mean value may be due to the shorter contact time of the water and rock and the presence of oxidizing pyrite present in the Chainman Formation which generates acidity and consumes some of the alkalinity. Mean Cl content is 9.5 mg/l, which is low compared to waters from two of the other rock types and is probably due to the shorter residence time of the water in contact with the rocks and lack of significant evaporation. Mean trace metal concentrations are elevated compared to average fresh water (Table4) for Mo, As, Cr, Ni, Li, and Se, which are 1.8, 3.9, 1.3, 1.7, 8.7, and 1.5 µg/l, respectively, probably because of the weathering pyrite present in the marine shale. Mean values of Cu and Zn are 1.2 and 0.33 µg/l. The mean concentrations of Al, Fe and Mn are 42, 52, and 3.3 µg/l. The Al and Fe concentrations are slightly elevated compared to average fresh water (Table 4). The shorter contact time of the water and rock and lack of significant evaporation and the presence of oxidizing pyrite favor moderately low alkalinity values. Waters from this area underlain by the Mississippian Chainman Shale are of acceptable chemical quality.

Siliceous and volcanic rocks

Water samples were collected from one spring and five streams in watersheds underlain mainly by the Havallah Sequence (Silbering and Roberts, 1962) along the northwestern and western flank of Battle Mountain (fig. 7). These eugeosynclinal rocks are part of a western Nevada siliceous and volcanic assemblage that were originally deposited west of the Antler orogenic belt and were thrust eastward as the upper plate of the Golconda thrust (Stewart and McKee, 1977). These rocks are Late Mississippian to Early Permian age and consist of chert, argillite, shale, greenstone, and minor siltstone, sandstone, conglomerate, and limestone (Steward and Carlson, 1978). In addition, water was collected from one stream along the western flank of the Shoshone Range (fig. 8) in a watershed underlain by Ordovician siliceous and volcanic rocks. These eugeosynclinal rocks have been moved eastward on the Roberts Mountain thrust and consist of chert, shale, quartzite, greenstone and minor limestone. Waters from both groups have been included because of similar composition. The ranges and means of selected species in the waters are shown in Table 7. Six of the waters are Ca^{2+}-HCO_3^- and one is a Na^+- HCO_3^- type waters with slightly alkaline to alkaline pH values and moderate to moderately high conductivity values. Mean value for pH is 8.38 and mean conductivity is 333 µS/cm. SiO_2 concentrations ranged from 11 to 15 mg/l with a mean of 12 µg/l, which is slightly lower in concentration than the average fresh water (Table 4). Sulfate concentrations ranged from 12 to 64 with a mean of 30 mg/l (Table 7) which is elevated compared to average fresh water (Table 4). The likely source of the sulfate is weathering pyrite. Alkalinity values ranged from 47 to 174 mg/l as HCO_3^- with a mean of 105 mg/l. Mean Cl content is 14

Table 6. Waters from five springs and 12 streams from watersheds underlain by Chainman Shale

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	142	663	280
pH	7.52	8.82	8.35
Ca	4.9	71	21
Mg	1.3	20	6.4
Na	7.5	71	19
K	0.2	9	2.5
SiO_2	7.3	19	12
Alkalinity	37	209	91
SO_4	9.9	89	24
Cl	2.7	39	9.5
F	<0.125	0.55	0.22
Nitrate	<0.25	1.2	0.29
Al	<3	1285	42
Fe	11	569	52
Mn	0.8	43	3.3
Cu	0.8	3.7	1.2
Zn	<0.2	10.9	0.33
Pb	<0.1	0.3	<0.1
Mo	<1	29	1.8
Sb	0.17	1.9	0.3
As	1.2	8.1	3.9
Cr	<0.1	5	1.3
Ni	0.7	11	1.7
U	0.1	2.5	0.45
Li	2	57	8.7
Se	0.4	9.2	1.5
Br	12	136	45
Ba	59	269	128
Sr	35	499	127
V	<2	25	5
Rb	0.2	1.4	0.68

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, F and nitrate in mg/l, alkalinity in mg/l HCO_3^-, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

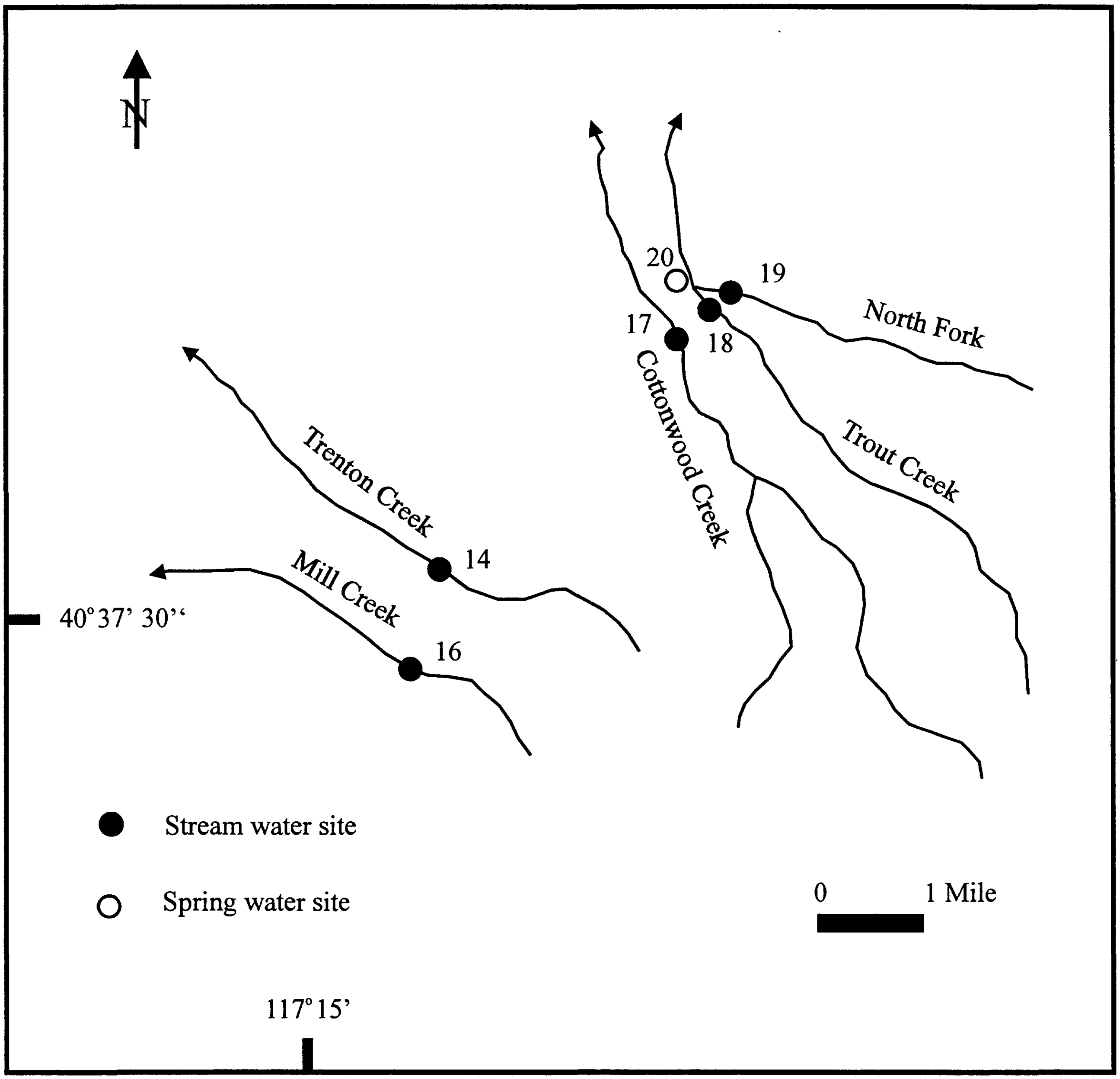

Figure 7. Site location of stream water sample (prefixed HB) from watershed underlain by Pennsylvanian and Permian Havallah Sequence of siliceous and volcanic rocks, of chert, quartzite, shale, sandstone, greenstone, lava, limestone, and conglomerate.

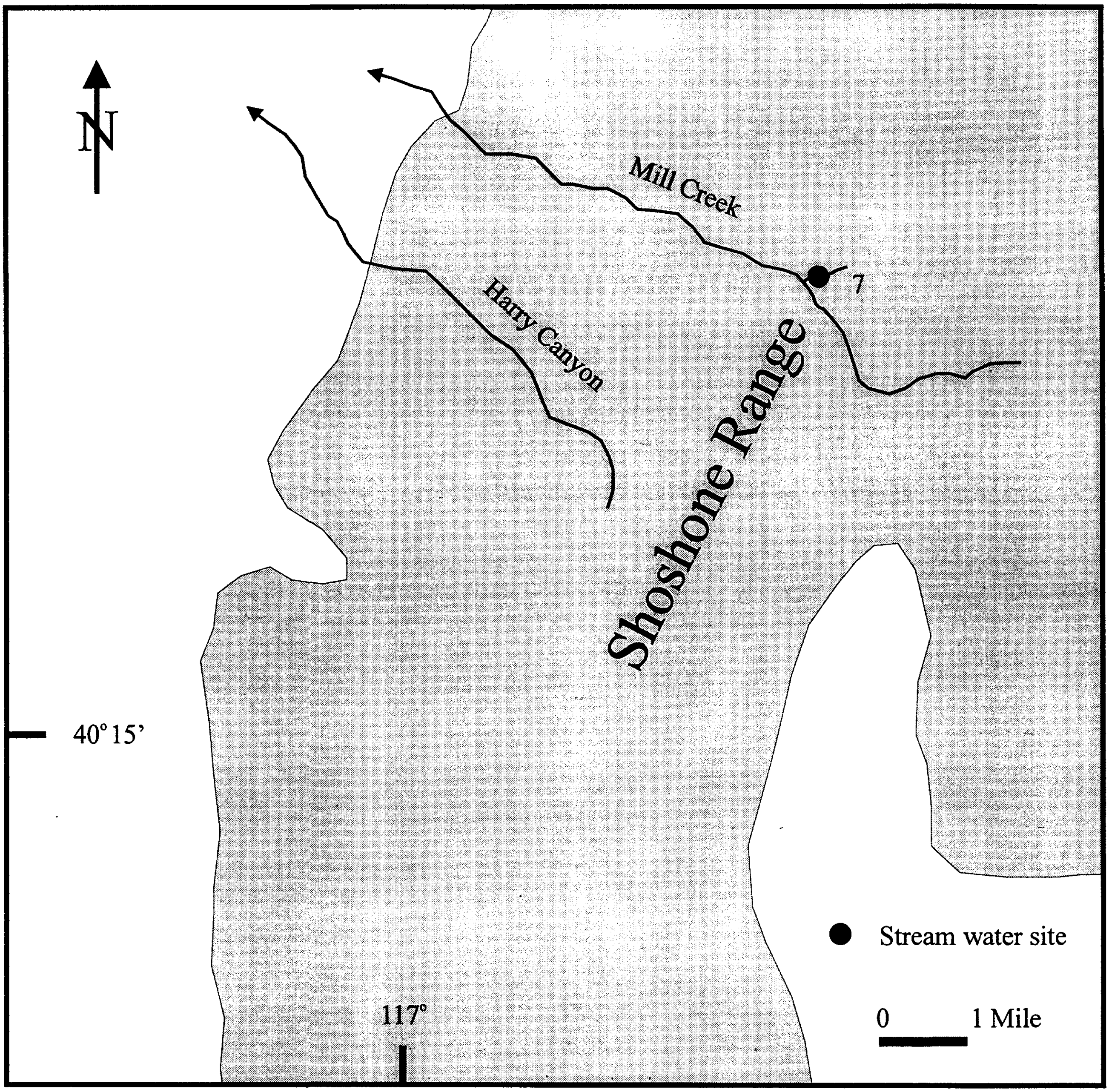

Figure 8. Site location of stream water samples (prefixed HB) from watershed underlain by Ordovician siliceous and volcanic rocks of chert, quartzite, shale, sandstone, greenstone, lava, limestone, and conglomerate.

Table 7. Waters from one spring and six streams from watersheds underlain by siliceous and volcanic rocks

Measurement[1]	Range		Mean[2]
	Minimum	Maximum	
Conductivity	217	524	333
pH	7.63	8.72	8.38
Ca	16	71	31
Mg	4.4	12	7.2
Na	15	33	22
K	1.6	2.7	1.9
SiO_2	11	15	12
Alkalinity	47	174	105
SO_4	12	64	30
Cl	7.5	24	14
F	0.14	0.4	0.24
Nitrate	<0.25	0.45	<0.25
Al	5	116	18
Fe	7	69	23
Mn	<0.3	4	0.9
Cu	0.3	1.9	0.84
Zn	<0.2	9	0.33
Pb	<0.1	0.1	<0.1
Mo	<1	29	3
Sb	0.17	1.9	0.79
As	1.2	8.1	6.8
Cr	<0.1	5	2.5
Ni	0.7	11	1.1
U	0.3	2.6	0.8
Li	2.4	12	4.8
Se	0.6	4.7	1.5
Br	25	61	41
Ba	32	85	44
Sr	101	218	146
V	<2	3	<2
Rb	0.5	1.7	0.9

[1] Ca, Mg, Na, K, SiO_2, SO_4, Cl, F and nitrate in mg/l, alkalinity in mg/l HCO_3^-, conductivity in uS/cm, remaining elements in ug/l

[2] All variables are geometric means except for pH which is arithmatic mean.

mg/l. The mean concentrations of As, Mo, Cr, Ni, Li, Se, and U are elevated at 6.8, 3, 2.5, 1.1, 4.8, 1.5, and 0.8 µg/l, respectively, compared average fresh waters (Table 4). This may be due to the presents of mineralized rocks in the watershed. Active mines are present within one mile downstream of several sites. Mean concentrations of Zn and Cu are low at 0.84 and 0.33 µg/l, respectively (Table 7). The mean concentrations of Al, Fe and Mn are low at 5, 7, and <0.3 µg/l, respectively. The probable presence of pyrite associated with mineralized rocks is probable the main reason that the mean alkalinity value is moderately low. Waters from areas underlain by the siliceous and volcanic rocks are of acceptable chemical quality.

Comparison of Water Chemistry from each of the Four Rock Types

The chemistry of water evolving in the watersheds depends on the chemical composition of the underlying rock type. A unique range of water chemistry evolves within each of the four rock compositional types (Table 2). The value of total dissolved solids (TDS) can be used to compute the rate at which rivers transport chemical weathering products to the ocean and can be used to calculate the chemical weathering rate. The TDS values can be used to compare waters from different geologic terrains as a means of comparing chemical weathering rates. TDS value represents the total amount of solids (mg/l) remaining when a water sample is evaporated to dryness. In calculation from the chemical data, TDS value is the sum of all dissolved constituents with bicarbonate converted to equivalent carbonate in the solid phase, which assumes that half the bicarbonate is volatilized (Hem, 1992). The TDS value is calculated for the waters from each site and is shown in appendix 1. Mean TDS values for waters from the four rock types are shown in Table 8. Waters with the highest mean TDS values evolve from areas underlain by felsic ash-flow tuff followed by siliceous and volcanic rocks. But the use of raw TDS values is misleading if used to calculate the potential chemical weathering rate. Dissolved solids in waters depend on the rock compositional type, but also time of contact of the waters and rocks and evaporation effects. These effects also lead to seasonal variation in chemical composition of the waters of an area. One way to minimize the time of contact of water and rock and evaporation effects is by normalizing TDS values by dividing by the Cl content for each site. This assumes that Cl content is conservative and there is no addition of Cl to the waters by the dissolution of minerals containing Cl (such as halite from road salts). This is done for the water at each site and then the mean is taken of all the sites of a rock type to get the mean TDS/Cl value for that rock compositional type. The waters with the highest mean normalized TDS value is from areas underlain by the basalt and basaltic andesite followed closely by the Chainman Shale. The waters with the lowest mean normalized TDS values are from areas underlain by felsic ash-flow tuffs followed by siliceous and volcanic rocks, which is the reverse of the raw TDS values (Table 8). The mean normalized TDS values show the approximate potential release of TDS for each rock compositional type. The areas underlain by basalt and basaltic andesite and the Chainman Shale are undergoing the most rapid potential rate of chemical weathering, supplying the most dissolved solids to the waters of the area. Watersheds underlain by felsic ash-flow tuff are undergoing the lowest potential rate of chemical weathering and supplying the lowest amounts of dissolved solids to the waters of the area. The ash-flow tuff is felsic in composition and more resistance to weathering than more mafic rocks.

The mean normalized TDS values can be recalculated so that the values are between 0 and 1 by dividing each mean normalized TDS value by the highest mean normalized value (in this case 16.2). Each rock compositional type can be represented by their recalculated mean normalized TDS value (Table 8) and maps can be made showing the potential release of TDS (see Miller (1999) as an example). Potential release of TDS is used to indicate the potential chemical weathering rates which does not take into account the variation in precipitation.

Table 8. Rankings of rock composition type as to potential release of total dissolved solids (TDS) and acid neutralizing capacity to introduced acidity in the Humboldt Basin

	Potential release of TDS		
Rock Composition Type	TDS	Normalized TDS	Recalculated Normalized TDS
Felsic ash-flow tuff	314.9	9.1	0.56
Basalt and basaltic andesite	120.4	16.2	1.00
Chainman Shale	151.7	16.0	0.99
Siliceous and volcanic rocks	173.7	12.4	0.77

	Acid-Neutralizing Capacity		
Rock Composition	Alkalinity as mg/l HCO3	Normalized Alkalinity	Recalculated Normalized Alkalinity
Felsic ash-flow tuff	183	5.29	0.49
Basalt and basaltic andesite	81	10.87	1.00
Chainman Shale	91	9.61	0.88
Siliceous and volcanic rocks	105	7.49	0.69

Table 9. Mean concentrations of selected species and their ratios with Cl, Humboldt Basin

Dominant rock composition type	pH	Cl	SO_4	SO_4/Cl	F	F/Cl	U	U/Cl
Felsic ash-flow tuff	7.50	35	41	1.19	0.31	0.009	3.1	0.090
Basalt and basaltic andesite	7.60	7.4	11	1.54	0.28	0.038	0.20	0.027
Chainman Shale	8.35	9.5	24	2.58	0.22	0.024	0.45	0.048
Siliceous and volcanic rocks	8.39	14	30	2.11	0.24	0.017	0.80	0.057

Alkalinity of a solution is the capacity for solutes it contains to react with and neutralize acid (Hem, 1992). The property of alkalinity is determined by titration with a strong acid. Several different solute species may contribute to alkalinity, but for almost all natural fresh waters, the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate (Hem, 1992). Alkalinity in this study is reported as equivalent amounts of bicarbonate. Therefore in this study, alkalinity is the capacity of the water to react and consume acid. If an area is affected by acid mine drainage or acid rain, the alkalinity will consume the introduced acid until all the alkalinity is consumed. After this, if acidity is still being introduced, the acidity of the water will increase. So the alkalinity is a measure of the capacity of a watershed to resist the introduction of acidity. The higher the alkalinity value, the greater the capacity of the water to consume acid. The mean alkalinity values of waters from areas underlain by the four rock types range from 81 to 183 mg/l as HCO_3^- (Table 8). The waters with the highest alkalinity values are from areas underlain by felsic ash-flow tuff, and the waters with the lowest alkalinity values are from areas underlain by basalt and basaltic andesite (Table 8). The use of mean raw alkalinity values to represent the acid-neutralizing capacity of an area is somewhat misleading. The waters from areas underlain by these different rock types are a mixture of waters containing surface runoff from storm and snow melt and groundwater inflow within streams and springs. Waters from springs, such as the waters from areas underlain by felsic ash-flow tuff, are in longer contact with rocks and evaporation effects are more likely. Conversely, waters containing abundant snow melt, such as waters from Sheep Creek Range underlain by basalt and basaltic andesite, have been subjected to minor evaporation effects. Therefore alkalinity in the waters depends on the rock compositional type, but also time of contact of the rocks and water and evaporation effects. To decrease these effect of time, alkalinity is normalized by dividing by Cl concentrations at each site in a manner similar to that done when normalizing TDS. This assumes that Cl content is conservative and there is no addition of dissolved solids to the waters by the dissolution of soluble salts containing Cl. The waters with the highest mean normalized alkalinity value are from areas underlain by basalt and basaltic andesite followed closely by Chainman Shale (Table 8). The waters with the lowest mean normalized alkalinity values are from areas underlain by felsic ash flow tuff. The normalized alkalinity can be recalculated between 0 and 1 in a manner similar to the recalculated mean normalized TDS values and the recalculated mean normalized acid-neutralized capacity (Table 8) for each rock compositional type can be mapped. The normalized alkalinity value is a measure of the susceptibility of the watershed to resist introduced acidity. If acidity is introduced to the watershed by processes such as mining or acid rain, the watersheds underlain by the felsic ash-flow tuff are the most susceptible to impact.

Mean values for pH of waters from areas underlain by the four rock compositional types range from the lowest of 7.50 for felsic ash-flow tuff, 7.60 for basalt and basaltic andesite, 8.35 for the Chainman Shale and 8.43 for siliceous and volcanic rocks (Table 9). The pH values in these headwater streams are affected by the amount of melting snow runoff as a component of the total flow and the time of contact of water and rock. The snow runoff will generally lower the pH, and the time of contact of water and rock will generally increase the pH value. In addition, high biotic activity in the soil zone may release organic acids and may lower pH. The rankings of mean pH by rock type is shown in Table 9.

Mean concentrations of silica in waters from areas underlain by the four rock compositional types range from 12 to 18 mg/l (Table 2). The highest mean values are from areas underlain by felsic ash-flow tuff and basalt and basaltic andesite. The elevated mean silica values are probably because these rocks contain fine-grained silicate minerals with high surface areas, particularly susceptible to the dissolution of silica.

Mean concentrations of trace elements such as Cu, Zn, and Pb in waters from watersheds underlain by the four rock types are generally low (Table 2), compared to average fresh water (Table 4). But Mo, As, Cr, Ni, Sb, and U are elevated (Table 4). Mean values for Al, Fe, and Mn are low in water from watersheds underlain by ash-flow tuff and siliceous and volcanic rocks but elevated for waters from basalt and basaltic andesite and Chainman Shale (Table 2).

Sulfate, F, and U are mobile as anionic species in alkaline waters. These elements will concentrate in waters, depending on the time of contact of water and rock and evaporation effects. The highest mean sulfate concentration (41 mg/l) is in waters from areas underlain by the felsic ash-flow tuff. (Table 2). To reduce the effects of evaporation and time of contact of water and rock, sulfate values are normalized by dividing by the Cl concentrations for each water sample and the means calculated. The highest mean normalized values for sulfate are waters from areas underlain by the Chainman Shale and siliceous and volcanic rocks (Table 9). The Chainman Shale contains pyrite and the siliceous and volcanic rock appears to have been effected by mineralization. Oxidizing pyrite present in both of these rock groups is probably the source of the higher sulfate values.

The highest mean F concentration of 0.31 mg/l is in water from areas underlain by felsic ash-flow tuff (Table 2). When F is normalized in a manner similar to sulfate, waters from areas underlain by basalt and basaltic andesite rocks have the highest normalized F values (Table 9).

The highest mean U value of 3.1 mg/l is in waters from areas underlain by felsic ash-flow tuff with a mean of 3.1 µg/l, which is high compared to the remaining rock compositional types (Table 9). If U is normalized to reduce the effects of time of contact of water and rock and evaporation effects in a similar manner to that above, the waters with the highest mean normalized U value is also from felsic ash-flow tuff, as would be expected for evolved felsic rocks.

Chemical Modeling of the Waters

To gain understanding of processes such as speciation of elements and identification of minerals that may control the concentration, mobility, and attenuation of elements in the stream waters, chemical modeling of the waters was carried out using PHREEQC (Parkhurst, 1995). The modeling program assumes mineral-solution equilibrium. For some chemical reactions, particularly with slow kinetics, this may not be the case. Except for Al, the cations in the stream waters occur mostly as simple cations and the anions as chloride, sulfate, carbonate, and bicarbonate complexes (Table 10). Si occurs as the uncharged specie $H_4SiO_4^0$. In addition, the state of saturation of the waters with mineral phases were calculated. Saturation indices were calculated for a suite of minerals to determine if concentrations of trace metals in water were controlled by mineral phases. The saturation index is a convenient means of expressing saturation states of minerals (Barnes and Clark, 1969) where:

$$SI=\log_{10} IAP/K_T.$$

In the expression, SI is the saturation index, IAP is the ion activity product, and K_T is the equilibrium constant of the dissolution reaction at the temperature of the sample. Mineral phases are supersaturated at $SI>0$, saturated at $SI=0$, and undersaturated at $SI<0$.

The input values for the modeling program were the mean values for each rock compositional type shown in Table 2. The waters are near saturation or supersaturated with respect to calcite except waters from areas underlain basalt and basaltic andesite. The waters from areas underlain by the Chainman Shale and the siliceous and volcanic rocks are near saturation or supersaturated with respect to dolomite (Table 11). Another mineral which has an influence on the control of species in water is chalcedony. The waters from all the rock compositional types are saturated or slightly over-saturated with respect to chalcedony (Table 10), which appears to control the amount of dissolved silica in the waters. The waters are all undersaturated with respect to other minerals such as siderite, gypsum, fluorite, aluminum hydroxide, and rhodochrosite (Table 11).

Table 10. Speciation of selected elements in waters from areas underlain by the four rock types

Element	Specie
Ca	Ca^{2+}
Mg	Mg^{2+}
Na	Na^{+}
K	K^{+}
S	SO_4^{2-}
C	HCO_3^{-}
Cl	Cl^{-}
F	F^{-}
Si	$H_4SiO_4^{0}$
Al	$Al(OH)_4^{-}$
Fe	Fe^{2+}
Mn	Mn^{2+}

Table 11. Saturation indices for selected minerals for waters from areas underlain by the four rock types

Rock composition type	pe	Calcite	Dolomite	Siderite	Chalcedony	Gypsum	Fluorite	$Al(OH)_3$	Rhodochrosite
Felsic ash-flow tuff	2.64	-0.18	-0.93	-1.62	**0.19**	-2.02	-1.91	-1.83	-3.19
Basalt and basaltic andesite	1.23	**-0.91**	-2.3	-0.76	**0.18**	-3.03	-2.51	-0.42	-2.08
Chainman Shale	-0.62	**0.08**	-0.15	-0.4	-0.04	-2.57	-2.62	-1.16	-1.44
Siliceous and volcanic rock	-0.25	**0.26**	**0.01**	-0.76	**0.02**	-2.32	-2.33	-2.13	-2.01

Bold type indicates satuartion or supersaturation of the waters with respect to mineral phase

Summary and Conclusions

This study determines, for headwater areas, the range of baseline geochemistry of stream and spring waters that evolve within each of four major rock compositional types present in the Humboldt Basin. By comparing the geochemistry of the waters that evolve in each of the dominant rock compositional types, conclusions can be drawn characterizing and ranking the rock compositional types as to their potential release of TDS and their acid-neutralizing capacities. Also, processes responsible for the control and mobility of elements in water are discussed. The following are the most significant conclusions based on these results:

- 1. The baseline geochemistry of stream and spring waters evolving in the headwater areas depends on the chemical composition of the underlying rock type. Within each rock compositional type, a unique range of water compositions evolve. Other factors such as annual precipitation, temperature, topographic setting, character of minerals, such as grain size and crystallinity, and biotic activity can be important, but mainly influence the rates of chemical reactions and not the type of elements present in the waters.

- 2. The waters that evolve in these headwater areas in Humboldt Basin are mainly Ca^{2+}- HCO_3^- or Na+- HCO_3^- type waters, with alkaline pH values and moderate total dissolved. Dominant species present in the water samples are Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, HCO_3^-, Cl^-, F^-, $H_4SiO_4^0$, $Al(OH)_4^-$, Fe^{2+}, and Mn^{2+}.

- 3. TDS values, which are measures of the chemical weathering rates, indicate that waters with the highest TDS values evolves from watersheds underlain by felsic ash-flow tuff. Waters with the lowest TDS values evolve from watersheds underlain by basalt and basaltic andesite rocks. If TDS values are normalized by dividing by Cl concentrations and reducing the effects of time of contact of water and rock and evaporation processes, the rocks with the highest potential release of TDS are the basalt and basaltic andesite and the Chainman Shale. The rocks with the lowest potential release of TDS is felsic ash-flow tuff.. This shows the importance of normalizing the time of contact of the rock and water and evaporation effects. Potential release of TDS does not take into account the amount of precipitation of an area.

- 4. Alkalinity is a measure of the acid-neutralizing capacity of waters to introduced acidification. Waters from felsic ash-flow tuff and siliceous sediments and volcanic rocks have the highest mean alkalinity values, but these mean raw values are misleading and do not take into account time of contact of water and rock and evaporation effects. When alkalinity is normalized by dividing by Cl to reduce these effects, the waters with the highest mean normalized alkalinity values are from watersheds underlain by the basalt and basaltic andesite and the Chainman Shale. The watersheds underlain by these rock types have the greatest acid-neutralizing capacities and are the most resistant to introduced acidification from processes such as acid-mine drainage or dry fallout from coal-burning power plants. The waters with the lowest mean normalized alkalinity values are watersheds underlain by ash-flow tuff and siliceous and volcanic rocks, which are the most susceptible to introduced acidification.

- 5. Mean pH values range from 7.5 to 8.39. The lowest pH values are from areas underlain by felsic ash-flow tuff and basalt and basaltic andesite rocks.

- 6. The highest normalized mean sulfate values are from areas underlain by the Chainman Sale and the siliceous and volcanic rocks. The source of the sulfate is probably oxidizing pyrite present in both rock types.

- 7. Generally, trace metals such as Cu and Zn are low in concentrations. Some waters may have slightly elevated concentrations of some trace metals such as Mo, As, U, Al, Fe, and Mn, because of the presence and weathering of minerals such as pyrite. Compared to average fresh water, the waters from areas underlain by felsic ash-flow tuff are elevated in mean sulfate, As, and U; from areas underlain by basalt and basaltic andesite, waters are elevated in mean Fe, Al, and As; from areas underlain by the Chainman Shale, waters are elevated in mean sulfate, Mo, and As; and from areas underlain by siliceous and volcanic rocks, waters are elevated in mean sulfate, As, and Mo concentrations. The chemical quality of the waters from the watersheds underlain by the four rock compositional types are of all acceptable chemical quality.

The unique geochemical baselines from the four rock compositional types demonstrates the importance of rock composition in determining the types of waters that are evolving in these headwater areas. These geochemical baselines provide a range of values that approximate the natural baseline geochemistry of the stream and spring waters in these watersheds for each of the four major rock compositional types. In addition, the comparison of these geochemical baselines with future baselines will allow the recognition of any significant changes in water quality that may occur in the future.

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Appendix 1. Chemical analyses of stream and spring water from the Humboldt Basin, Nevada

Site	Latitude			Longitude			Rock Type	Date	Water Type
	Degre	inut	econd	Degre	inut	econd			
quartz monzonite									
HB01	39	29	19	117	3	0	Jg, qtz monznonite	05/21/98	stream
felsic ash-flow tuff									
HB02	39	43	2	117	4	3	Tbm, rhyolite ash flow tuff	05/21/98	China Spring
HB03	39	43	42	117	3	18	Tbm, rhyolite ash flow tuff	05/21/98	stream
HB04	39	45	11	117	2	38	Tbm, rhyolite ash flow tuff	05/21/98	spring
HB05	40	16	22	117	1	8	Twt, rhyolite to qtz latite ash flow tuff	05/21/98	Red rock spring
HB06	40	12	34	116	58	40	Tc, tbm, rhyolite to qtz latite ash flow tuff	05/21/98	spring
basalt and basaltic andesite									
HB08	40	45	7	116	46	1	Tb, olivine basalt	05/22/98	spring
HB09	40	43	58	116	47	30	Tba, basaltic andesite	05/22/98	spring
HB10	40	43	59	116	47	21	Tba, basaltic andesite	05/22/98	stream
HB11	40	46	11	116	46	41	Tb and Tba, mafic vol.	05/22/98	spring
HB12	40	43	56	116	46	37	Tba, basaltic andesite	05/22/98	spring
HB13	40	43	35	116	45	46	Tba and dacite porp.	05/22/98	spring
Chainman Shale									
HB21	40	33	59	116	4	11	Mc, Chainman Sh	05/24/98	stream
HB22	40	33	44	116	4	31	Mc, Chainman Sh	05/24/98	spring
HB23	40	33	46	116	4	20	Mc, Chainman Sh	05/24/98	Web Ck
HB24	40	34	21	116	3	36	Mc, Chainman Sh	05/24/98	stream
HB25	40	34	19	116	3	32	Mc + Mw, Webb Fm, sh, ls, calc.	05/24/98	stream ?
HB26	40	34	32	116	2	40	Mc + Mw, Webb Fm, sh, ls, calc.	05/24/98	stream
HB27	40	34	34	115	2	41	Mw + Mc	05/24/98	stream ?
HB28	40	34	32	116	2	48	Mc + Mw, Webb Fm, sh, ls, calc.	05/24/98	stream
HB29	40	34	4	116	4	6	Mc + PMd, Diamond Pk Fm, cong, ss, sh	05/24/98	stream
HB30	40	33	17	116	2	31	Mc, Chainman Sh	05/24/98	spring

HB31	40	32	58	116	0	39	Mc, Chainman Sh	05/24/98	stream
HB32	40	42	58	115	52	47	Mc, Chainman Sh	05/25/98	stream
HB33	40	38	48	115	55	19	Mc, Chainman Sh	05/26/98	Reinhart Spring
HB34	40	38	25	115	55	13	Mc, Chainman Sh	05/26/98	stream
HB35	40	39	1	115	57	0	Mc, Chainman Sh	05/26/98	stream
HB36	40	38	57	115	56	56	Mc, Chainman Sh	05/26/98	stream
HB37	40	38	42	115	56	38	Mc, Chainman Sh	05/26/98	stream

siliceous and volcanic rocks

HB07	40	19	24	116	54	44	Ov, chert, qtzite, greenstone, etc., silicified	05/21/98	stream
HB14	40	37	57	117	13	34	PPh, Havallah Fm, silicic. sed + vol.	05/23/98	Trenton Ck
HB16	40	37	8	117	13	53	PPh, Havallah Fm, silicic. sed + vol.	05/23/98	Mill Ck
HB17	40	39	50	117	10	58	Ov, chert, qtzite, greenstone, etc., silic W assemb	05/23/98	Cottonwood Ck
HB18	40	40	14	117	10	47	Ov, chert, qtzite, greenstone, etc., silic W assemb	05/23/98	Trout Ck
HB19	40	40	15	117	10	43	Ov, chert, qtzite, greenstone, etc., silic W assemb	05/23/98	No Trout Ck
HB20	40	40	21	117	10	50	Ov, chert, qtzite, greenstone, etc., silic W assemb	05/23/98	spring

siltstone, sandstone, gravel, tuff, and ash

HB38	40	50	36	115	51	12	Ts3, sed + vol, tuff, ash, siltstone, ss, gravel	05/26/98	stream

Site	Flow	Comments	Temp	pH	Conductivity	TDS
			deg C		uS/cm	ppm
quartz monzonite						
HB01	2 gal/sec	recent 4" snow, mining below, unaltered rocks	16.1	7.97	320	183.0
felsic ash-flow tuff						
HB02	—	clear, flowing	6.2	7.52	558	247.9
HB03	½ -1 gal/sec	emmitting from underground in cut	6.6	7.68	597	300.0
HB04	1-3 qt/sec	from galv. pipe	12.1	7.57	613	326.7
HB05	2-3	from galv. pipe, drill roads to east	11.3	7.57	1155	634.4
HB06	1 gal/sec	natural, clear, other springs nearby, some altered rx	13.7	7.17	396	200.7
basalt and basaltic andesite						
HB08	2-4 gal/sec	galv. pipe, clear	10.3	7.51	243	126.5
HB09	1-2 gal/sec	natural, wetlands, hard to filter, prob. organics, sl cloudy	15.8	8.25	165	96.5
HB10	—	clear	14.0	7.86	196	113.1
HB11	1-2 gal/sec	galv. pipe, pool water above, sl cloudy w/ algae, hard to filter	10.7	6.82	212	124.0
HB12	1-2 qt/sec	series of seeps, algae, filtered hard	13.0	7.58	186	99.7
HB13	1 pt/sec	seeps nearby, could be flow from Battle Ck, filtered hard	9.9	7.59	327	178.2
Chainman Shale						
HB21	5 gal/sec	sl sed	10.5	8.38	215	111.6
HB22	1 qt/sec	wetland	14.5	7.76	392	207.9
HB23	5-10 gal/sec	sl sed	11.9	8.20	188	93.9
HB24	1 cfs	stream cutting Mc	16.9	8.41	324	170.9
HB25	2-3 cfs	springs above, sl sed	13.8	8.26	216	110.0
HB26	1-2 gal/sec	nearly clear, seeps and springs, good sample cutting Mc	18.8	8.82	418	222.0
HB27	2-4 cfs	mod silt	16.6	8.30	195	107.8
HB28	1 cfs	sl mod silt	15.4	8.06	142	75.4
HB29	1 pt/sec	sl mod silt	25.6	8.78	579	325.6
HB30	2 gal/sec	many springs, top of divide under head,wetlands, clear	15.2	7.52	164	85.6

HB31	—	draining from Cherry Spring, wetlands	10.2	7.86	158	81.4
HB32	1-2 qt/sec	below Cherry Sp, silt, hard to filter, cows upstream	12.7	8.69	472	242.6
HB33	low	pool covered w/ algae, fenced, natural, hard to see flow	15.5	8.24	584	317.2
HB34	2-3 gal/sec	nearly clear	16.9	8.76	663	229.6
HB35	2 qt/sec	nearly clear, v. hard to filter	14.4	8.82	213	126.8
HB36	2-3 qt/sec	nearly clear, hard to filter	14.3	8.29	235	129.6
HB37	½ -1 qt/sec	from seeps above, hard to filter	15.5	8.76	228	244.7

siliceous and volcanic rocks

HB07	1 gal/sec	v. sl sed., altered and silicified vol.	8.8	8.45	454	248.3
HB14	1-2 cfs	mouth of canyon, nw side Battle Mtn, mining below not above	9.1	8.59	434	240.0
HB16	2-3 qt/sec	sl sed	16.9	8.72	524	282.6
HB17	2-3 cfs	sl sed, drill roads above, altered rock in bed	10.0	8.46	217	110.2
HB18	2-5 cfs	within canyon, no mining, sl mod sed	10.2	8.43	261	139.2
HB19	2 cfs	sl mod sed, no mining above	10.5	8.46	236	107.2
HB20	2 gal/sec	natural, clear, wetlands	7.3	7.63	330	171.9

siltstone, sandstone, gravel, tuff, and ash

HB38	½ -1 qt/sec	clear, hard to filter, small stream prob. from Mary Larson Sp	15.2	8.45	822	324.8

Site	Fluoride	Chloride	Nitrate	Sulfate	Alkalinity	Ca	Mg	Na	K	SiO_2	Al	Fe	Mn
	ppm	ppm	ppm	ppm	ppm HCO3	ppm	ppm	ppm	ppm	ppm	ppb	ppb	ppb
quartz monzonite													
HB01	0.19	13	<0.25	32.3	110	29.1	7.67	20.1	6.7	19.4	115	66	0.4
felsic ash-flow tuff													
HB02	0.23	20	0.28	30.3	237	26.5	7.7	19.9	6.6	19.5	89	60	0.3
HB03	0.17	14	<0.25	23.0	276	72.1	17.8	21.2	2.2	13.7	3	12	<0.3
HB04	0.26	27	0.26	37.3	240	76.7	12.3	28	4.7	22	<3	11	<0.3
HB05	1.0	161	<0.25	134	146	89	15.2	126	9.4	27.4	<3	24	<0.3
HB06	0.28	40	0.47	33.6	89	32.3	6.66	29.5	5	9.16	<3	<5	<0.3
basalt and basaltic andesite													
HB08	0.38	7.5	0.64	12.1	87	14.1	3.77	22.4	1.8	21	1175	616	4.4
HB09	0.19	5.0	<0.25	7.79	68	10.6	2.55	15.7	2.7	18.3	252	160	1.5
HB10	0.24	5.7	<0.25	9.29	82	13.2	3.48	20.3	3.5	16.9	61	48	1.5
HB11	0.23	5.3	<0.25	8.55	90	10.6	2.7	24.7	6.3	21.2	424	294	16.4
HB12	0.24	7.1	<0.25	12.1	67	14.2	2.68	15.1	2	13.1	59	42	1.1
HB13	0.52	21	0.73	25.0	96	23.8	4.76	26	6.8	22.1	74	67	6.6
Chainman Shale													
HB21	0.12	5.9	0.64	23.5	69	13.6	6.5	13.2	2	12.3	1090	472	4.4
HB22	0.46	4.4	<0.25	51.7	139	44.4	14.6	9.49	4.7	9.61	27	333	36.9
HB23	0.20	2.7	1.2	17.6	63	18.3	5.83	7.5	1.6	8.05	12	11	2.1
HB24	0.19	8.0	<0.25	34.3	116	23.9	11	16.8	3.4	16	1285	569	5.6
HB25	0.14	14	0.39	17.6	61	15.5	5.07	14	2	11.6	30	26	2.1
HB26	0.46	21	<0.25	32.8	145	33.8	9.06	37.2	3.2	13.5	17	21	0.8
HB27	0.13	18	<0.25	13.0	57	14.8	5.08	12.5	2.3	14.1	133	74	2.4
HB28	<0.125	8.0	0.75	15.1	37	9.84	2.35	12.2	1.5	7.36	87	50	1.1
HB29	0.51	26	<0.25	65.1	209	56.6	20	38.4	4.7	11.3	51	60	2
HB30	0.13	4.8	<0.25	9.90	62	13.2	3.06	14.5	0.2	9.14	75	65	1.4

HB31	0.11	7.2	0.86	15.9	45	10.6	3.39	12.4	1.5	7.34	23	36	7.9
HB32	0.33	18	<0.25	25.2	167	47.5	7.49	35.7	9	17	3	18	16.2
HB33	0.55	23	<0.25	66.1	162	48.7	19.3	62.3	4.3	13.3	13	12	1.1
HB34	0.47	39	<0.25	89.3	148	4.92	1.31	7.86	1.1	12.3	27	37	1.2
HB35	0.19	5.5	<0.25	14.9	79	16	4.17	23.8	4.2	19	72	54	2
HB36	0.21	4.8	<0.25	15.6	92	15.4	4.52	21.7	3.1	18.9	111	70	2
HB37	0.19	4.5	<0.25	13.9	92	71.3	18.5	70.8	6.9	13.2	<3	15	42.8
siliceous and volcanic rocks													
HB07	0.40	17	<0.25	54.5	156	49.6	11.9	24.8	2.7	10.6	5	7	0.6
HB14	0.37	18	<0.25	57.5	133	42.9	9.27	30.9	1.7	13.4	12	15	1.2
HB16	0.14	24	<0.25	52.2	174	70.6	7.1	26	2.4	14.6	5	15	0.5
HB17	0.16	7.5	0.45	12.0	80	18	4.47	15	1.6	11.7	50	41	1.6
HB18	0.24	12	<0.25	23.3	91	20.9	6.69	19.1	1.6	10.6	62	58	4
HB19	0.16	11	<0.25	15.5	47	16.4	4.39	22.7	1.8	12.1	116	69	1.2
HB20	0.34	15	<0.25	27.8	113	27.3	9.7	21.8	2.1	12.3	5	12	<0.3
siltstone, sandstone, gravel, tuff, and ash													
HB38	0.57	66	<0.25	106	216	13.7	3.68	22.6	1.8	3.9	19	<5	0.5

Site	Ba	Be	Li	Mo	Sr	Ti	V	Zn	Sc	Cr	Co	Ni	Cu	Ga
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
quartz monzonite														
HB01	61	<0.05	20.4	2	159	2	<2	<0.2	8	1.3	0.1	0.9	0.5	0.04
felsic ash-flow tuff														
HB02	60	<0.05	20.4	2	153	<2	<2	<0.2	9	2.7	0.1	1.8	0.1	0.01
HB03	109	<0.05	7.2	2	359	<2	3	<0.2	5	1.5	0.2	1.8	0.2	<0.01
HB04	102	<0.05	11.6	2	367	<2	9	<0.2	9	3.3	0.2	1.9	0.5	<0.01
HB05	32	<0.05	81	10	346	<2	14	3.3	11	21	0.2	2.1	0.6	0.01
HB06	59	<0.05	43.3	2	220	<2	<2	<0.2	4	7.8	0.1	0.8	<0.1	<0.01
basalt and basaltic andesite														
HB08	61	0.098	11.7	1	140	33	8	11	10	1.9	0.1	1.4	1.4	0.33
HB09	62	<0.05	2.8	<1.0	98	7	3	0.2	8	1.1	0.1	0.6	0.7	0.07
HB10	59	<0.05	4.6	<1.0	120	<2	<2	<0.2	6	0.8	0.1	0.7	0.7	0.01
HB11	72	<0.05	3.2	2	117	14	3	0.2	7	0.7	0.1	1.0	1.7	0.08
HB12	40	<0.05	3.5	<1.0	102	<2	2	<0.2	4	0.7	0.0	0.4	0.3	<0.01
HB13	37	<0.05	12.2	1	150	2	4	<0.2	8	2.5	0.1	0.7	0.3	<0.01
Chainman Shale														
HB21	164	0.06	7.3	<1.0	135	24	5	2.2	4	1.8	0.2	1.7	1.7	0.07
HB22	59	<0.05	8.8	29	125	<2	25	10.9	4	0.7	1.2	11.0	3.7	0.03
HB23	108	<0.05	2	5	71	<2	11	4.4	3	<0.1	0.1	2.5	0.8	<0.01
HB24	105	0.08	11	1	133	31	6	2.5	5	1.0	0.1	1.5	1.0	0.02
HB25	118	<0.05	15.6	1	103	<2	3	<0.2	4	1.6	0.1	1.4	1.1	0.02
HB26	104	<0.05	13.8	5	201	<2	9	<0.2	5	2.7	0.1	2.2	1.1	<0.01
HB27	100	<0.05	26	1	108	5	4	<0.2	5	2.5	0.2	1.3	1.2	0.04
HB28	162	<0.05	2	<1.0	71	2	<2	<0.2	2	1.0	0.1	0.7	0.8	0.02
HB29	125	<0.05	26.7	3	279	<2	11	<0.2	4	3.2	0.2	2.3	1.9	0.02
HB30	127	<0.05	4.1	<1.0	95	3	<2	<0.2	3	0.9	0.1	0.9	1.0	0.02

HB31	269	<0.05	2.3	<1.0	61	<2	<2	<0.2	2	1.1	0.1	1.3	0.8	0.01
HB32	238	<0.05	14.9	2	240	<2	16	<0.2	7	2.8	0.2	1.9	1.0	<0.01
HB33	105	<0.05	21.4	3	245	<2	6	<0.2	2	2.7	0.1	1.8	0.9	<0.01
HB34	65	<0.05	2.3	<1.0	35	<2	2	<0.2	5	5.0	0.2	1.9	1.0	<0.01
HB35	160	<0.05	7.3	2	117	2	6	<0.2	6	1.2	0.1	1.2	1.4	0.02
HB36	127	<0.05	7	1	125	4	4	<0.2	6	0.9	0.1	1.4	1.5	0.02
HB37	207	<0.05	57.1	3	499	<2	5	<0.2	7	0.6	0.1	1.2	1.0	0.04
siliceous and volcanic rocks														
HB07	42	<0.05	4.6	5	192	<2	<2	0.4	4	3.8	0.1	1.6	0.9	<0.01
HB14	32	<0.05	10.6	70	190	<2	<2	<0.2	5	2.9	0.1	1.3	1.6	<0.01
HB16	32	<0.05	6.9	1	218	<2	3	<0.2	6	4.3	0.2	1.9	0.3	<0.01
HB17	85	<0.05	2.7	<1.0	101	<2	<2	<0.2	5	1.4	0.1	0.8	1.0	0.01
HB18	34	<0.05	4.2	2	120	<2	<2	9	3	2.2	0.1	1.1	1.0	0.01
HB19	67	<0.05	2.4	2	111	2	2	<0.2	4	1.7	0.1	0.7	1.0	0.02
HB20	37	<0.05	6.1	2	132	<2	<2	<0.2	4	2.4	0.1	0.9	0.7	<0.01
siltstone, sandstone, gravel, tuff, and ash														
HB38	25	<0.05	10.7	15	111	<2	<2	29.3	4	8.2	0.3	2.4	0.7	<0.01

Site	Ge	As	Se	Br	Rb	Y	Zr	Nb	Cd	In	Sn	Sb	I	Cs
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
quartz monzonite														
HB01	<0.01	4.9	0.8	75	4.7	0.09	0.28	0.05	0.01	0.063	0.26	0.40	9.3	0.235
felsic ash-flow tuff														
HB02	0.06	6.0	1.1	66	9.4	0.03	0.05	0.02	<0.01	0.022	0.12	0.25	6.8	0.413
HB03	<0.01	2.7	0.6	52	1.0	0.08	0.05	0.02	0.02	0.013	0.10	0.34	5.4	0.011
HB04	0.06	7.7	1.8	77	9.4	0.02	0.04	0.02	0.04	0.012	0.08	0.30	7.1	0.329
HB05	0.04	23.9	7.5	351	9.3	0.02	0.14	0.03	0.04	0.009	0.08	0.73	16	0.472
HB06	0.02	1.4	1.3	93	14.7	0.02	0.02	0.01	0.01	0.005	0.08	0.05	8.8	3.070
basalt and basaltic andesite														
HB08	0.05	4.7	0.2	34	2.9	0.38	2.01	0.17	0.02	0.004	0.09	0.20	7.2	0.217
HB09	0.01	1.3	0.3	20	1.2	0.22	0.66	0.05	0.02	0.002	<0.05	0.16	2.2	0.036
HB10	<0.01	1.1	0.3	28	1.1	0.11	0.24	0.02	0.03	<0.001	<0.05	0.15	3.1	0.009
HB11	0.02	2.3	0.4	27	1.3	0.51	0.84	0.06	0.04	<0.001	<0.05	0.19	5.9	0.034
HB12	0.01	1.3	0.3	24	1.6	0.08	0.09	0.01	0.01	<0.001	0.13	0.09	3.9	0.008
HB13	0.02	2.4	0.7	69	4.5	0.05	0.15	0.02	0.01	<0.001	<0.05	0.13	6.6	0.005
Chainman Shale														
HB21	0.03	2.9	1.4	28	0.8	0.32	0.35	0.12	0.05	<0.001	<0.05	0.25	4.2	0.066
HB22	0.02	7.5	9.2	40	1.2	0.26	0.96	0.07	0.66	0.018	0.18	1.92	9.0	0.012
HB23	<0.01	2.7	4.4	12	0.6	0.02	0.06	0.02	0.11	0.003	0.10	0.82	2.4	0.007
HB24	<0.01	2.9	2.5	34	0.8	0.13	0.34	0.03	0.02	<0.001	0.07	0.23	3.5	0.021
HB25	<0.01	4.2	1.6	63	0.6	0.09	0.19	0.02	0.04	<0.001	0.06	0.30	4.5	0.011
HB26	<0.01	6.2	2.6	71	0.8	0.06	0.13	0.02	0.03	<0.001	0.05	0.37	13	0.004
HB27	<0.01	4.2	1.7	85	0.8	0.17	0.45	0.04	0.03	<0.001	0.12	0.29	4.0	0.030
HB28	<0.01	3.8	0.8	38	0.6	0.07	0.18	0.02	0.02	<0.001	<0.05	0.17	3.7	0.018
HB29	<0.01	2.7	5.9	82	0.7	0.14	0.15	0.02	0.09	<0.001	<0.05	0.42	6.2	0.006
HB30	<0.01	6.9	0.5	27	0.2	0.15	1.65	0.03	0.02	<0.001	<0.05	0.19	4.9	0.017

HB31	<0.01	2.3	1.1	33	0.6	0.09	0.12	0.01	0.02	<0.001	<0.05	0.17	4.0	0.016
HB32	<0.01	8.1	0.8	63	1.4	0.08	0.12	0.01	0.02	<0.001	<0.05	0.36	13	0.004
HB33	<0.01	1.2	1.6	70	0.7	0.01	0.04	0.01	0.03	<0.001	<0.05	0.05	14	<0.002
HB34	<0.01	4.9	4.3	136	0.7	0.08	0.15	0.01	0.02	<0.001	<0.05	0.35	9.9	0.006
HB35	<0.01	4.9	0.4	34	0.5	0.12	0.31	0.02	0.03	<0.001	<0.05	0.31	3.9	0.023
HB36	<0.01	5.3	0.4	36	0.8	0.11	0.21	0.02	0.01	<0.001	<0.05	0.36	3.9	0.012
HB37	<0.01	2.7	0.4	34	0.7	0.15	0.51	0.04	0.01	<0.001	<0.05	0.24	4.0	0.034
siliceous and volcanic rocks														
HB07	<0.01	3.4	4.7	57	0.9	0.02	0.08	0.01	0.03	0.003	0.06	0.35	6.0	0.045
HB14	<0.01	26.4	2.7	53	1.0	0.03	0.05	0.01	0.26	<0.001	<0.05	1.22	7.0	0.021
HB16	<0.01	14.6	3.6	61	1.7	0.03	0.03	0.01	0.04	<0.001	<0.05	0.78	6.3	0.005
HB17	<0.01	7.2	0.7	25	0.5	0.05	0.09	0.01	0.03	<0.001	<0.05	0.47	3.7	0.010
HB18	<0.01	3.2	0.9	31	0.7	0.04	0.09	0.01	0.31	<0.001	<0.05	0.64	4.3	0.033
HB19	<0.01	3.7	0.6	34	0.9	0.06	0.11	0.01	0.02	<0.001	<0.05	1.74	6.0	0.083
HB20	<0.01	6.1	1.0	37	1.1	0.01	0.03	0.01	<0.01	<0.001	<0.05	1.15	4.6	0.012
siltstone, sandstone, gravel, tuff, and ash														
HB38	0.02	7.3	4.3	194	2.6	0.07	0.06	0.01	0.05	<0.001	<0.05	0.28	8.8	0.006

Site	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
quartz monzonite												
HB01	0.108	0.183	0.048	0.091	0.052	0.04	0.053	0.027	0.031	0.020	0.024	0.018
felsic ash-flow tuff												
HB02	0.009	0.008	0.007	0.006	0.008	0.04	0.012	0.006	0.006	0.005	0.004	0.004
HB03	0.016	0.012	0.006	0.018	0.009	0.03	0.009	0.004	0.006	0.003	0.008	0.002
HB04	<0.005	0.006	<0.002	<0.004	0.003	0.03	0.004	0.002	0.003	<0.001	<0.001	<0.001
HB05	0.006	0.007	<0.002	<0.004	0.003	0.01	0.002	0.001	0.001	<0.001	<0.001	<0.001
HB06	<0.005	<0.005	<0.002	0.005	0.003	0.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
basalt and basaltic andesite												
HB08	0.298	0.706	0.076	0.306	0.062	0.03	0.086	0.012	0.069	0.013	0.043	0.006
HB09	0.182	0.414	0.054	0.229	0.044	0.02	0.049	0.006	0.038	0.005	0.022	0.003
HB10	0.079	0.150	0.022	0.097	0.025	0.02	0.029	0.003	0.021	0.002	0.009	0.001
HB11	0.389	0.830	0.099	0.441	0.086	0.03	0.126	0.015	0.092	0.016	0.049	0.007
HB12	0.053	0.123	0.013	0.061	0.016	0.01	0.017	0.002	0.013	0.002	0.007	0.001
HB13	0.045	0.109	0.011	0.056	0.010	0.01	0.015	0.001	0.011	0.001	0.005	<0.001
Chainman Shale												
HB21	0.174	0.563	0.054	0.241	0.062	0.06	<0.001	0.010	0.064	0.011	0.033	0.005
HB22	0.090	0.200	0.059	0.160	0.065	0.06	0.088	0.037	0.065	0.022	0.040	0.016
HB23	0.010	0.016	0.005	0.013	0.004	0.03	0.007	0.004	0.003	0.001	0.003	0.001
HB24	0.089	0.182	0.027	0.095	0.026	0.03	0.033	0.005	0.023	0.004	0.011	0.002
HB25	0.058	0.122	0.018	0.073	0.015	0.03	0.029	0.003	0.017	0.002	0.009	0.001
HB26	0.040	0.067	0.010	0.051	0.013	0.03	0.014	<0.001	0.009	0.001	0.005	<0.001
HB27	0.128	0.252	0.037	0.150	0.028	0.03	0.051	0.005	0.029	0.005	0.016	0.002
HB28	0.058	0.122	0.017	0.078	0.021	0.04	0.026	0.003	0.013	0.002	0.009	<0.001
HB29	0.094	0.183	0.025	0.096	0.023	0.04	0.029	0.003	0.020	0.004	0.012	0.001
HB30	0.073	0.168	0.024	0.118	0.032	0.04	0.039	0.005	0.023	0.004	0.014	0.002

HB31	0.045	0.079	0.015	0.062	0.020	0.06	0.030	0.003	0.018	0.003	0.010	<0.001
HB32	0.036	0.079	0.008	0.051	0.013	0.06	0.015	0.002	0.014	0.002	0.007	<0.001
HB33	0.006	0.011	<0.002	<0.004	0.003	0.02	0.003	<0.001	<0.001	<0.001	<0.001	<0.001
HB34	0.039	0.066	0.011	0.054	0.014	0.03	0.014	0.002	0.014	0.002	0.005	0.001
HB35	0.108	0.167	0.025	0.101	0.026	0.03	0.039	0.003	0.021	0.004	0.012	<0.001
HB36	0.076	0.115	0.018	0.096	0.027	0.05	0.024	0.003	0.020	0.003	0.009	<0.001
HB37	0.208	0.319	0.045	0.173	0.037	0.04	0.051	0.005	0.030	0.005	0.016	0.002

siliceous and volcanic rocks

HB07	0.006	0.013	<0.002	0.009	0.002	0.01	0.004	<0.001	0.002	<0.001	0.002	<0.001
HB14	0.022	0.044	0.004	0.024	0.003	0.01	0.006	<0.001	0.006	<0.001	0.001	<0.001
HB16	0.010	0.034	0.003	0.013	0.003	0.01	0.005	<0.001	0.001	<0.001	<0.001	<0.001
HB17	0.044	0.097	0.011	0.046	0.009	0.03	0.019	<0.001	0.007	0.001	0.003	<0.001
HB18	0.032	0.086	0.009	0.039	0.007	0.01	0.014	<0.001	0.005	<0.001	0.004	<0.001
HB19	0.038	0.105	0.011	0.051	0.012	0.02	0.011	<0.001	0.007	0.001	0.006	<0.001
HB20	<0.005	0.011	<0.002	0.006	<0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

siltstone, sandstone, gravel, tuff, and ash

HB38	0.020	0.033	0.005	0.022	0.010	0.05	0.012	<0.001	0.007	0.001	0.004	<0.001

Site	Yb	Lu	Hf	W	Re	Tl	Pb	Bi	Th	U
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
quartz monzonite										
HB01	0.034	0.022	0.069	0.62	0.007	0.03	<0.1	1.04	0.47	31.4
felsic ash-flow tuff										
HB02	0.006	0.005	0.019	0.36	0.009	0.01	<0.1	0.22	0.15	5.4
HB03	0.010	0.003	0.015	0.26	0.009	0.01	<0.1	0.31	0.11	2.5
HB04	0.001	0.001	0.011	0.31	0.015	<0.01	0.5	0.17	0.11	4.4
HB05	0.001	0.001	0.041	0.31	0.034	0.01	<0.1	0.29	0.25	7.2
HB06	0.001	<0.001	0.008	0.11	0.004	<0.01	<0.1	0.13	0.06	0.7
basalt and basaltic andesite										
HB08	0.050	0.009	0.037	0.28	0.002	0.01	0.2	0.16	0.17	0.7
HB09	0.022	0.005	0.015	0.11	<0.001	0.01	0.1	0.28	0.10	0.1
HB10	0.013	0.002	0.009	0.07	<0.001	<0.01	<0.1	0.24	0.07	0.1
HB11	0.070	0.012	0.016	0.15	0.001	0.01	0.2	0.19	0.10	0.1
HB12	0.010	0.002	0.005	0.06	0.002	<0.01	<0.1	0.07	0.04	0.2
HB13	0.007	<0.001	0.010	0.08	0.004	<0.01	<0.1	0.09	0.06	0.2
Chainman Shale										
HB21	0.037	0.004	0.024	0.14	0.004	0.02	0.1	0.03	0.18	0.4
HB22	0.053	0.030	0.178	0.58	0.067	<0.01	0.3	0.66	0.68	0.7
HB23	0.003	0.003	0.019	0.15	0.031	<0.01	<0.1	0.09	0.11	0.2
HB24	0.014	0.003	0.020	0.13	0.008	<0.01	<0.1	0.08	0.12	0.7
HB25	0.008	0.002	0.012	0.09	0.006	<0.01	<0.1	0.05	0.07	0.3
HB26	0.003	<0.001	0.018	0.12	0.020	<0.01	<0.1	0.05	0.10	2.1
HB27	0.019	0.002	0.011	0.09	0.004	<0.01	0.1	0.03	0.08	0.3
HB28	0.008	<0.001	0.009	0.04	0.003	<0.01	<0.1	0.02	0.04	0.1
HB29	0.009	<0.001	0.016	0.15	0.010	<0.01	<0.1	0.05	0.12	2.2
HB30	0.016	0.002	0.033	0.07	0.002	<0.01	<0.1	0.03	0.06	0.2

HB31	0.009	<0.001	0.005	0.03	0.004	<0.01	<0.1	0.01	0.04	0.1
HB32	0.008	<0.001	0.008	0.24	0.003	<0.01	<0.1	0.03	0.06	2.5
HB33	<0.001	<0.001	0.007	0.04	0.023	<0.01	<0.1	0.01	0.07	0.7
HB34	0.007	<0.001	0.010	0.13	0.016	<0.01	<0.1	0.03	0.07	2.5
HB35	0.015	<0.001	0.008	0.10	0.002	<0.01	<0.1	0.03	0.06	0.4
HB36	0.009	<0.001	0.008	0.08	<0.001	<0.01	<0.1	0.03	0.05	0.2
HB37	0.019	0.002	0.013	0.07	<0.001	<0.01	<0.1	0.02	0.08	0.3
siliceous and volcanic rocks										
HB07	<0.001	<0.001	0.012	0.14	0.024	<0.01	<0.1	0.44	0.09	1.1
HB14	0.002	<0.001	0.005	1.12	0.014	<0.01	<0.1	0.06	0.05	2.6
HB16	0.003	<0.001	0.003	0.28	0.011	<0.01	<0.1	0.04	0.03	2.6
HB17	0.004	<0.001	0.004	0.08	0.006	<0.01	<0.1	0.05	0.02	0.3
HB18	0.003	<0.001	0.004	0.07	0.005	<0.01	0.1	0.03	0.03	0.4
HB19	0.002	<0.001	0.003	0.05	0.006	<0.01	<0.1	0.04	0.03	0.7
HB20	<0.001	<0.001	0.003	0.06	0.009	<0.01	<0.1	0.03	0.03	0.4
siltstone, sandstone, gravel, tuff, and ash										
HB38	0.008	<0.001	0.007	0.13	0.026	<0.01	<0.1	0.01	0.06	1.9