

Hydrogeochemical Investigations in the Osgood Mountains, North-Central Nevada



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Chapter B *of*

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Preface

Northern Nevada is one of the world's foremost regions of gold production. The Humboldt River Basin (HRB) covers 43,500 km² in northern Nevada (Crompton, 1995), and it is home to approximately 18 active gold and silver mines (Driesner and Coyner, 2001) among at least 55 significant metallic mineral deposits (Long and others, 1998). Many of the gold mines are along the Carlin trend in the east-central portion of the HRB, and together they have produced 50 million ounces of gold from 1962 (when the Carlin mine first opened) through April 2002 (Nevada Mining Association, 2002). Mining is not new to the region, however. Beginning in 1849, mining has taken place in numerous districts that cover 39 percent of the land area in the HRB (Tingley, 1998). In addition to gold and silver, As, Ba, Cu, Fe, Hg, Li, Mn, Mo, Pb, S, Sb, V, W, Zn, and industrial commodities such as barite, limestone, fluorite, sand and gravel, gypsum, gemstones, pumice, zeolites, and building stone, have been extracted from the HRB (McFaul and others, 2000).

Due to the large amount of historical and recent mining in the HRB, the Bureau of Land Management (BLM) in Nevada asked the U.S. Geological Survey (USGS) Mineral Resources Program to conduct a series of mineral-deposit-related environmental studies in the HRB. BLM required data and geoenvironmental interpretations regarding (1) the chemical composition of water, soil, sediment, and mine waste in the HRB, (2) the natural background chemistry of these materials, and (3) how mining activities may have altered their chemistry. The paper that follows describes one of the studies conducted by the USGS Minerals Program to answer these and similar questions.

All papers within this series of investigations can be found as lettered chapters of USGS Bulletin 2210, *Geoenvironmental Investigations of the Humboldt River Basin, Northern Nevada*. Each chapter is available separately online.

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Abstract

Field investigations performed in the Osgood Mountains during the summers of 1999 and 2000 were designed to test methods of combining geologic, hydrologic, and geochemical investigations. The goals were to develop a more thorough understanding of the movement of water through the study area and to understand the water-rock reactions that may occur along flow paths. The Osgood Mountains were chosen for study because they represent a well-defined geologic system, based on existing and new field data. New work in the area focused on gathering more data about fractures, faults, and joints and on collecting water samples to evaluate the role of geologic structures on hydrologic and geochemical properties of the ground-water/surface-water system. Chemical methods employed in the study included measuring traditional field parameters (e.g., pH, temperature, conductivity, dissolved oxygen) as well as Fe²⁺ and collecting a variety of samples that were preserved for later laboratory analysis. Hydrologic methods included closely spaced evaluations of substream hydraulic head to define ground-water discharge and recharge zones as well as some measurements of stream discharge. Geologic investigations focused on the locations and orientations of fractures and kinematic indicators of slip observable in outcrops.

Introduction

Purpose and Scope

This study was designed to test the hypothesis that a well-developed conceptual model of the geologic and structural characteristics of an area can be used to help evaluate the hydrology and hydrochemistry of that area. The geologic

model for the Osgood Mountains, described in detail below, accounts for the orientations of fractures observed in the granodiorite bedrock. The combined network of northwest-, northeast-, and east-trending fractures should comprise a regional flow network, with local flow (at the scale of meters to perhaps hundreds of meters) conducted by single fractures or sets of fractures. Water samples were collected in an attempt to evaluate the roles that individual fractures or fracture sets may play in the local and regional hydrologic regime. Although most of our samples were collected from streams, a number of springs were sampled as well as one artesian well. During our sampling trips, we walked along the major streams in the area, monitoring field parameters such as conductivity and pH, and collecting samples when changes were observed; we also measured the hydraulic head of hyporheic water (Wanty and Winter, 2000) to evaluate the hydraulic relationships between surface water and ground water. Using the hydrologic and chemical results, we can evaluate flow systems at a variety of spatial scales.

Physical Geography

The Osgood Mountains in north-central Nevada include two large granodioritic intrusive-rock bodies, which form the eastern half of the range (Hotz and Willden, 1964). Elevations in the valley bottom are approximately 1,500 m above sea level, and the elevation of Adam Peak, the highest point in the range, is 2,625 m. Slopes are generally steep and rocky, with only thin soil development (fig. 1).

The average annual rainfall in Winnemucca, Nev., approximately 40 km southwest of the Osgoods, is 20 cm; that for Golconda, approximately 30 km south, is 18 cm. Both of these weather stations are located in valleys, well below the elevation of the Osgood Mountains where a slightly higher precipitation is expected. Potential evaporation in the area varies from < 600 mm to 1,800 mm per year (Shevenell, 1996). As a result, the vegetative cover is limited to sparse cover with grasses and short shrubs, with trees and taller shrubs confined to riparian zones (Bailey, 1995, 1998).

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Figure 1. Photograph showing the upper reaches of Granite Creek in the southeastern Osgood Mountains. Steep rocky slopes and dry climate result in thin soil development and sparse vegetative cover.

Geology

The Osgood Mountains intrusive rocks were emplaced about 95 m.y. ago (B.R. Berger and L. Snee, oral commun., 2002) under regional tectonic stresses dominated by compression, the maximum principal stress axis (σ_1) of which was parallel to Earth's surface and oriented slightly east of north. Under these tectonic conditions, long strike-slip faults (kilometers to tens of kilometers) developed, with an azimuth of approximately 330° . There are three such faults in the field area, shown on figure 2. These faults are the major bounding structures for the Osgood Mountains stock. The Getchell fault, one of the bounding structures, forms the northeast edge of the northern intrusive body and controls gold mineralization in the Getchell mine in Paleozoic sedimentary rocks near their contact with granodiorite. The Osgood Creek fault is shown as a dashed line (fig. 2) between the two intrusive rock bodies. The southernmost bounding fault is not observed in outcrop but is inferred by a pervasive alteration zone parallel to Granite Creek, observed by Neuerberg (1966) as a zone of sulfide mineral enrichment in the stock.

As displacement occurred along the strike-slip faults, they interacted mechanically where they overlap. As a consequence, displacement on the strike-slip faults was partially accommodated through extension between them, thereby resulting in the development of two extensional stepovers, or pull-apart structures, between them. The extensional sidewall

faults of the pull-aparts strike $N. 45^\circ E. (\pm 15^\circ)$. The two lobes of the Osgood Mountains stock were emplaced into the two pull-apart structures and accommodated extensional strain between the master strike-slip faults. In this structural model, regional compression formed a container for present-day regional fluid flow, the details of which are related to the compartmentalization of permeability imposed on the area during strike-slip transtensional tectonics.

Due to the oblique angle of convergence of the North American and Pacific tectonic plates during the Late Cretaceous, northwest-striking strike-slip faults in what is now the Great Basin had a right-lateral sense of displacement. Ideally, north- to north-northeast-striking faults would accommodate extension and northeast-striking faults would accommodate antithetic shear. Slip indicators observed within the Osgood Mountains stock are consistent with this model. However, the north-northeast to northeast strikes of normal faults along the margins of the two lobes of the stock imply that extensional strain was accommodated heterogeneously, and the differing shapes of the lobes reflect different responses to local mechanical conditions. We suggest that this heterogeneity in strain accommodation is in part a reflection of some left-lateral slip being accommodated on east-west-striking fractures that, in turn, led to northeast-striking extension. Kinematic indicators of slip within the stock were recorded in the field and are shown in figure 2. The transverse set of fractures and dikes is oriented $N. 90^\circ E. (\pm 15^\circ)$. Thus, the fracture network consists of two predominant sets of shear fractures and a range of

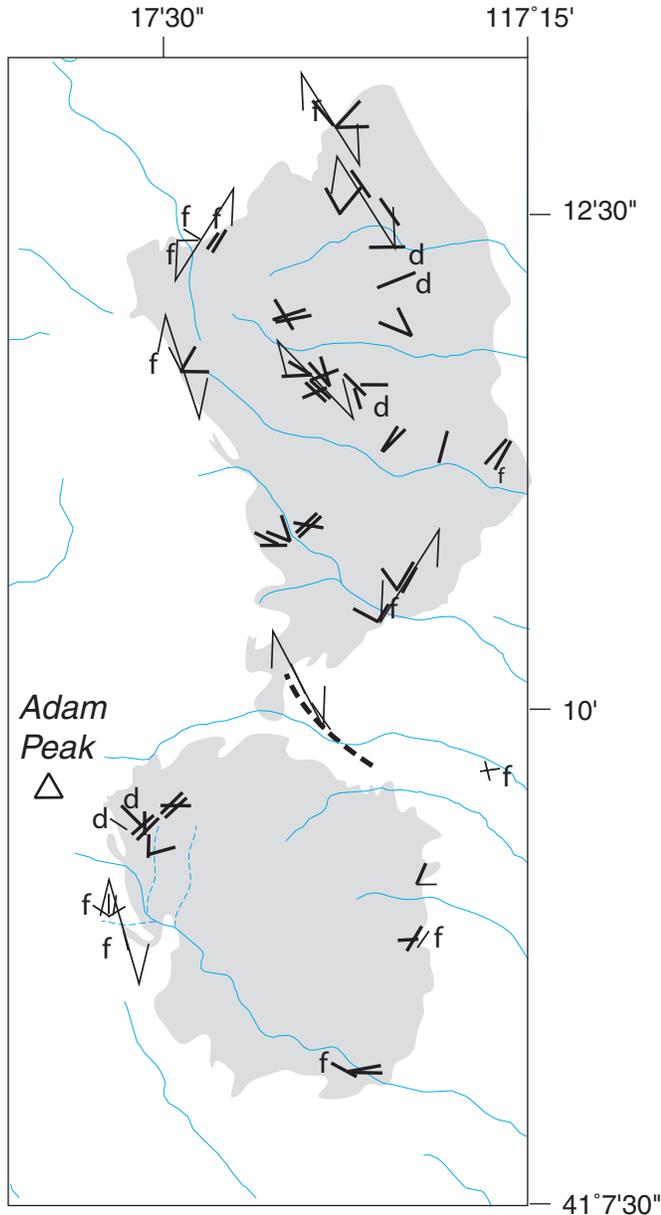


Figure 2. Geologic map of the Osgood Mountains intrusive rocks. Base map from Hotz and Willden (1964). Short lines represent measured orientations of fractures, joints, and dikes (marked with the letter "d"). Faults are marked with the letter "f." Where observed in the field, kinematic indicators are shown as arrows denoting the sense of observed strike-slip offset of fractures.

extensional fractures that resulted from the far- and near-field stresses acting on intrusive rocks at the time of emplacement and one set of antecedent, basement shear fractures that were reactivated during the Late Cretaceous. Each of these fracture sets now provides pathways for present-day ground-water flow and for interactions between ground and surface water.

Methods

Field Methods

Water samples were collected in the field in June and September of 1999 and in June of 2000. In the latter two sampling trips, sites that were sampled in the first trip were resampled to evaluate the degree of change of the overall system and to give some idea of whether the results from each trip could be directly compared. In 1999, 21 samples were collected from streams and springs; in 2000, 24 samples were collected. Of the sites sampled in 2000, five were repeat visits to previous sampling sites.

Field sampling methods included geochemical and hydrologic techniques. At each sampling site, measurements were made for temperature, specific conductivity, and pH of the water using methods cited in Wood (1976). The pH of each sample was measured using a portable pH meter with automatic temperature compensation. The pH meter was calibrated each morning using three standard buffers, with nominal pH values of 7.00, 4.01, and 10.00 at 25°C. Calibration slopes were always within 5 percent of ideal Nernstian behavior. At each subsequent stop during the day, the pH calibration was checked by measuring the pH of one of the standard buffers. Resulting values were always within ± 0.05 pH units of the accepted value. The accuracy of each sample pH measurement is probably also within this range. Temperature was measured using a NIST-traceable electronic thermistor, accurate to within $\pm 0.1^\circ\text{C}$. The stainless steel housing of the temperature sensor allowed temperature measurements to be made in the stream itself, as well as in the streambed by inserting the sensor into the bed. In most cases, temperature differences of several degrees Celsius were observed. Specific conductivity (SpC) was measured using a portable temperature-compensated probe, sensitive to within ± 10 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) and accurate to within ± 20 $\mu\text{S}/\text{cm}$.

Field analyses also were conducted for Fe^{2+} and dissolved oxygen (DO) using colorimetric methods developed by Chemetrics, Inc. In both cases, measurements were made by breaking the tip off an evacuated ampoule that had reagents sealed inside. When the tip was broken, sample was rapidly drawn into the ampoule, mixing with the reagents. Analytical determinations were made by comparison to standards sealed in similar ampoules or by comparison to a printed color chart. Between 0.1 and 1 mg/L, ferrous iron was determined with an accuracy of ± 0.1 mg/L. Between 1 and 10 mg/L, the accuracy was ± 1 mg/L. Dissolved oxygen was determined to a minimum level of 1 mg/L, with an accuracy of ± 1 mg/L.

Samples were collected in the field for later laboratory analyses for major and trace cations, anions, alkalinity, and mercury. Anion samples were filtered through 0.45- μm -nominal-pore-diameter cellulose acetate filters and refrigerated with no further treatment. Cation samples were filtered through the same 0.45- μm filter and acidified by adding 0.5 mL of concentrated ultra high purity nitric acid to each 30-mL

sample. Samples for alkalinity analyses were collected by filling a 125-mL bottle, without filtering or acidification and refrigerating. Mercury samples were filtered with the same 0.45- μm filter into a 60-mL glass bottle. The bottles for mercury analyses were acid washed prior to sampling, and mercury was preserved with a solution of nitric acid and sodium dichromate (O'Leary and others, 1996). For sulfur isotopes, samples were collected into 1-L high-density polyethylene bottles and refrigerated. The samples were filtered through 0.45- μm filters within 2 weeks of sample collection. For every sample type except alkalinity, field blanks were collected using deionized water that was brought from the laboratory and treated as a sample in the field. This procedure helped assure the purity of reagents used for sample preservation, as well as assuring that the samples were not contaminated. In every case, analyses of the field blanks showed below detection concentrations for all constituents.

Laboratory Methods

Upon completion of field work, samples were transported back to USGS laboratories in Denver, Colo. Anion and alkalinity samples were kept cool during transport in insulated containers. Cation analyses were performed by inductively coupled plasma, atomic emission spectroscopy (ICP-AES) (Briggs, 1996) and by ICP-mass spectrometry (ICP-MS) (Lamothe and others, 1996). The ICP-AES results are preferred for major cations (Mg, Ca, Na, K) and Fe, Al, and Si. The ICP-MS results are preferred for all other constituents, including first- and second-row transition elements, rare earth elements, some actinides, etc. All results are reported in the data tables accompanying this report.

Anion analyses were conducted on a Dionex DX-500 ion chromatography (IC) system. The chromatography columns used were the AG-14 and AS-14 guard and separator columns, with a CO_3/HCO_3 eluent. Using this method, good analytical separations were made for fluoride, chloride, nitrate, phosphate, and sulfate. The IC was calibrated each day with a minimum of six standards. The accuracy and precision of the IC was checked by running standards as unknowns in at least 10 percent of the IC runs and by running duplicate analyses of 5 to 10 percent of all samples.

Alkalinity was determined by titrating a 50-mL aliquot of sample with standardized sulfuric acid (Papp and others, 1996). An Orion model 960 automatic titrator was used for these analyses. This instrument includes a 15-sample carousel in which to load samples and standards. For each set of 15 analyses, at least two standards were run to check for accuracy and precision.

Samples collected for mercury analyses were filtered in the field through 0.45- μm filters and stored in glass bottles that had been previously washed with nitric acid and dried. The samples were preserved with a mixture of nitric acid and sodium dichromate (O'Leary and others, 1996). Total mercury in these waters was determined using a cold vapor flow

injection-atomic fluorescence spectrometry method modified from the method as given in O'Leary and others (1996).

Sulfate was precipitated as BaSO_4 from 0.45- μm -filtered samples for isotope analysis. Approximately 0.7 mg of BaSO_4 was combusted with V_2O_5 in an elemental analyzer. The SO_2 gas released was analyzed by mass spectrometry with a reproducibility of $\pm 0.2\%$. Isotope values are reported relative to the Cañon Diablo Troilite standard.

Results and Discussion

Results of field analyses are shown in table 1, including locations as determined by global positioning system (GPS). Laboratory results are shown in tables 2 (anions by IC) and 3 (cations by ICP-AES and ICP-MS). Results of isotopic analyses are shown in table 4.

The sampling strategy employed in this study is amenable to evaluating spatial as well as some temporal variations of the Osgood Mountains hydrogeologic system. Evaluation of temporal variations is mostly limited to direct comparison of results of repeated sampling at selected individual sites, whereas the evaluation of spatial variations can be made at scales ranging from several kilometers to several meters.

Temporal Variability

Table 5 shows the direct comparisons of data for consecutive years for the same sample site. Five sites that were sampled in 1999 were resampled in 2000. Table 5 is displayed in three parts: the first shows selected field parameters and anion data; the second shows selected ICP-MS analytical results; and the third part shows ICP-MS results normalized to chloride. This latter operation was performed to evaluate whether variations between the 2 years worth of sampling can be attributed to evaporation, or if some other process(es) must have occurred. For each parameter from each pair of samples, the difference from 1999 to 2000 is calculated as the difference between the two numbers divided by their mean. For the most part, the differences are less than 25 percent, which is a reasonable threshold above which the differences are unlikely to be due simply to analytical error. As seen in table 5, the parameters whose differences exceed 25 percent are not systematic throughout the range of results for a sample pair, nor do they differ in the same direction (i.e., some parameters increased while others decreased from 1999 to 2000).

When normalizing to chloride, the observations are substantially the same—the differences are not systematic and not in the same direction. Another observation is that, with only a few exceptions, the major cations (Ca, Mg, Na, and K) and anions (F, Cl, and SO_4) are within 25-percent variation. There

Table 1A. Sample-site descriptions and locations, and results of field analyses for samples collected in 1999.

[Latitude (Lat) and longitude (Long) given in decimal degrees (North American Datum of 1927). SpC (specific conductivity) given in microsiemens per cm corrected to 25°C. nd, not detected]

Sample no.	Description	Sample date	Lat	Long	pH	SpC	Water temp (°C)	Streambed temp (°C)	Dissolved oxygen (mg/L)	Fe ²⁺ (mg/L)	Alkalinity	
											(ppm as CaCO ₃)	(ppm as HCO ₃)
99NV-20	Spring at top of drainage north of Rocky Cr.	22-Jun-99	41.2107	-117.2675	7.06	410	11.9		3	nd	193	
99NV-21	Spring at top of Hansen Canyon	22-Jun-99	41.1989	-117.2808	7.41	220	15	12.3	3	nd	124	
99NV-22	Small stream draining wetland area	22-Jun-99	41.1979	-117.2802	7.36	280	23		3.5	nd	116	
99NV-23	Low-conductivity spring about 20 m S. of site 22	22-Jun-99	41.1977	-117.2798	6.46	120	9.5	9.5	3.5	nd	69	
99NV-24	Hansen Creek	22-Jun-99	41.1972	-117.2778	8.03	210	18.4	16.2	4	nd	111	
99NV-25	Summer Camp Creek	22-Jun-99	41.1865	-117.2670	8.14	240	14.4	14	7.5	nd	129	
99NV-26	Rocky Creek	22-Jun-99	41.2070	-117.2692	8.12	310	14.6	15.2	6.5	nd	154	
99NV-27	Alpine mine spring	23-Jun-99	41.1957	-117.2875	7.56	220	8	7.1	6.5	nd	132	
99NV-28	Anderson Canyon near Richmond mine	23-Jun-99	41.2067	-117.2884	8.23	270	9.7	9.1	6.5	nd	136	
99NV-29	Julian Creek west of Osgood stock	23-Jun-99	41.1870	-117.2844	7.07	140	11	10.3	6.5	nd	70	
99NV-30	Julian Creek about 500-800 m inside Osgood stock	23-Jun-99	41.1838	-117.2783	7.95	150	15.2	16	3.5	nd	78	
99NV-31	Julian Creek above unnamed tributary	23-Jun-99	41.1775	-117.2711	8.10	180	19.3	19.5	5	nd	87	
99NV-32	Julian Creek below sites 31 and 33	23-Jun-99	41.1763	-117.2674	8.08	250	17.5		4.5	nd	114	
99NV-33	Unnamed tributary to Julian Creek	23-Jun-99	41.1771	-117.2712	8.02	300	13.3	13.8	6	nd	142	
99NV-34	Unnamed tributary to Granite Creek	24-Jun-99	41.1486	-117.2943	8.46	180	17.4	15.3	4.5	nd	91	
99NV-35	Tributary to Granite Creek	24-Jun-99	41.1520	-117.2883	8.20	170	19.2	16.7	5.5	nd	74	
99NV-36	Small tributary to Granite Creek	24-Jun-99	41.1522	-117.2921	7.95	120	15.9	12.8	6.5	nd	50	
99NV-37	Granite Creek	24-Jun-99	41.1517	-117.2939	8.09	210	13.2	12	5.5	nd	97	
99NV-38	Granite Creek	24-Jun-99	41.1365	-117.2705	8.26	240	17.5	15.1	5	nd	108	
99NV-39	Bunch Canyon	24-Jun-99	41.1508	-117.2612	8.12	210	14.7		6.5	nd	101	
99NV-40	Osgood Creek	24-Jun-99	41.1632	-117.2603	8.31	230	18.9		4.5	nd	99	

Table 1B. Sample-site descriptions and locations, and results of field analyses for samples collected in 2000.

[Latitude (Lat) and longitude (Long) given in decimal degrees (North American Datum of 1927). SpC (specific conductivity) given in microsiemens per cm corrected to 25°C. nd, not detected]

Sample no.	Description	Sample date	Lat	Long	pH	SpC	Water temp (°C)	Streambed temp (°C)	Dissolved oxygen (mg/L)	Fe ²⁺ (mg/L)	Alkalinity	
											(ppm as CaCO ₃)	(ppm as HCO ₃)
00NV-1	Spring north of Rocky Canyon, on Burma Rd.	01-Jun-00	41.2071	-117.2743	6.76	130	9.0	8.7	4	nd		
00NV-2	Spring at head of Rocky Canyon	01-Jun-00	41.2052	-117.2737	6.75	160	9.2	n.d.	4	nd	100	130
00NV-3	Rocky Creek just below road	01-Jun-00	41.2072	-117.2689	8.30	300	16.	n.d.	5	nd	180	220
00NV-4	Spring at crest of ridge along Rocky Creek	01-Jun-00	41.2055	-117.2641	6.63	220	10.5	n.d.	8	nd	95	120
00NV-5	Spring above N. Rocky Cr.	02-Jun-00	41.2103	-117.2675	7.44	370	15.1	11.8	5	nd		
00NV-6	Spring 5-10 m N. of 00NV-5	02-Jun-00	41.2103	-117.2675	7.75	480	18.1	11.2		nd	230	280
00NV-7	Rocky Creek at jog	02-Jun-00	41.2060	-117.2641	8.17	290	21.4	11.1	6	nd	180	220
00NV-8	Hansen Creek below possible lineament	02-Jun-00	41.1964	-117.2657	8.25	320	15.3	13.9	6	nd	150	180
00NV-9	Hansen Creek above dike ridge	02-Jun-00	41.1972	-117.2658	7.75	370	21.6	18.8	6	nd	190	230
00NV-10	Osgood Creek above Valley View mine road.	03-Jun-00	41.1637	-117.2605	8.23	220	11.5	10.6	10	nd	120	140
00NV-11	Tributary to Osgood Creek from south	03-Jun-00	41.1641	-117.2738	7.62	180	12.3	10.5	7	nd	68	83
00NV-12	Osgood Creek above 2nd road crossing	03-Jun-00	41.1655	-117.2762	8.22	170	12.9	10.7	8.5	nd	110	130
00NV-13	N. Fork Osgood Creek	03-Jun-00	41.1662	-117.2798	7.87	270	12.8	11.7	8	nd	150	190
00NV-14	S. Fork Osgood Creek	03-Jun-00	41.1659	-117.2799	7.74	160	12.7	11.2	8	nd	86	110
00NV-15	S. Fork Osgood Creek	03-Jun-00	41.1652	-117.2866	7.91	130	14.3	13.3	9	nd	63	77
00NV-16	Small tributary to S. fork of Osgood Cr.	03-Jun-00	41.1633	-117.2843	7.57	140	16.1	13.1	8	nd	67	82
00NV-17	Small drainage to south of Osgood Cr.	04-Jun-00	41.1594	-117.2715	6.79	120	10.9	n.d.	7	nd	66	80
00NV-18	Approx. 200-300 m downstream from site 17	04-Jun-00	41.1594	-117.2695	7.61	140	20.6	n.d.	7	0.1 to 0.2	76	93
00NV-19	Same creek, lower elevation from site 18	04-Jun-00	41.1596	-117.2644	7.76	170	19.7	n.d.	8	0.2	94	110
00NV-20	Summer Camp Creek at lower road crossing	05-Jun-00	41.1853	-117.2534	8.28	280	12.3	12.0	8	nd		
00NV-21	Small stream along N of Summer Camp Cr.	05-Jun-00	41.1891	-117.2567	7.41	280	13.3	12.1	8	0.1		
00NV-22	Approx 500 m upstream from site 20 on Summer Camp Creek	05-Jun-00	41.1872	-117.2577	8.43	270	13.3	12.2	7	nd		
00NV-23	Summer Camp Creek at upper road	05-Jun-00	41.1868	-117.2668	8.28	270	17.1	12.6	7	nd		
00NV-25	Anderson Canyon south of Richmond mine	05-Jun-00	41.2066	-117.2886	8.34	270	11.3	10.4	7	nd		

Table 2. Results of anion analyses of water samples.

[All results reported in mg/L. n.d., not detected. Samples 99NV-41 and 00NV-24 are field blanks]

Sample no.	F	Cl	NO ₃	PO ₄	SO ₄
Samples collected in 1999					
99NV-20	0.33	13.5	4.2	0.45	40.5
99NV-21	0.21	4.97	0.36	0.58	7.44
99NV-22	0.23	5.53	0.23	0.62	9.03
99NV-23	0.16	3.78	0.2	n.d.	8.72
99NV-24	0.21	4.61	n.d.	0.62	7.59
99NV-25	0.2	4.46	1.39	0.28	12.3
99NV-26	0.29	7.69	0.73	0.52	18.1
99NV-27	0.09	1.16	3.37	n.d.	4.75
99NV-28	0.17	5.37	0.39	0.23	13.3
99NV-29	0.07	2.56	1.43	n.d.	9.33
99NV-30	0.08	2.88	1.52	n.d.	10.7
99NV-31	0.11	3.71	1.92	0.2	12.6
99NV-32	0.16	4.09	1.6	0.17	14.6
99NV-33	0.2	4.47	0.7	n.d.	20.0
99NV-34	0.11	0.99	0.29	n.d.	11.4
99NV-35	0.18	2.08	4.38	n.d.	10.5
99NV-36	0.15	2.35	12.78	n.d.	7.95
99NV-37	0.16	1.24	1.69	n.d.	17.6
99NV-38	0.21	3.74	2.45	n.d.	17.4
99NV-39	0.23	5.85	n.d.	0.52	10.6
99NV-40	0.18	3.15	1.17	0.36	18.4
99NV-41	0	0	0.2	0	0
Samples collected in 2000					
00NV-1	0.22	8.1	4.1	n.d.	18
00NV-2	0.21	2.84	1.1	n.d.	8.84
00NV-3	0.31	8.5	0.06	0.36	19
00NV-4	0.24	5.79	5.1	n.d.	14
00NV-5	0.37	12.5	n.d.	0.26	36.8
00NV-6	0.3	13.1	n.d.	0.26	38
00NV-7	0.37	7.54	n.d.	2	18
00NV-8	0.29	9.4	n.d.	n.d.	24.9
00NV-9	0.24	10.2	n.d.	n.d.	24.8
00NV-10	0.16	2.98	0.1	0.36	18.2
00NV-11	0.19	4.84	n.d.	n.d.	26.7
00NV-12	0.15	1.91	0.18	n.d.	12.84
00NV-13	0.17	1.47	n.d.	n.d.	15.54
00NV-14	0.13	1.79	0.34	n.d.	10.37
00NV-15	0.1	1.09	n.d.	n.d.	8.77
00NV-16	0.15	2.32	n.d.	1.92	10.9
00NV-17	0.13	2.64	n.d.	n.d.	11.71
00NV-18	0.17	2.85	n.d.	n.d.	7.86
00NV-19	0.17	2.42	n.d.	n.d.	6.32
00NV-20	0.29	6.61	0.11	n.d.	17
00NV-21	0.34	7.08	13.3	n.d.	23
00NV-22	0.28	5.42	n.d.	1.97	14.1
00NV-22a	0.29	5.38	n.d.	1.95	14
00NV-23	0.24	5.3	0.06	0.46	14.2
00NV-24	0	0	0	0	0
00NV-25	0.19	5.5	0.1	0.36	12

Table 3A. ICP-AES results for water samples collected in 1999.

[Analyses not shown include Be, V, Co, Cr, Ag, Ni, and Zn (all < 10 µg/L), Ti (all < 50 µg/L), As and Sb (all < 100 µg/L), Mo (all < 20 µg/L, except 99NV-39, which was 25 µg/L), Cd (all < 5 µg/L), and Pb (all < 50 µg/L)]

Field no.	Sample description	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Li (µg/L)	B (µg/L)	Al (mg/L)	Si (mg/L)	Mn (µg/L)	Fe (mg/L)	Cu (µg/L)	Sr (µg/L)	Ba (µg/L)
99NV20	Spring north of Rocky Cr.	51	9.9	36	4.3	18.	140	0.22	19.1	<10	<0.02	<10	400	92.
99NV21	Spring at top of Hansen Canyon	31	5.7	16	4.1	<10	71.	0.020	21.3	22	0.048	<10	255	114
99NV22	Small stream in Hansen canyon	29	5.4	17	4.8	37.	140	0.014	23.4	22.	0.12	<10	273	108
99NV23	Small stream in Hansen canyon	17	3.1	13	3.2	<10	34	0.27	22.8	150	0.17	<10	174	80.
99NV24	Hansen Creek	27	4.9	16	4.3	<10	65	0.012	22.4	25	0.025	<10	239	96.
99NV25	Summer Camp Cr.	39	4.6	14	4.3	<10	55	0.11	19.8	<10	0.13	12	207	88.
99NV26	Rocky Cr.	38	7.5	24	4.2	13	110	<0.01	20	27	<0.02	10	366	123
99NV27	Alpine mine pit water	51	1.6	3.2	0.64	<10	15	<0.01	13	<10	<0.02	11	92	6.9
99NV28	Andersen Canyon near Richmond mine	45	4.0	11.	2.3	<10	45	<0.01	19.6	<10	<0.02	10	162	62.
99NV29	Julian Cr. near top of drainage	19	3.8	8.0	2.5	<10	24	<0.01	12.5	<10	<0.02	10	66	13.
99NV30	Julian Cr.	21	4.2	8.9	2.8	<10	26	<0.01	13.1	<10	<0.02	<10	73.	16.
99NV31	Julian Cr.	23	4.9	12	3.8	<10	39	<0.01	14.5	<10	<0.02	<10	116	37.
99NV32	Julian Cr.	34	4.9	12	3.2	<10	46	<0.01	15.9	<10	<0.02	<10	136	52.
99NV33	Tributary to Julian Cr.	52	3.5	11	2.1	<10	45	<0.01	17.3	<10	<0.02	<10	136	55
99NV34	Tributary to Granite Cr.	30	4.8	5.8	0.79	<10	19	<0.01	10.7	<10	<0.02	<10	76.	22.
99NV35	Tributary to Granite Cr.	19	3.6	12	2.8	<10	48	<0.01	14.1	<10	<0.02	<10	182	86.
99NV36	Tributary to Granite Cr.	14	3.3	9.6	2.1	<10	29	<0.01	12.5	<10	<0.02	<10	160	74.
99NV37	Granite Cr.	36	2.2	5.5	1.5	<10	21	<0.01	14.8	<10	<0.02	<10	68.	27.
99NV38	Granite Cr.	33	4.6	12	2.8	<10	52	<0.01	14.6	<10	<0.02	<10	156	71.
99NV39	Bunch Canyon	22	5.2	18	4	<10	77	<0.01	16.5	<10	<0.02	<10	234	100
99NV40	Osgood Cr.	35	3.2	8.9	2.4	<10	38	<0.01	15.2	<10	<0.02	<10	104	43.
99NV41	Field blank	<0.1	<0.1	<0.1	<0.1	<10	<10	<0.01	<0.1	<10	<0.02	<10	<1	2.2

Table 3B. ICP-AES results for water samples collected in 2000.

[Analyses not shown include Be, V, Cr, Co, Ni, Cu, Zn, Ag, and Cd (all < 10 µg/L), Al (all < 10 µg/L, except 00NV-16, which was 18 µg/L), Ti (all < 50 µg/L), Fe (all < 50 µg/L, except 00NV-18, and 00NV-19, which were both 13 µg/L), As and Sb (all < 100 µg/L), Mo (all < 20 µg/L), and Pb (all < 100 µg/L)]

Field no.	Sample description	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Li (µg/L)	B (µg/L)	Si (mg/L)	Mn (µg/L)	Sr (µg/L)	Ba (µg/L)
00NV-1	Spring north of Rocky Canyon	28	4.9	22	3.4	13	76	16	<10	290	130
00NV-2	Spring at head of Rocky Canyon	22	3.9	14	2.1	<10	50	14	<10	220	76
00NV-3	Rocky Creek just below road	36	6.8	26	3.9	14	120	19	<10	370	120
00NV-4	Spring at ridge crest above Rocky Cr.	21	3.9	20	2.3	16	69	16	<10	240	96
00NV-5	Spring above N Rocky Cr.	47	9.1	36	4.1	20	150	19	31	450	130
00NV-6	Spring 5-10 m N. of 00NV-5	50	9.6	38	4.3	21	160	18	34	430	100
00NV-7	Rocky Creek at jog	35	6.1	26	4.2	14	130	19	<10	360	120
00NV-8	Hansen Creek below lineament	35	6.6	26	3	13	110	18	<10	340	96
00NV-9	Hansen Creek above dike ridge	39	6.8	27	2	11	130	19	55	370	96
00NV-10	Osgood Creek above Valley View mine	35	2.9	8.9	2.1	<10	42	15	<10	100	42
00NV-11	Tributary to Osgood Creek from south	21	3.4	12	1.9	<10	46	12	<10	140	41
00NV-12	Osgood Creek above 2nd road crossing	28	2.5	7.6	2.2	<10	35	14	<10	83	40
00NV-13	N. fork Osgood Creek	44	2.6	7.6	2	<10	39	15	<10	95	47
00NV-14	S. Fork Osgood Creek	22	2.3	7.1	2.2	<10	29	13	<10	76	36
00NV-15	S. Fork Osgood Creek	19	1.5	5	2	<10	23	12	<10	51	21
00NV-16	Small tributary to S. fork of Osgood Cr.	13	2.8	9.5	3.6	<10	34	15	<10	130	73
00NV-17	Small drainage to south of Osgood Cr.	12	2.6	9.1	1.5	<10	36	11	<10	110	58
00NV-18	Approx. 200-300 m downstream from site 17	14	2.8	11	2	<10	49	13	<10	140	70
00NV-19	Same creek lower elevation from site 18	18	3.4	13	2.6	<10	61	14	10	160	70
00NV-20	Summer Camp Creek at lower road crossing	32	5.3	20	2.6	14	82	18	<10	240	84
00NV-21	Small stream N. of Summer Camp Cr.	27	5.8	22	5.7	21	99	16	<10	230	88
00NV-22	500 m upstream of site 20 on Summer Camp Cr.	32	4.9	18	2.5	10	74	19	<10	220	76
00NV-22a	Sample duplicate	32	4.9	18	2.6	11	76	19	<10	230	82
00NV-23	Summer Camp Cr. at upper road crossing	33	4.3	16	2.8	<10	64	19	11	220	86
00NV-24	Field blank	<0.1	<0.1	<0.1	<0.1	<10	<10	<0.1	<10	<1	<1
00NV-25	Anderson Canyon near Richmond mine	41	4	12	2.2	<10	50	19	<10	170	61

Table 3C. ICP-MS results for water samples collected in 1999.

[All results shown, except for Be (all < 60 µg/L), Cr (all < 1 µg/L), Ag, Cs, and Bi (all < 10 µg/L), Pr (all < 10 µg/L, except 99NV-23, which was 30 µg/L, and 99NV-25, which was 20 µg/L), Sm (all < 10 µg/L, except 99NV-23, which was 30 µg/L, and 99NV-25, which was 10 µg/L), Yb (all < 10 µg/L, except 99NV-23, which was 20 µg/L), Tb, Ho, and Tm (all < 5 µg/L), Tl (all < 50 µg/L, except 99NV-23, which was 20 µg/L), and Th (all < 30 µg/L)]

Field no.	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (µg/L)	Li (µg/L)	Al (µg/L)	SiO2 (mg/L)	Sc (µg/L)	Ti (µg/L)	V (µg/L)	Fe (µg/L)	Mn (µg/L)	Co (µg/L)	Ni (µg/L)	Cu (µg/L)	Zn (µg/L)	As (µg/L)	Se (µg/L)
99NV-20	36	6.8	24	3100	15	5	27	1	0.52	4.3	< 30	1.1	0.03	0.1	15	2	4.5	0.8
99NV-21	22	3.6	9.8	3200	6.8	3	29	1	0.2	1.4	< 30	15	0.09	0.4	9	1	2	< 0.2
99NV-22	18	3.2	10	3300	3.5	16	29	0.4	0.1	0.65	99	15	0.2	0.3	4	1	2.2	< 0.2
99NV-23	10	1.9	7.7	2100	2	160	28	0.9	4.9	1.4	80	110	0.3	0.8	6	6	0.3	< 0.2
99NV-24	19	3.0	10	3100	5.6	7	30	1	0.2	1.6	< 30	19	0.09	0.2	4	0.6	2.1	< 0.2
99NV-25	26	2.7	8.6	3100	6.9	69	27	1	4.2	3.2	68	6.7	0.03	0.3	3	2	1	< 0.2
99NV-26	27	4.7	15	3100	10	4	27	1	0.3	3.7	< 30	20	0.04	0.2	4	2	3.3	< 0.2
99NV-27	36	1.1	2.0	460	< 0.8	< 2	19	0.8	< 0.1	0.73	< 30	0.10	< 0.02	0.2	7	2	0.7	< 0.2
99NV-28	33	2.6	7.2	1700	4.6	< 2	28	1	0.1	2.6	< 30	0.47	< 0.02	0.2	3	< 0.5	0.8	< 0.2
99NV-29	12	2.6	4.8	1900	< 0.8	< 2	17	0.5	< 0.1	1.1	< 30	1.3	< 0.02	0.1	3	1	1	< 0.2
99NV-30	15	2.7	5.5	2100	< 0.8	2	18	0.6	< 0.1	1.3	< 30	0.56	< 0.02	< 0.1	2	0.6	1	< 0.2
99NV-31	15	3.3	7.1	2800	2	6	20	0.4	0.1	1.7	< 30	2.1	< 0.02	< 0.1	2	< 0.5	1	< 0.2
99NV-32	24	3.2	7.4	2600	3	6	21	0.2	0.1	2.3	< 30	2.3	0.03	0.3	2	0.6	2.1	0.3
99NV-33	35	2.2	6.6	1600	3.6	< 2	24	0.6	< 0.1	3.0	< 30	2.9	< 0.02	0.3	2	< 0.5	2.5	0.3
99NV-34	20	3.2	3.7	510	< 0.8	< 2	15	0.2	< 0.1	0.2	< 30	0.51	< 0.02	0.1	1	< 0.5	0.7	< 0.2
99NV-35	14	2.3	7.9	2200	5.5	5	20	0.4	0.2	2.0	< 30	0.37	< 0.02	< 0.1	2	1	0.2	< 0.2
99NV-36	9.4	2.3	6.2	1600	3	9.2	17	0.3	< 0.1	1.8	< 30	0.47	< 0.02	< 0.1	1	3	< 0.2	< 0.2
99NV-37	26	1.6	3.8	1200	0.9	< 2	21	0.6	< 0.1	1.8	< 30	1.1	< 0.02	1.1	2	< 0.5	0.9	0.3
99NV-38	25	3.2	7.9	2200	4.1	< 2	21	0.5	< 0.1	2.6	< 30	3.1	< 0.02	0.2	1	< 0.5	1	0.3
99NV-39	16	3.5	12	3200	5.3	3	25	0.9	< 0.1	3.2	< 30	0.30	< 0.02	0.2	2	< 0.5	1	< 0.2
99NV-40	26	2.2	5.9	2000	2	2	24	0.4	0.1	2.5	< 30	1.4	< 0.02	0.4	1	0.6	1	0.4
99NV-41	< 0.05	< 0.01	< 0.01	< 5	< 0.8	< 2	< 0.5	< 0.1	< 0.1	< 0.2	< 30	< 0.04	< 0.02	< 0.1	0.9	1	< 0.2	< 0.2

Table 3C. ICP-MS results for water samples collected in 1999—*Continued.*

Field no.	Rb (µg/L)	Sr (µg/L)	Y (µg/L)	Mo (µg/L)	Cd (µg/L)	Sb (µg/L)	Ba (µg/L)	La (µg/L)	Ce (µg/L)	Nd (µg/L)	Eu (µg/L)	Gd (µg/L)	Dy (µg/L)	Er (µg/L)	W (µg/L)	U (µg/L)
99NV-20	0.54	290	0.01	20	< 0.02	0.24	81	< 0.01	< 0.01	< 0.01	0.006	0.005	< 0.005	< 0.005	0.53	13
99NV-21	0.60	200	0.03	2.5	< 0.02	0.13	100	< 0.01	0.01	0.02	< 0.005	< 0.005	0.01	< 0.005	0.4	1.4
99NV-22	0.98	220	0.05	0.84	< 0.02	0.12	96	0.02	0.03	0.03	0.009	0.01	0.01	< 0.005	0.2	0.35
99NV-23	0.90	130	0.1	0.4	< 0.02	3.0	73	0.06	0.08	0.1	0.005	0.04	0.02	0.02	0.07	0.16
99NV-24	0.70	190	0.04	1.6	< 0.02	0.14	83	< 0.01	0.02	0.02	< 0.005	< 0.005	0.006	< 0.005	0.4	1.4
99NV-25	0.74	160	0.07	5.1	< 0.02	0.22	77	0.04	0.07	0.08	0.009	0.02	0.02	0.006	0.54	3.8
99NV-26	0.50	290	0.04	5.8	< 0.02	0.21	110	< 0.01	0.02	0.02	0.006	0.005	0.005	< 0.005	0.66	8.8
99NV-27	0.50	77	0.07	0.90	0.02	0.07	7.1	< 0.01	< 0.01	0.01	< 0.005	< 0.005	0.006	0.008	0.2	0.26
99NV-28	0.2	130	0.01	13	< 0.02	0.12	59	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	1.9	3.0
99NV-29	0.2	54	0.01	0.70	< 0.02	0.096	11	< 0.01	< 0.01	0.02	< 0.005	0.005	< 0.005	< 0.005	0.1	0.17
99NV-30	0.2	62	< 0.01	0.87	< 0.02	0.18	15	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.1	0.29
99NV-31	0.3	88	0.02	2.8	< 0.02	0.17	36	< 0.01	< 0.01	0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.3	0.75
99NV-32	0.4	110	0.03	5.7	< 0.02	0.13	49	< 0.01	0.01	0.02	< 0.005	0.01	0.005	< 0.005	0.50	1.7
99NV-33	0.4	110	0.02	14	< 0.02	0.15	50	< 0.01	< 0.01	0.02	< 0.005	< 0.005	< 0.005	< 0.005	0.92	2.2
99NV-34	0.2	59	0.03	0.96	< 0.02	0.12	20	< 0.01	< 0.01	0.01	< 0.005	< 0.005	0.006	< 0.005	0.2	0.43
99NV-35	0.2	140	0.01	5.0	< 0.02	0.14	75	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.1	0.68
99NV-36	0.1	130	0.01	8.8	< 0.02	0.10	69	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.50	0.60
99NV-37	0.4	55	0.01	4.4	0.04	0.28	30	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.3	0.68
99NV-38	0.5	120	0.02	12	0.04	0.22	70	< 0.01	< 0.01	< 0.01	0.005	< 0.005	< 0.005	< 0.005	0.74	2.0
99NV-39	0.3	200	0.02	26	< 0.02	0.13	90	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	1.1	1.3
99NV-40	0.61	95	0.02	8.8	0.02	0.16	42	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.4	1.3
99NV-41	< 0.01	0.06	< 0.01	0.2	< 0.02	0.05	2.3	< 0.01	< 0.01	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	0.03	< 0.006

Table 3D. ICP-MS results for water samples collected in 2000.

[All results shown, except for the following: Au, Bi, In, Pr, Sm, and Yb (all < 10 µg/L), Cs (all < 10 µg/L, except 00NV-4, which was 40 µg/L, and 00NV-25, which was 10 µg/L), Be and Tl (all < 50 µg/L), Pb (all < 50 µg/L, except 00NV-1, which was 60 µg/L), Ga, Ge, and Re (all < 20 µg/L), Co (all < 20 µg/L, except 00NV-19, which was 20 µg/L), Cr and Ni (all < 100 µg/L), Er, Eu, Ho, Tb, and Tm (all < 5 µg/L), Gd (all < 5 µg/L, except 00NV-16, which was 5 µg/L, and 00NV-18, which was 7 µg/L), and Th (all < 5 µg/L, except 00NV-1, which was 30 µg/L)]

Field no.	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (µg/L)	Li (µg/L)	Al (µg/L)	SiO ₂ (mg/L)	V (µg/L)	Fe (µg/L)	Mn (µg/L)	Cu (µg/L)	Zn (µg/L)	As (µg/L)	Se (µg/L)
00NV-1	23	3.7	13	2400	11	<0.5	28	4	10	2.2	0.7	4	1	0.3
00NV-2	16	2.8	8.4	1400	4	<0.5	24	2	42	1.6	<0.5	10	0.6	0.2
00NV-3	29	4.8	16	2600	12	<0.5	34	4	18	4.7	<0.5	0.7	2.8	0.3
00NV-4	16	2.9	12	1600	13	<0.5	28	4	4.9	1.6	<0.5	1	1	< 0.2
00NV-5	39	6.6	23	2800	17	<0.5	33	3	42	28	<0.5	1	3	0.4
00NV-6	42	6.8	24	2900	19	<0.5	32	4	32	31	0.6	<0.5	4.2	1
00NV-7	27	4.6	16	2900	12	<0.5	34	6.3	21	2.7	0.5	0.7	3.8	0.4
00NV-8	29	4.8	17	2100	12	<0.5	33	3	16	1.1	<0.5	0.8	2.3	0.3
00NV-9	35	5.2	19	1500	11	<0.5	36	1	34	52	<0.5	1	3.1	0.3
00NV-10	29	2.4	6.2	1500	2.2	<0.5	27	2	15	0.59	<0.5	0.9	1	0.5
00NV-11	19	3	8.9	1500	3.1	<0.5	23	2	6.9	1.2	0.5	1	1	0.4
00NV-12	24	2	5.4	1700	1.1	<0.5	25	2	12	1.2	<0.5	0.7	0.7	0.2
00NV-13	38	2.2	5.6	1500	1.6	<0.5	28	2	23	0.2	<0.5	0.6	1	0.3
00NV-14	19	1.9	5.2	1700	1.2	6.4	24	1	14	1.8	<0.5	1	0.5	0.2
00NV-15	16	1.2	3.7	1500	< 0.4	<0.5	21	1	4.6	0.3	0.5	0.6	0.5	< 0.2
00NV-16	12	2.3	7.1	2700	5.7	13	27	2	11	4.8	<0.5	0.6	0.7	< 0.2
00NV-17	11	2.2	7.2	1200	2.7	<0.5	21	0.7	1.7	0.3	<0.5	1	0.2	< 0.2
00NV-18	12	2.3	8.1	1600	3.1	2	24	1	78	6.1	<0.5	1	0.8	< 0.2
00NV-19	15	2.9	9.6	2000	4.9	0.6	26	2	77	10	<0.5	0.6	1	< 0.2
00NV-20	30	4.4	15	2100	13	<0.5	35	4	20	1.6	<0.5	0.6	2.1	0.3
00NV-21	25	5	16	4600	22	4.3	30	4	18	4.1	<0.5	0.8	1	0.4
00NV-22	30	4.2	14	2100	11	<0.5	36	3	26	3.2	<0.5	1	2	0.2
00NV-22a	30	4.3	14	2100	11	5.2	37	4	31	2.9	<0.5	0.6	2	0.3
00NV-23	30	3.8	13	2200	9.2	<0.5	36	4	26	11	<0.5	0.6	1	0.3
00NV-24	<0.05	<0.01	<0.01	<2	< 0.4	<0.5	< 0.5	<0.1	<1	<0.02	<0.5	2	<0.2	< 0.2
00NV-25	37	3.4	9.8	1800	5.8	<0.5	36	3	25	0.34	0.9	2	0.8	< 0.2

Table 3D. ICP-MS results for water samples collected in 2000—*Continued.*

Field no.	Rb (µg/L)	Sr (µg/L)	Y (µg/L)	Mo (µg/L)	Ag (µg/L)	Cd (µg/L)	Sb (µg/L)	Ba (µg/L)	La (µg/L)	Ce (µg/L)	Nd (µg/L)	Dy (µg/L)	W (µg/L)	U (µg/L)
00NV-1	0.2	270	0.03	6.2	0.05	<0.02	0.08	130	0.03	0.04	0.03	< 0.005	0.4	9.7
00NV-2	0.3	180	0.03	4.4	0.02	0.04	0.05	72	0.02	0.01	0.02	< 0.005	0.1	2.3
00NV-3	0.5	320	0.04	5.8	0.01	<0.02	0.1	120	0.02	0.03	0.02	0.006	0.57	8.4
00NV-4	0.2	200	0.03	0.95	<0.01	<0.02	0.06	91	0.02	< 0.01	0.02	< 0.005	0.09	6.6
00NV-5	0.68	400	0.05	16	<0.01	<0.02	0.1	120	< 0.01	0.02	< 0.01	< 0.005	0.68	18
00NV-6	0.69	390	0.04	21	<0.01	<0.02	0.2	100	0.02	0.05	0.02	< 0.005	0.64	14
00NV-7	0.56	310	0.04	5.4	<0.01	<0.02	0.2	120	0.02	0.04	0.03	0.005	0.58	11
00NV-8	0.69	300	0.03	18	<0.01	<0.02	0.1	94	0.01	0.02	0.01	< 0.005	0.88	11
00NV-9	1	370	0.06	18	<0.01	<0.02	0.1	100	0.01	0.03	0.02	< 0.005	0.8	4.8
00NV-10	0.52	100	0.02	8.5	<0.01	<0.02	0.08	44	< 0.01	< 0.01	< 0.01	< 0.005	0.3	1.4
00NV-11	0.3	140	0.02	5.9	<0.01	0.04	0.08	46	0.01	0.02	0.02	< 0.005	0.3	0.68
00NV-12	0.54	84	0.02	5.4	<0.01	<0.02	0.07	44	< 0.01	< 0.01	< 0.01	< 0.005	0.07	0.86
00NV-13	0.54	96	0.01	4.1	<0.01	0.02	0.1	51	< 0.01	< 0.01	< 0.01	< 0.005	0.1	1.1
00NV-14	0.5	79	0.02	5.2	<0.01	<0.02	0.06	40	< 0.01	< 0.01	0.01	< 0.005	0.06	0.65
00NV-15	0.73	51	0.01	4.6	<0.01	<0.02	0.05	24	< 0.01	< 0.01	< 0.01	< 0.005	0.08	0.34
00NV-16	0.3	130	0.04	3.9	<0.01	<0.02	0.05	81	0.03	0.04	0.04	< 0.005	0.08	0.41
00NV-17	0.1	110	0.01	1.5	<0.01	<0.02	0.02	65	< 0.01	< 0.01	0.01	< 0.005	0.1	0.14
00NV-18	0.55	140	0.03	1.1	<0.01	<0.02	0.03	78	0.02	0.04	0.02	< 0.005	0.3	0.16
00NV-19	0.57	150	0.04	2.1	<0.01	<0.02	0.04	76	0.02	0.03	0.03	0.007	0.4	0.72
00NV-20	0.4	230	0.03	15	<0.01	<0.02	0.1	90	0.01	0.01	0.01	< 0.005	1.4	7.2
00NV-21	1.2	220	0.03	20	<0.01	<0.02	0.08	93	0.02	0.03	0.03	< 0.005	1.8	5.6
00NV-22	0.4	210	0.03	10	<0.01	<0.02	0.09	88	0.01	0.02	0.02	< 0.005	0.91	6.1
00NV-22a	0.4	220	0.03	11	<0.01	<0.02	0.09	90	0.01	0.01	0.02	< 0.005	0.89	6.1
00NV-23	0.5	200	0.02	6.1	<0.01	<0.02	0.08	90	0.01	0.02	0.01	< 0.005	0.52	4.5
00NV-24	< 0.01	< 0.02	< 0.01	0.09	<0.01	<0.02	<0.02	0.2	< 0.01	< 0.01	< 0.01	< 0.005	0.03	< 0.005
00NV-25	0.3	160	0.02	17	<0.01	<0.02	0.09	65	< 0.01	< 0.01	< 0.01	< 0.005	1.9	4.6

Table 4. Results of sulfur isotopic analyses of water samples.

[All values are given in permil deviations relative to Cañon Diablo Troilite (CDT). na, not analyzed]

Sample no.	$\delta^{34}\text{S SO}_4$	Sample no.	$\delta^{34}\text{S SO}_4$
99NV-20	8.7	00NV-1	8.09
99NV-21	11.8	00NV-2	6.89
99NV-22	13.9	00NV-3	8.70
99NV-23	9.7	00NV-4	8.09
99NV-24	11.6	00NV-5	10.45
99NV-25	9.4	00NV-6	7.83
99NV-26	na	00NV-7	9.56
99NV-27	12.3	00NV-8	6.95
99NV-28	10.6	00NV-9	8.20
99NV-29	15.3	00NV-10	8.41
99NV-30	14.9	00NV-11	5.41
99NV-31	13.5	00NV-12	9.05
99NV-32	11.9	00NV-13	10.71
99NV-33	10.1	00NV-14	8.76
99NV-34	7.2	00NV-15	8.40
99NV-35	6.6	00NV-16	7.71
99NV-36	7.3	00NV-17	7.28
99NV-37	6	00NV-18	8.98
99NV-38	7.2	00NV-19	na
99NV-39	9	00NV-20	8.26
99NV-40	8.4	00NV-21	6.58
		00NV-22	8.95
		00NV-23	8.64
		00NV-25	11.42

Table 5. Comparison of 1999 and 2000 samples from the same locations.

[In "Percent difference" rows, the percentage of difference is calculated by the following formula: %diff. = (1999 value – 2000 value)/(average of 1999 and 2000 values). Values in excess of ± 25 percent appear in bold]

ANION DATA AND SELECTED FIELD PARAMETERS							
Sample no.	pH	SpC ($\mu\text{S/cm}$)	T ($^{\circ}\text{C}$)	F (mg/L)	Cl (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)
00NV-25	8.33	270	11.3	0.19	5.5	0.1	12
99NV-28	8.23	265	9.7	0.17	5.37	0.39	13.3
Percent difference		-1.9	-15	-11	-2.4	120	10
00NV-3	8.3	300	16	0.31	8.5	0.06	19
99NV-26	8.11	310	14.6	0.29	7.69	0.73	18.1
Percent difference		3.3	-9.2	-6.7	-10	170	-4.9
00NV-23	8.28	270	17.1	0.24	5.3	0.06	14.2
99NV-25	8.14	240	14.4	0.2	4.46	1.39	12.3
Percent difference		-12	-17	-18	-17	180	-14
00NV-10	8.23	220	11.5	0.16	2.98	0.1	18.2
99NV-40	8.31	230	18.9	0.18	3.15	1.17	18.4
Percent difference		4.4	49	12	5.5	170	1.1
00NV-6	7.75	480	18.1	0.3	13.1		38
99NV-20	7.061	410	11.9	0.33	13.5	4.2	40.5
Percent difference		-16	-41	9.5	3.0		6.4

Table 5. Comparison of 1999 and 2000 samples from the same locations—*Continued.*

ORIGINAL ICP-MS DATA																			
Sample no.	Major cations					Other major and minor constituents													
	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (μg/L)	Li (μg/L)	SiO ₂ (mg/L)	Ba (μg/L)	Sr (μg/L)	Rb (μg/L)	V (μg/L)	Mn (μg/L)	Fe (μg/L)	Cu (μg/L)	As (μg/L)	Y (μg/L)	Mo (μg/L)	Sb (μg/L)	W (μg/L)	U (μg/L)
00NV-25	37	3.4	9.8	1800	5.8	36	65	160	0.3	3	0.34	25	0.9	0.8	0.02	17	0.09	1.9	4.6
99NV-28	33	2.6	7.2	1700	4.6	28	59	130	0.2	2.6	0.47	< 30	3	0.8	0.01	13	0.12	1.9	3.0
Percent difference	-11	-27	-31	-6	-23	-25	-10	-21	-40	-14	32		108	0	-67	-27	29	0	-42
00NV-3	29	4.8	16	2600	12	34	120	320	0.5	4	4.7	18	<0.5	2.8	0.04	5.8	0.1	0.57	8.4
99NV26	27	4.7	15	3100	10	27	110	290	0.50	3.7	20	< 30	4	3.3	0.04	5.8	0.21	0.66	8.8
Percent difference	-7	-2	-6	18	-18	-23	-9	-10	0	-8	124			16	0	0	71	15	5
00NV-23	30	3.8	13	2200	9.2	36	90	200	0.5	4	11	26	<0.5	1	0.02	6.1	0.08	0.52	4.5
99NV25	26	2.7	8.6	3100	6.9	27	77	160	0.74	3.2	6.7	68	3	1	0.07	5.1	0.22	0.54	3.8
Percent difference	-14	-34	-41	34	-29	-29	-16	-22	39	-22	-49	89		0	111	-18	93	4	-17
00NV-10	29	2.4	6.2	1500	2.2	27	44	100	0.52	2	0.59	15	<0.5	1	0.02	8.5	0.08	0.3	1.4
99NV40	26	2.2	5.9	2000	2	24	42	95	0.61	2.5	1.4	< 30	1	1	0.02	8.8	0.16	0.4	1.3
Percent difference	-11	-9	-5	29	-10	-12	-5	-5	16	22	81			0	0	3	67	29	-7
00NV-6	42	6.8	24	2900	19	32	100	390	0.69	4	31	32	0.6	4.2	0.04	21	0.2	0.64	14
99NV20	36	6.8	24	3100	15	27	81	290	0.54	4.3	1.1	< 30	15	4.5	0.01	20	0.24	0.53	13
Percent difference	-15	0	0	7	-24	-17	-21	-29	-24	7	-186		185	7	-120	-5	18	-19	-7

Table 5. Comparison of 1999 and 2000 samples from the same locations—*Continued.*

ICP-MS DATA NORMALIZED TO CHLORIDE CONCENTRATION																			
Sample no.	Major cations					Other major and minor constituents													
	Ca	Mg	Na	K	Li	SiO ₂	Ba	Sr	Rb	V	Mn	Fe	Cu	As	Y	Mo	Sb	W	U
00NV-25	6.7	0.62	1.78	327	1.05	6.55	11.8	29.1	.055	0.55	.062	4.55	0.16	0.15	.004	3.09	.016	0.35	0.84
99NV-28	6.1	0.48	1.34	316	0.86	5.21	11.0	24.2	.037	0.48	.087		0.56	0.15	.002	2.42	.022	0.35	0.56
Percent difference	-9	-24	-28	-3	-21	-23	-7	-18	-38	-12	34		109	2	-65	-24	31	2	-40
00NV-3	3.4	0.56	1.88	306	1.41	4	14.1	37.6	.059	0.47	0.55	2.12		0.33	0.00	0.68	.012	.067	0.99
99NV26	3.5	0.61	1.95	403	1.30	3.51	14.3	37.7	.065	0.48	2.60		0.52	0.43	.005	0.75	.027	.086	1.14
Percent difference	3	8	4	27	-8	-13	1	0	10	2	130			26	10	10	80	25	15
00NV-23	5.7	0.72	2.45	415	1.7	6.79	17.	37.7	.094	0.75	2.07	4.91		0.19	.004	1.15	.015	.098	0.85
99NV25	5.8	0.61	1.93	695.	1.5	6.05	17.	35.9	.166	0.72	1.50	15.2	0.67	0.22	.016	1.14	.049	.121	0.85
Percent difference	3	-17	-24	50	-11	-11	2	-5	55	-5	-32	103		17	122	-1	106	21	0
00NV-10	9.7	0.81	2.08	503	0.74	9.06	14.8	33.6	.174	0.67	0.20	5.03		0.34	.007	2.85	.027	0.10	0.47
99NV40	8.3	0.70	1.87	635	0.63	7.62	13.3	30.2	.194	0.79	0.44		0.32	0.32	.006	2.79	.051	0.13	0.41
Percent difference	-16	-14	-10	23	-15	-17	-10	-11	10	17	77			-6	-6	-2	62	23	-13
00NV-6	3.21	0.52	1.83	221	1.45	2.44	7.6	29.8	.053	0.31	2.37	2.44	.046	0.32	.003	1.60	.015	.049	1.07
99NV20	2.67	0.50	1.78	230	1.11	2.0	6	21.5	.04	0.32	.081		1.11	0.33	.001	1.48	.018	.039	0.96
Percent difference	-18	-3	-3	4	-26	-20	-24	-32	-27	4	-187		184	4	-122	-8	15	-22	-10

are fewer instances of exceeding this 25-percent threshold for the cation data when normalized to chloride, suggesting that evaporation likely does not explain the annual variations and there must be other processes active in the system. Another reason that evaporation probably plays a minor role in the differences is that the trace element results are more variable than the major elements, even when normalized to chloride. According to weather records from Winnemucca, Nev., some 40 km to the southwest of the Osgood Mountains in the Humboldt River valley, 1999 was drier (5.33 inches total precipitation in 1999; 9.85 inches in 2000) and slightly cooler than 2000 (48.7°F average in 1999; 49.6°F in 2000). If evaporation was a major factor in the difference between 1999 and 2000 samples, then we should expect to see slightly higher concentrations of major and trace elements for 1999 samples than for 2000 samples. In table 5, positive percent differences should be observed between samples from 1999 to 2000 if greater evaporation occurred in 1999. In fact, when all the differences are considered (not just those above 25 percent), there are more negative than positive differences, indicating that samples were slightly more concentrated in 2000 than in 1999. Thus, water-rock interactions such as precipitation, dissolution, and adsorption/ion exchange might be occurring in the system. Adsorption may be the least important of these, as it depends strongly on pH. The pH differences between the 1999 and 2000 samples are not significant in any of the sample pairs. The greatest difference is 0.7 pH units at one sample site, but the rest of the sample pairs are within 0.2 pH units of each other.

Hydrologic differences also could be the cause of the observed chemical differences between 1999 and 2000. For example, if precipitation was different in timing or amount (which it was), different ground-water sources could be contributing to the streams in different years. For example, if some springs dried up or contributed less flow to streams in one year compared to the other, the resultant chemistry of the streams would be different to the extent that the loads from those springs was decreased. Thus, a temporal hydrologic difference could be an indicator of relatively local scale spatial differences in rock chemistry or mineralogy, as the springs that decreased (or increased) their flow to streams could indicate spatial differences in rock properties. Temporal hydrologic differences also could be the result of compartmentalization of ground-water flow. For example, relatively isolated packets of water could be discharging at different proportions between the two sampling years. Another possibility could be that the composition of discharging waters could change if there were "layered" chemical properties of the ground water. In this scenario, there could be a layer of water with one chemical character sitting atop a layer of water with a different chemical character. The two waters could be in hydrologic continuity with each other, but mixing is limited in the laminar flow regime in the ground. In this study, no data were collected to evaluate these possible hydrologic effects, although methods exist, such as the in-stream tracer methods as described by Kimball and others (1999).

The variations between 1999 and 2000 sample sites are small relative to the variations in parameters observed throughout the Osgood Mountains study area, so the full data set from the two sampling years can be interpreted as one, and major variations in water chemistry between sample sites are likely due to processes other than those brought about by temporal variations.

Spatial Variability

Figure 3 shows the study area in the Osgood Mountains. Sample locations from the two sampling trips are shown on the figure. By comparing the chemical and hydrologic variations throughout the study area, we can follow processes occurring at a variety of spatial scales. The following discussion is organized by extent of spatial scale and keyed to locations marked A through E on the map (fig 3).

Variations at Tens of Kilometers

Although there were no obvious compositional differences in the intrusive rocks between the two lobes of the stock, there appears to be a compositional and isotopic difference in spring and stream waters collected from the south vs. the north lobe. More dilute waters with isotopically lighter sulfate-sulfur were found in the southern lobe, and somewhat more concentrated waters with heavier, more variable sulfate-sulfur isotopic compositions were found in the northern lobe. Figure 4 shows this relationship, using sulfate-sulfur isotope compositions as an example. Similar variations were observed in the aqueous concentrations of a number of trace metals as well. This separation is readily apparent at a sample density of 2 per square kilometer, but it is still apparent at average sample densities slightly below 1 per square kilometer. This trend is likely due to subtle lithochemical variations in the Osgood intrusive rocks.

Variations at Hundreds to Thousands of Meters

Between points A and B along Granite Creek (fig. 3), changes were observed in the chemistry of surface water. Upstream, near point A, conductivity values were less than or equal to 210 $\mu\text{S}/\text{cm}$. By the time Granite Creek reached point B, conductivity increased to 240 $\mu\text{S}/\text{cm}$ and flow increased by more than five times. The creek follows an alteration zone that is defined by an abundance of sulfide (and other) minerals in the rocks (Neuerberg, 1966). No tributaries to Granite Creek exist other than those shown on the figure, so any chemical changes from A to B must be explained by mixing of upstream samples at A with ground-water discharge to produce the observed chemistry at B. The small tributaries near A were more dilute than the main stream at A and do not account for the increase in solute load from A to B. Therefore,

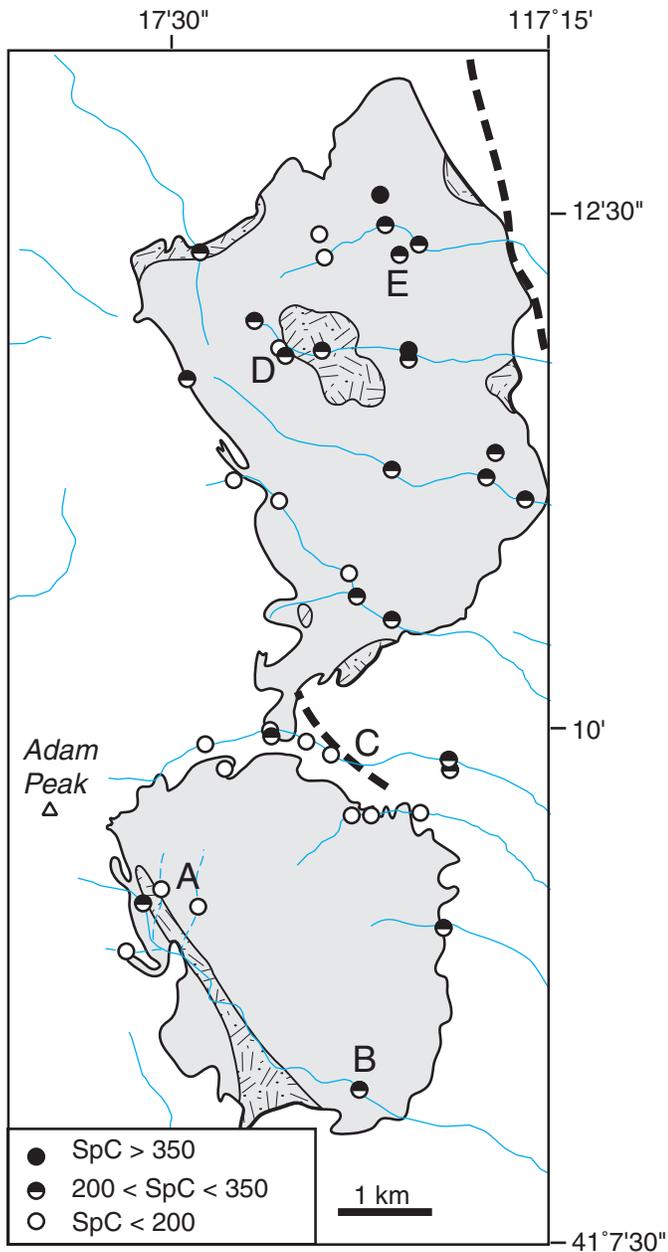


Figure 3. Index map of the Osgood Mountains study area. Shaded area represents outcrop of two large granodiorite intrusive-rock bodies. Altered areas shown by stippled pattern; major faults shown by heavy dashed lines; round symbols show locations of water-sampling sites, coded with specific-conductance values (SpC, in $\mu\text{S}/\text{cm}$). Letters A through E correspond to locations mentioned in the text.

the observed changes (more than double) in the concentrations of Cl, B, K, Ba, Mg, Na, Sr, Mo, W, U, and Mn can be attributed to weathering of altered rocks in the ground-water environment and discharge of that ground water to Granite Creek. Ground water discharging along this several-kilometer reach of stream should reflect the chemical signature of rock alteration. The alteration is characterized by sulfide minerals (mostly pyrite) as well as enrichments of gold (Neuerberg,

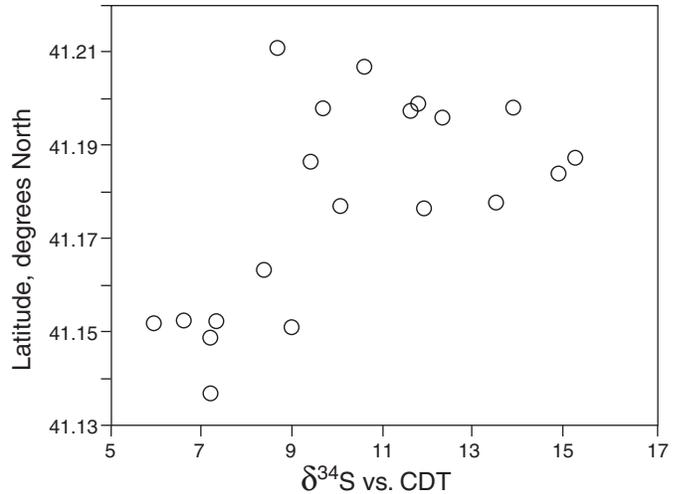


Figure 4. Variation in sulfate-sulfur $\delta^{34}\text{S}$ (‰) as a function of latitude. Values of $\delta^{34}\text{S}$ are reported relative to Cañon Diablo troilite (CDT) standard, which has a value of 0 ‰. This plot demonstrates a regional compositional variation between the southern and northern lobes of the granodiorite intrusive rocks in the Osgood Mountains. Similar variations are observed for a number of other chemical parameters.

1966), but dissolved sulfate does not increase along Granite Creek from point A to B. It is possible that other minerals are dissolving more rapidly than the sulfides and contributing the elements listed above to Granite Creek, or perhaps the exposed sulfide minerals have already been weathered and the listed elements are derived from minerals that dissolve more slowly. Either way, it is somewhat surprising that dissolved sulfate does not increase along Granite Creek. Because Granite Creek follows a mapped alteration zone (Neuerberg, 1966), which is in turn related to a bounding strike-slip fault, it is inferred that the structure is hydraulically conductive.

The spring sample collected at point E in the northern lobe of granodiorite (fig. 3) is unusual from a geomorphological point of view. The spring is located on a ridge crest, rather than in a valley. The localization of the spring along the ridge is controlled by a zone of east-west-trending fractures in the rock that extend to the west for at least several kilometers. Although these fractures are obviously hydraulically conductive, their connection to crosscutting fractures in the area must be limited, or else the spring would not be found on a ridge top.

Variations at Meters to Tens of Meters

The fault at point C (fig. 3) is one of the principal bounding faults for Osgood Mountains intrusive rocks. In today's stress regime, it is also expected to be a hydraulically conductive fracture set because it is oriented subparallel to the present-day maximum principal stress direction as shown by

Zoback and others (1990). The fault is regionally extensive (many kilometers), but the hydrologic effects on Osgood Creek are localized within a very narrow zone. As Osgood Creek crossed the fault, flow increased by more than a factor of 30, and specific conductivity decreased from more than 300 $\mu\text{S}/\text{cm}$ to about 250 $\mu\text{S}/\text{cm}$. Ground-water discharge from the fault provided water to Osgood Creek that was more dilute than the headwaters.

There were two springs at point D (fig. 3), approximately 20 m apart from each other. Despite their proximity to each other, one had a conductivity of 120 $\mu\text{S}/\text{cm}$, whereas the other had a conductivity of 280 $\mu\text{S}/\text{cm}$. Because of the thin soil cover, ground-water flow is predominantly in bedrock, and the locations of these springs are likely structurally controlled. The difference in water chemistry between these two adjacent springs is attributed either to differences in residence times of the spring waters in the ground or to local variations in litho-chemistry along different ground-water flow paths. Regardless of their cause, these chemical differences demonstrate the compartmentalization of flow by unconnected fracture sets.

Conclusions

The average sample density in the Osgood Mountains study area was approximately 2 per square kilometer. Many of these samples were collected while walking along the drainages and monitoring conductivity and temperature, and measuring hydraulic heads of ground water beneath streambeds using a device described by Wanty and Winter (2000). At the same time, geologists were nearby observing fracture orientation, density, and kinematic indicators (if any). The continuous interaction between geologists and chemists led to many of the observations described in this paper. With little prior knowledge of the hydrology of the Osgood Mountains, we collected several important pieces of data that will help unravel the hydrology and chemistry of ground and surface waters in the region. Many of the features described in this paper would have been missed without a geologic context or perhaps with a less dense sampling pattern. It should be noted, however, that the sample density was not predetermined. Rather, samples were collected based on observations of geologic, hydrologic, and geochemical parameters as field work progressed. This approach, even though somewhat more time consuming than traditional methods of surface-water investigations, is needed to fully characterize the ground-water/surface-water flow systems.

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