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SOURCE AND RESIDENCE TIME OF GROUND WATER
ISSUING FROM SEEPS AND SPRINGS IN THE HANGING
GARDENS AREA, ZION NATIONAL PARK, SOUTHWESTERN
UTAH ^{dated} 1993 or laterBy Briant A. Kimball and Paul Christensen¹

ABSTRACT

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The hanging gardens in Zion National Park are a unique feature supported by ground water from seeps and springs. Understanding the source of recharge to the springs is important to make decisions about ground-water withdrawals around the park. Chemical and isotopic data provide a means to evaluate possible recharge areas and residence time of water supporting the springs. Two distinct water types occur among the sampled springs, a very dilute water with conductivity less than 300 microsiemens per centimeter and a more mineralized water with conductivity greater than 1,000 microsiemens per centimeter. A simple conceptual model of the flow system that could generate these two waters was tested by calculating water-rock mass transfer that could account for the changes in water chemistry, and predicting the effects on stable-isotope ratios of carbon. Observed changes for the more mineralize spring water are consistent with a residence time on the order of 1,000 to 4,000 years. It is likely that these waters

isotopic in Abs? :

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originate as recharge on the plateaus to the east of the park, and that the dilute waters originate as more localized recharge. Results of the geochemical model are consistent with simulations of ground-water flow for this area.

(KEY TERMS: Geochemistry, Modeling, Water Management)

INTRODUCTION

One of the unique characteristics of Zion National Park (Zion) is the hanging gardens in Zion Canyon. The gardens are characterized by vegetation growing on canyon walls where ground water issues as seeps and springs. Knowledge of the source and residence time of this ground water is necessary to support water-rights claims of the National Park Service and to preserve these hydrologic and botanical features.

Purpose and scope

The purpose of this study is to characterize the source of recharge to the seeps that support the hanging gardens in Zion Canyon and to estimate the residence time of the ground water moving through the sandstone aquifer between the recharge area and the seeps. Using available chemical and isotopic data, the characterization can be done through application of geochemical modeling techniques to correct apparent carbon 14 (^{14}C) dates of water discharging at the hanging gardens. An exact solution to residence time of the ground water is limited by the number of unknown variables compared to the number of known variables; however, a general age can be evaluated in terms of geologic, hydrologic, and thermodynamic constraints.

Physiographic, geologic, and hydrologic settings

Zion National Park is located in southwestern Utah where the Virgin River cuts deeply into a plateau, forming Zion Canyon (fig. 1). Regional dip of the sedimentary strata is about 2° to the northeast (Gregory, 1950). A schematic geologic section (fig. 2) illustrates the geologic formations in the Zion Park area. Jurassic age formations crop out in the general vicinity of the hanging hardens. The Jurassic Moenave and Kayenta Formations are near the bottom of the canyon, and ground water discharges from these sandstones at the hanging gardens. The Jurassic Navajo Sandstone, overlying the Kayenta Formation, crops out in the canyon walls. The Temple Cap Formation overlies the Navajo Sandstone. The Carmel Formation, which contains limestone and evaporite minerals, covers the top of much of the plateau on the eastern side of the canyon. Jointing in a north-northwest direction is common in the sandstones, but no major faults occur in the immediate area of the hanging gardens (Gregory, 1950). C.F. Hamill

The Navajo Sandstone contains water wherever the formation is present (Heilweil and Freethey, 1992, p. 10). Where the Navajo Sandstone crops out, the Navajo aquifer is unconfined, but may become confined to the north where the sandstone underlies younger rocks. Movement of ground water east of Zion Canyon within the Navajo aquifer and the underlying formations is from east to west, from the tops of plateaus to discharge points in Zion Canyon. Recharge to the Navajo aquifer is from precipitation on the outcrop, from precipitation on the tops of the plateaus, and from infiltration from streams.

Previous Investigations

The geology of Zion Canyon is described by Gregory (1950). Danielson and Hood (1984) studied recharge to the Navajo Sandstone in southern Utah, showing that recharge can result from precipitation on outcrops of the Navajo and other sandstones that are

common throughout the Colorado Plateau. Blanchard (1986) studied the Navajo Sandstone in the Kaiparowits Plateau area. The hydrology of the Navajo Sandstone was studied by Heilweil and Freethey (1992) to simulate ground-water flow and possible water-level declines from proposed withdrawals for coal mining. They describe the general geologic setting and hydrology of the Zion Canyon area, but focus more on the area to the east, north of Kanab, Utah. Hydrologic and petrographic characteristics of the Navajo Sandstone are summarized by Uygur (1980), Freethey (1988), and Freethey and Cordy (1991). Reported porosity for the Navajo Sandstone where it is overlain by less than 2,000 ft of younger rocks is about 20 percent, and the median hydraulic conductivity was about 0.15 feet per day (Freethey, 1988). Cordy and others (1993) have reported on the hydrology of a coal-lease trace near Zion Canyon, concluding that recharge to springs that discharge on the east side of Zion Canyon likely originates on the top of the plateaus. This conclusion is based on the higher conductivity values of water from those springs than the springs on the west side of the canyon. *swinnel basin in the collect groundwater*

METHODS OF INVESTIGATION

Collection of Water Samples

Water samples were collected from discharge points into polyethelene bottles for major-ion and trace-element analyses and into glass bottles or teflon-lined drums for isotope analyses. Samples were filtered through 0.45-micrometer membrane filters, and samples for metals were acidified onsite to a pH of less than 2.0. Temperature, pH, water conductivity, and alkalinity were measured onsite. Stable and radioactive isotopic analyses included carbon, hydrogen, and oxygen.

Mass-transfer model

Major-ion concentrations and stable isotope ratios were used as input to the geochemical modeling computer code, NETPATH (Plummer and others, 1991). NETPATH quantifies the changes in water chemistry between two points along a flow path by calculating the required amount of mass transfer between water, minerals, and gases to account for the chemical changes. It is strictly a mathematical solution and must be interpreted with an understanding of the relevant geology, mineralogy, hydrology, and thermodynamic information. The NETPATH code combines mass-transfer calculations for geochemical reactions with isotope mass-balance and chemical-equilibrium calculations. This approach is described by Plummer and others (1983) and has been used in many reports from the Regional Aquifer Systems Analysis Program of the U. S. Geological Survey (Weeks and Sun, 1987).

The change in chemical concentration between the initial and final samples is represented as:

$$\Delta m_{T,i} = m_{T,i(\text{final})} - m_{T,i(\text{initial})} = \sum_{p=1}^P \alpha_p b_{p,i} \quad (1)$$

where $\Delta m_{T,i}$ is the net change in total solution concentration of the i th component, in millimoles per liter (mM/L); $m_{T,i(\text{final})}$ is the final solution composition of the i th component, in mM/L; $m_{T,i(\text{initial})}$ is the initial solution composition of the i th component, in mM/L; α_p is the mass-transfer coefficient for dissolving (positive) or precipitating (negative) the p th solid phase, in mM/L; and $b_{p,i}$ is the stoichiometric coefficient for the i th component in the p th phase, dimensionless.

The change in carbon concentration, for example, might be:

$$\Delta m_{C_T} = m_{C_{T,f}} - m_{C_{T,i}} = \alpha_1 \text{CaCO}_3 + 2\alpha_2 \text{CaMg}(\text{CO}_2) + \alpha_3 \text{CO}_{2(g)} \quad (2)$$

Equation (1) solves for each α_i for the given chemical change. To solve this problem, six equations were chosen. Components, phases, and stoichiometric coefficients are listed in table 1. Common chemical equations for water-rock interaction were chosen to test the basic hypotheses with basic chemical assumptions.

Several isotopic inputs, needed to solve for isotopic mass balance, are unknown. Carbonate minerals from the Carmel Formation are marine. Generally, marine carbonate minerals have $\delta^{13}\text{C}$ values of about 0 permil (Keith and Weber, 1964). $\delta^{13}\text{C}$ of ground water in recharge areas is usually negative because of soil-zone reactions. Thus, contact of this water with the Carmel Formation should cause $\delta^{13}\text{C}$ to increase toward 0 permil. Within the Navajo Sandstone, carbonate minerals are authigenic carbonate cements, not marine. Carbonate cements precipitated from water that contains atmospheric CO_2 , soil-zone CO_2 , and dissolved marine carbonate will have a lighter carbon-isotope ratio than marine carbonate minerals because of the mixed isotopic composition of the precipitating solution and because of isotopic fractionation during precipitation. A value of about -7 permil is used for the calculations to represent carbonate minerals in outcrop that have precipitated as cements in the sandstones. This represents a mass balance between marine carbonate at 0 permil and soil-zone CO_2 at -15 permil. $\delta^{13}\text{C}$ of soil gas CO_2 can range from -25 permil in temperate climates to -15 permil in arid climates (Pearson and Friedman, 1970). The plateaus are semi-arid, and the outcrops are essentially arid. Values of $\delta^{13}\text{C}$ of CO_2 in soil zones on the plateau are assumed to be -20 permil. Without a soil zone, the outcrops are assumed to have $\delta^{13}\text{C}$ of CO_2 of the atmosphere, near -7 permil. Thus, the basic assumption is made that the starting $\delta^{13}\text{C}$ values for the plateau and the outcrop are different.

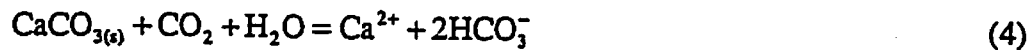
Age dating

Activity of ^{14}C can be measured for the total dissolved inorganic carbon (TIC) of a water sample. If part of the TIC is derived from atmospheric carbon that subsequently becomes isolated from the atmosphere, ^{14}C will decay with increased residence time in the ground. The half-life of ^{14}C is 5,730 years (Faure, 1977), and the decrease in ^{14}C activity may indicate the period of time that the ^{14}C has been isolated from the atmosphere by the equation:

$$RT = \frac{5,730}{\ln 2} \times \ln \frac{A_{nd}}{A_{obs}} \quad (3)$$

Where RT is the residence time, in years, A_{nd} is the ^{14}C activity with no decay, in percent modern carbon (pmc); and A_{obs} is the ^{14}C activity measured in the water sample, in pmc.

If the TIC in ground water comes from many sources the calculation of residence time is not straightforward (Pearson and Hanshaw, 1970; Wigley and others, 1978, 1979). In the case of simple dissolution of carbonate minerals, half of the TIC will be from mineral carbonate and half will be from carbon dioxide (CO_2) in soil zones or in the atmosphere. This follows the equation:



Thus, the value of A_{nd} for modern carbon dissolved in ground water with calcite present would be 50 pmc rather than 100 pmc due to mineral dilution by "dead" mineral carbon with no ^{14}C activity. Other sources of TIC that may dilute ^{14}C activity include degradation of organic matter and dissolution of other carbon-bearing minerals that have no ^{14}C activity. In addition to dilution, apparent ^{14}C activity may be altered by the

precipitation of carbonate minerals that causes isotope fractionation and the exchange of dissolved carbon with carbon containing minerals, such as calcite.

RESULTS AND DISCUSSION

Stable-isotope samples were collected to test hypotheses about the origin of ground water in Zion Canyon. The geochemistry and isotopic character of water is expected to be different if the water comes from the high plateaus and has been in contact with marine carbonate minerals of the Carmel Formation (path A, fig. 2) than if it comes from recharge to the outcrop below the top of the plateau (path B, fig. 2). Water that originates on the plateaus should have a much longer residence time than ground water that originates from precipitation directly on outcrops of the sandstones because of the longer flow path. Water from the plateaus also should have had contact with marine carbonate minerals and not just carbonate cements of the Navajo Sandstone. Results of field measurements and chemical and isotopic sampling are listed in table 2. Trace metals were also determined for most samples; however, none of the springs had substantial concentrations of any trace metal.

On the basis of on values of conductivity and bicarbonate, samples cluster into two groups (fig. 3). One cluster includes samples of relatively dilute water discharging from seeps and springs on the east and west sides of Zion Canyon. Conductivity values are less than about 300 microsiemens per centimeter ($\mu\text{S}/\text{cm}$), and bicarbonate concentrations are less than 150 mg/L. Samples in the second cluster, only from springs on the east side of the canyon, have conductivity values greater than 1,000 $\mu\text{S}/\text{cm}$, and bicarbonate concentrations range from 140 to 255 mg/L. These east-side springs that have higher concentrations of dissolved solids also contain more sulfate and strontium (Cordy and others, 1993), which is consistent with a flow path through the Carmel Formation.

Samples in the dilute cluster are less likely to have been influenced by flow through the Carmel Formation.

Stable and radioactive isotopes of carbon (only 4 samples) show a similar pattern. The Grotto and Refrigerator Spring, which have lower conductivity values than Larry's Grotto and Weeping Rock, have ratios near -10 permil (table 3). Larry's Grotto and Weeping Rock have $\delta^{13}\text{C}$ ratios near -7 permil. The heavier $\delta^{13}\text{C}$ represent increased water-rock interaction. Values of ^{14}C activity are near 50 pmc in the low conductivity samples with lighter $\delta^{13}\text{C}$, and near 25 pmc in the higher conductivity samples with heavier $\delta^{13}\text{C}$.

Activity of ^3H , in picocuries per liter (pCi/L), does not show the same clustering. Echo Canyon Spring has the highest ^3H values, indicating the spring represents current atmospheric precipitation (table 2). Unlike the pattern for the major ions and other isotopes, Weeping Rock has higher ^3H values than The Grotto or Refrigerator Spring. This likely reflects some mixing of modern and older waters. Tritium values for the other four springs and seeps range from 0.3 to 9.3 pCi/L, indicating all samples contain water that is older than current precipitation, but less than about 60 years old. Thus, although the major-ion chemistry and δD and $\delta^{18}\text{O}$ indicate that the waters had different origins and have undergone different chemical reactions, the waters are all about the same age, or some of the waters may represent a mixture of modern and old waters. This mixing may be indicated by both the heavier $\delta^{13}\text{C}$ and low ^{14}C activity and lighter δD values.

Origin of ground water

Mass-transfer calculations can account for several plausible scenarios to distinguish recharge that originates in the high plateaus from recharge that originates on the bare sandstone outcrops. Because many variables are unknown in this problem, the

most reasonable approach is to test the most likely ranges of variation and compare the calculated results with the measured isotopic values. With recharge on the outcrop, there may not be any impact of soil-zone CO_2 . Instead, the dissolved carbonate would likely come from dissolution of carbonate cements and atmospheric CO_2 . Alternatively, if recharge originated on the tops of plateaus, soil-zone CO_2 likely will influence the carbon isotope values and there would be contact with marine carbonates of the Carmel Formation. Partial pressure of CO_2 (P_{CO_2}) in the soil zone could range from 10^{-2} to $10^{-3.5}$ atmospheres (atm), and would likely have a more negative $\delta^{13}\text{C}$. For the initial water composition in each calculation, pure water was equilibrated with varying concentrations of CO_2 in equilibrium with calcite. This represented the range of possible P_{CO_2} concentrations, and resulted in different values for the initial carbon, m_{C} . Because atmospheric precipitation, either to the plateau top or to the outcrop, would be very dilute, other major ions were not included in the starting water compositions.

Residence time from aqueous geochemical models

Residence time of ground water was calculated as a corrected ^{14}C age for each scenario for the four sites having carbon-isotope data. This residence time represents the time since dissolved ^{14}C in recharge water lost contact with the atmosphere, most likely when it reached the water table below the unsaturated zone in the ground. The results of calculations are listed with a summary of the input values for each scenario (table 3). For the two springs with the longest apparent ^{14}C residence times, Larry's Grotto and Weeping Rock, the age corrections are similar and substantial. On the basis of measured $\delta^{13}\text{C}$ values the mass-transfer models indicate the likely residence time for ground water discharging at Larry's Grotto, is about 4,100 years and for Weeping Rock is 1,200 years. Both models suggest soil-zone P_{CO_2} near $10^{-2.25}$ atm, which is a reasonable value between scenarios 3 and 4. These residence times would allow sufficient travel time from the

plateau tops east of Zion Canyon. Thus, water from Larry's Grotto and Weeping Rock likely originates on the tops of plateaus to the east of Zion Canyon. This is represented by path A in fig. 2.

For The Grotto, none of the models could match the observed $\delta^{13}\text{C}$ value, thus age corrections could not be calculated. For Refrigerator Spring, no suitable mass-transfer model could be found at all. Both springs have apparent ages that indicate modern water. However the more negative $\delta^{13}\text{C}$ values suggest these springs have been influenced by soil-zone CO_2 . These results could indicate that both springs discharge water that has mixed with modern water along the flow path before discharging from the springs. They also could contain water that is recharged locally on outcrops, but gathers within their small side canyons. There it may be affected by soil-zone CO_2 of the vegetation. The general chemistry of these springs is not consistent with flow paths from the tops of plateaus; the springs plot with the low conductivity cluster in fig. 3. Water from The Grotto, also on the east side of the canyon, does not originate on the plateau top and no residence time could be calculated. Water from Refrigerator Spring, on the west side of the canyon, originates locally and is essentially modern. Both springs likely represent local flow paths, similar to path B in fig. 2.

Each of the geochemical mass-transfer models suggests that water from these springs should precipitate carbonate minerals. Saturation indices (Plummer and others, 1983) for calcite in each well, calculated by the thermodynamic speciation program, WATEQF (Plummer and others, 1991), indicate that these waters are indeed supersaturated with respect to calcite, which is consistent with thermodynamic constraints.

Choosing the most likely residence times for water from Larry's Grotto and Weeping Rock, a calculated average linear velocity was calculated for both. This value was used in Darcy's Law to solve for hydraulic conductivity, giving values from about

0.03 to 0.07 ft/day (table 3). This velocity assumes a minimum distance of about 9,850 ft from the nearest Carmel Formation outcrop on the plateau top and an effective porosity of about 20 percent (Freethy, 1988, figure 3). These hydraulic conductivity values are slightly less than the median value of 0.15 ft/day (Freethy, 1988, figure 5), but fall well within the range of measured values.

SUMMARY AND CONCLUSIONS

Major ion chemistry and stable isotope ratios of samples from seeps and springs that sustain the hanging gardens of Zion Canyon indicate that there is a distinction between springs of relatively higher and lower dissolved-solids concentrations. Springs with relatively high concentrations of dissolved solids only occur on the east side of the canyon. Water from springs on the west side of Zion Canyon, and from springs with lower concentrations of dissolved solids on the east side, likely originates from nearby recharge. Water from these springs is essentially modern as indicated by ^{14}C and mass-balance modeling. Springs that have relatively high concentrations of dissolved solids on the east side of Zion Canyon likely originate from recharge to the plateaus above the east side of the canyon, and the ground water obtains high dissolved-solids concentrations because it has had contact with the Carmel Formation, a marine limestone. Residence time of water for these springs is on the order of 1,000 to 4,000 years, as indicated by geochemical modeling using major-ion chemistry and carbon isotope data. These conclusions are consistent with conclusions based on the major ion and trace element data (Cordy and others, 1993).

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Table 1 -- Matrix of coefficients for solution of mass-transfer calculations.

Component	Phase					
	Calcite	Dolomite	Albite	Halite	Gypsum	CO ₂
Calcium	1	1	0	0	1	0
Magnesium	0	1	0	0	0	0
Sodium	0	0	1	1	0	0
Chloride	0	0	0	1	0	0
Sulfur	0	0	0	0	1	0
Carbon	1	2	0	0	0	1

Table 2 -- Results of chemical analyses for selected seeps and springs in Zion Canyon, Utah.

Values in milligrams per liter, except as noted.

[Cond, conductivity, in microsiemens per centimeter at 25° Celsius; pH, in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Cl, chloride; SO₄, sulfate; Alk, alkalinity as CaCO₃; δ¹⁸O, oxygen 18/16 ratio, in permil relative to VSMOW; δD, deuterium/hydrogen ratio, in permil, relative to ; ³H, tritium, in picocuries]

Site	Date	Cond.	pH	Ca	Mg	Na	K	Cl	SO ₄	Alk	δ ¹⁸ O	δD	³ H	Mg/Cl	Mg/Se	
East Side of Canyon																
PMC Echo Canyon	8/26/88	171	7.0	33.0	3.0	1.0	2.0	3.0	2.0	91.0	-5.7	-35.0	46.0	.091	1.5	
	Spring	10/12/88	222	7.3	38.4	3.0	1.1	0.7	1.8	1.9	95.0	-10.5	-76.0	34.0	.078	1.6
	11/3/88	281	7.2	49.7	3.7	1.4	0.9	2.5	1.6	131	-8.6	-70.0	33.0	.078	2.3	
	5/4/89	159	7.7	26.0	2.9	1.7	0.7	1.0	0.8	78.0	-12.6	-97.0		.112	3.6	
49.2 The Grotto	8/17/88	166	7.9	18.0	11.0	3.0	2.0	2.0	3.0	89.0	-12.9	-94.0	5.8	.61	3.7	
	11/4/88	170	8.2	15.5	9.2	2.3	0.7	2.3	2.9	77.0	-13.0	-93.0	4.8	.59	3.2	
	11/4/88	170	8.0	15.6	9.4	2.5	<0.5	2.4	2.9	78.0	-13.1	-94.0	4.5	.60	3.2	
	2/17/89	165	7.9	16.6	9.7	2.2	<0.5	2.9	3.3	78.0	-13.1	-95.0	6.1	.58	2.9	
	5/4/89	168	8.1	15.4	9.4	2.7	0.8	3.2	3.0	78.0	-13.1	-94.0		.61	3.1	
	5/4/89	173	8.0	15.5	9.5	2.5	0.9	2.1	2.8	80.0	-13.1	-95.0		.61	3.4	
20 Larry's Grotto	8/16/88	1,620	7.7	82.0	38.0	229	9.0	271	241	209	-14.5	-106.0	1.9	.40	0.15	
	8/16/88	1,664	7.7	82.0	38.0	228	9.0	269	239	206			2.2	.46	0.15	
	11/4/88	1,511	7.7	76.6	37.7	224	8.1	293	256	161	-14.6	-104.0	0.3	.49	0.14	

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Table 3 -- Results of mass-transfer and isotope-balance calculations and estimates of residence time for ground water from selected seeps and springs in Zion Canyon, Utah.

[P_{CO2}, partial pressure of carbon dioxide; atm, atmospheres; mM/L, millimoles per liter; δ¹³C, carbon 13/12 ratio, in parts per thousand; A_{nd}, carbon 14 activity, calculated for no decay, in percent modern carbon-14; ft/day, feet per day; K, hydraulic conductivity; '-', no value possible]

Site	Uncor- rected age	¹⁴ C (pmc)	δ ¹³ C (permil)	Scenario	Log P _{CO2} (atm)	Initial carbon (mM/L)	δ ¹³ C dissolving minerals	δ ¹³ C gas	δ ¹³ C calculated	A _{nd} (pmc)	¹⁴ C age (years)	Velocit y (ft/day)	K (ft/day)
Larry's Grotto	13,305	20.0	-7.13	Plateau 1	-3.5	0.98	0.0	-7.0	-3.60	42.8	6,290	0.004	0.021
				Plateau 2	-3.0	1.50	0.0	-20.0	-8.71	10.5	5,820	0.005	0.023
				Plateau 3	-2.5	2.38	0.0	-20.0	-7.88	36.7	5,010	0.005	0.027
				Plateau 4	-2.0	3.98	0.0	-20.0	-6.19	30.1	3,390	0.008	0.040
				Outcrop	-3.5	0.98	-7.0	-7.0	-3.86	42.8	6,290	0.000	0.002
Weeping Rock	10,406	28.7	-7.05	Plateau 1	-3.5	0.98	0.0	-7.0	-3.7	44.8	2,690	0.010	0.050
				Plateau 2	-3.0	1.50	0.0	-20.0	-8.981	42.0	3,150	0.009	0.043
				Plateau 3	-2.5	2.38	0.0	-20.0	-7.97	37.5	2,260	0.012	0.060

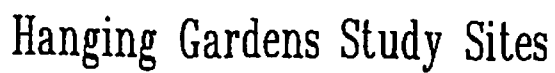
				Plateau 4	-2.0	3.98	0.0	-20.0	-5.93	29.8	300	0.090	0.450
				Outcrop	-3.5	0.98	-7.0	-7.0	-4.03	44.8	3,690	0.001	0.004
The Grotto	5,780	49.7	-9.35	Plateau 1	-3.5	0.98	0.0	-7.0	-2.82	38.4	< 0	-	-
				Plateau 2	-3.0	1.50	0.0	-20.0	-6.44	32.7	< 0	-	-
				Plateau 3	-2.5	2.38	0.0	-20.0	-5.12	36.5	< 0	-	-
				Plateau 4	-2.0	3.98	0.0	-20.0	-3.08	43.8	< 0	-	-
				Outcrop	-3.5	0.98	-7.0	-7.0	-4.24	38.4	< 0	-	-
Refrigerator Spring	4,575	57.5	-10.10	Plateau 1	-3.5	0.98	0.0	-7.0	-	-	-	-	-
				Plateau 2	-3.0	1.50	0.0	-20.0	-	-	-	-	-
				Plateau 3	-2.5	2.38	0.0	-20.0	-	-	-	-	-
				Plateau 4	-2.0	3.98	0.0	-20.0	-	-	-	-	-
				Outcrop	-3.5	0.98	-7.0	-7.0	-	-	-	-	-

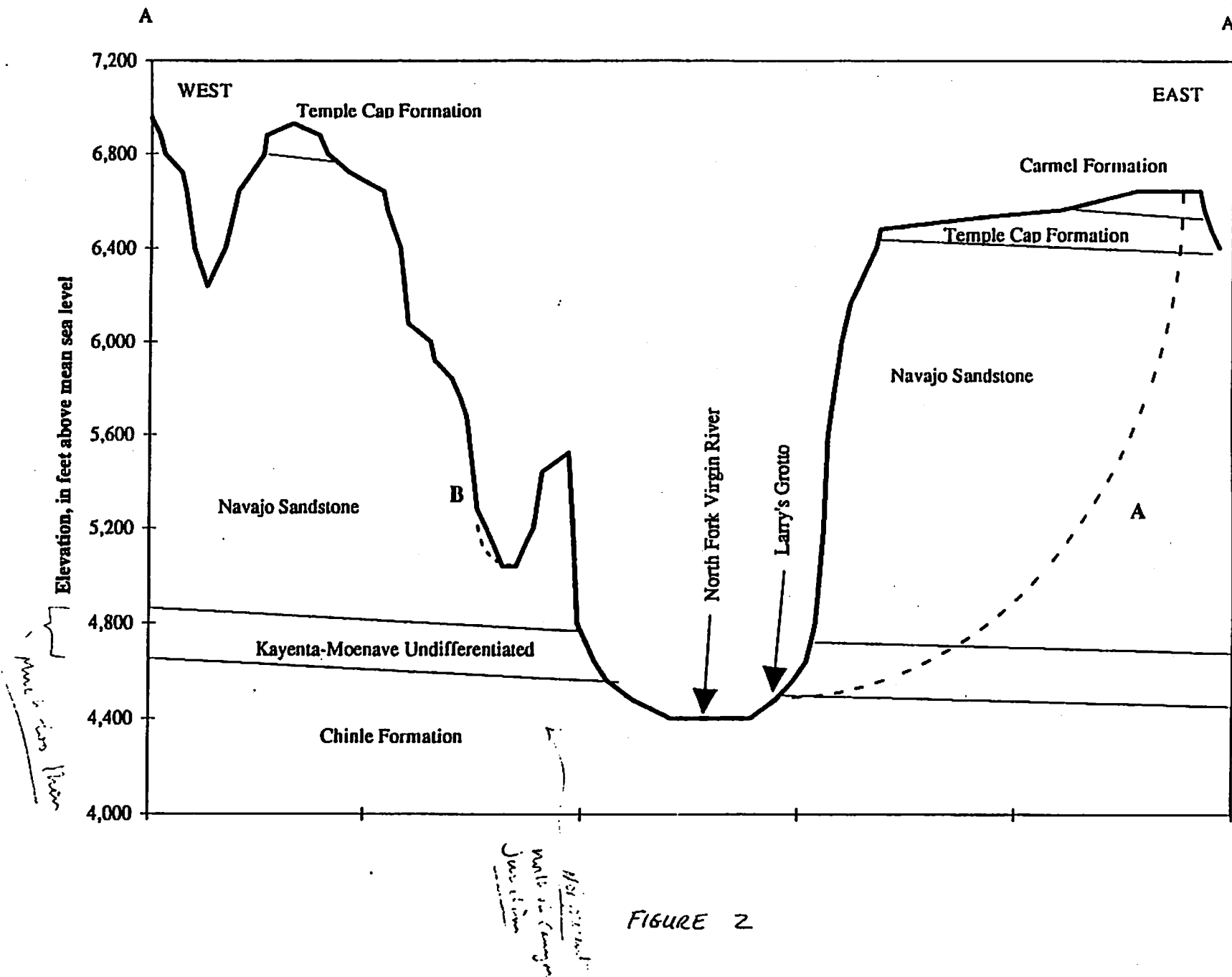
ILLUSTRATIONS

Figure 1. Map showing locations of sampling sites and the schematic cross section.

2. Schematic cross section A-A', showing the generalized stratigraphic sequence of rocks and possible flow paths for different springs. Path A results from recharge to the top of plateaus. Path B results from more local recharge on outcrops of the Navajo Sandstone.

3. Variation of bicarbonate with specific conductance of water from seeps and springs from the Hanging Gardens area, Zion National Park.





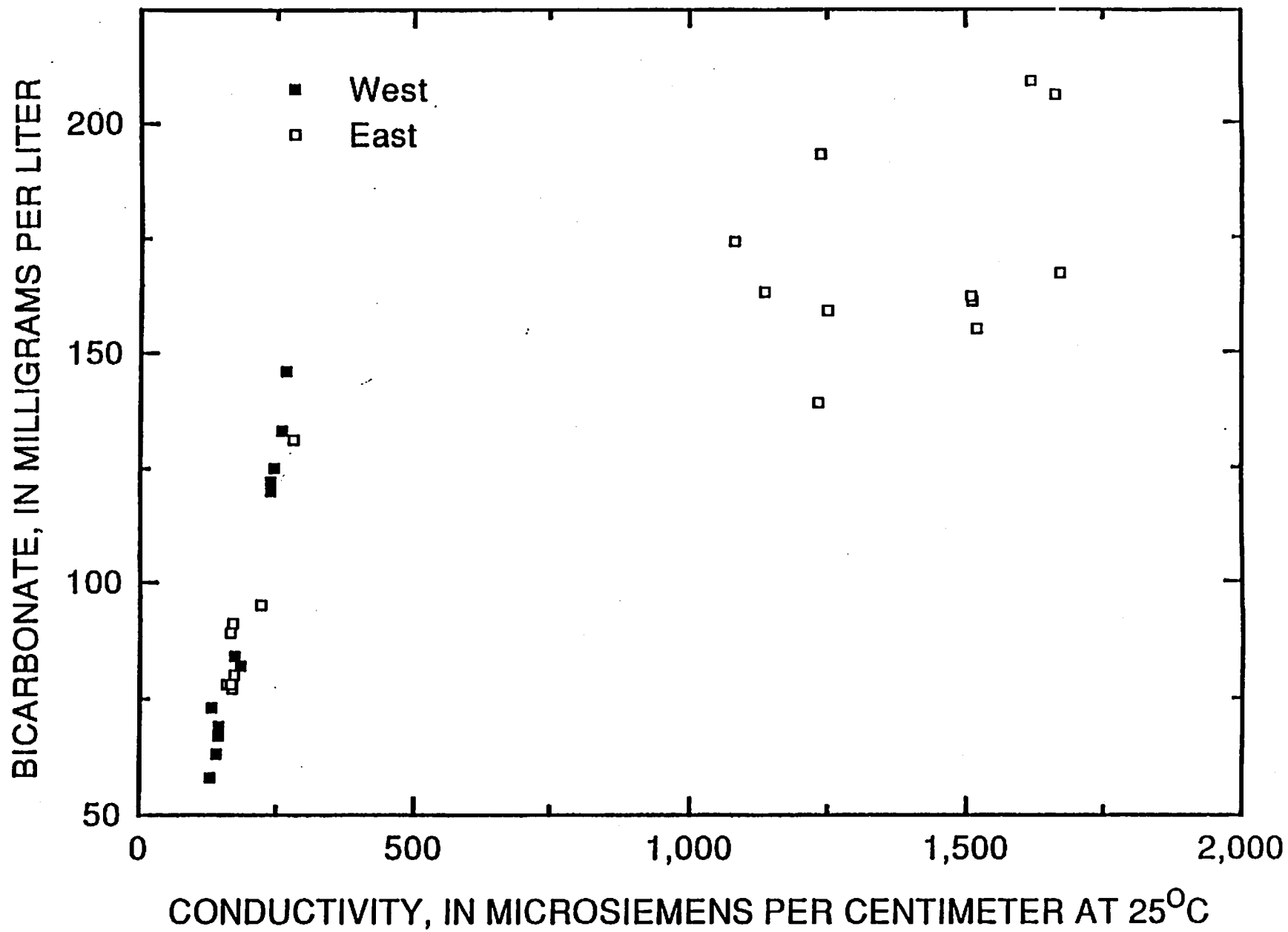


FIGURE 3

16 November, 1994

Greater Yellowstone Field Station
National Biological Survey
Yellowstone Park, WY 82190

Briant Kimball
U.S.G.S., W.R.D. Rm. 1016
1745 W. 1700 S.
Salt Lake City, UT 84104-3839

Dear Briant:

I enjoyed visiting with you on the phone yesterday. Your manuscript Source and Residence Time of Ground water Issuing From Seeps and Springs in the Hanging Gardens Area, Zion National Park, Southwestern Utah, with Paul Christiansen, has been a pleasure to read. I've been waiting to see where this work would come out.

When you see my Geological Map of Zion National Park, Utah (1978), I believe you will see that two interesting relationships appear that support your two-component water model.

1. Given, that the lower member of the Temple Cap formation (described in Hamilton, 1984, The Sculpturing of Zion) is an impermeable, red siltstone, test the hypothesis that area of exposed Navajo sandstone (Jn) in the catchment of each of your springs determines the (relative?) amount of the dilute component that comes out in the spring.

2. Looking at the map, I've traced the area of exposed Jn in your seven catchments. It appears that those with small areas of Jn outcrop have high [Ca] while those with large areas of Jn have low [Ca]. This applies to those that are obviously joint-related and those that are less so. I was amazed.

As to the question of what controls the amount of the concentrated component, my mapping shows an east-down normal fault in Echo Canyon. There may be enough offset to allow some Temple Cap water to enter the Jn exactly where you need a substantial amount of the concentrated component.

Could the east versus west hypothesis be more a case of area of Carmel exposure? If so, that might fit the hypothesis I advanced in 1984 that springs are less alkaline down-canyon. Also, what do you think about the seasonal variation in chemistry?

Please forgive this unsolicited review! I can only plead unrelenting interest in Zion. You can reach me at 307-344-2225, or at <wayne_hamilton@nps.gov>.

Sincerely yours,

Wayne L. Hamilton