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CHARACTERIZATION OF INFILTRATION INTO FRACTURED, WELDED TUFF USING SMALL BOREHOLE DATA COLLECTION TECHNIQUE

by:

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The Nevada Agency for Nuclear Projects/Nuclear Waste Project Office was created by the Nevada Legislature to oversee federal high-level nuclear waste activities in the state. Since 1985, it has dealt largely with the U.S. Department of Energy's siting of a high-level nuclear waste repository at Yucca Mountain in southern Nevada. As part of its oversight role, NWPO has contracted for studies of various technical questions at Yucca Mountain.

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INTRODUCTION

Water infiltrating into a fractured bedrock surface, or into a thin layer of colluvium covering fractured bedrock, will exhibit fluxes and chemistries influenced by processes occurring in the surface zone. In particular, the surface zone has the ability to produce chemical signatures strikingly different than other parts of the flow path due to exposure to environmental conditions characteristic of the surface environment (Bonazountas, 1983). The resulting chemistries may exhibit contributions from highly weathered rock, plant and animal organic matter, and deposits of loess representing different chemistries than those seen on a local basis. Also, atmospheric carbon dioxide is present in essentially limitless supply and carbon dioxide from plants is present in the root zone at higher than atmospheric levels, both effecting the water chemistry.

Since the surface zone has the ability to produce unique water chemistries, characterization of the chemistries and the fluxes is important for a complete flow path analysis. In evaluating these chemistries in a fractured rock environment, the first step is to obtain access to the infiltrating water. Small diameter boreholes, with adequate collection devices, can provide access to infiltrating waters in order to obtain information on the physics and chemistry of flow.

Purpose/Scope

Knowledge of all aspects of the hydrologic cycle is required for consideration of Yucca Mountain as a high level radioactive waste site. Surface processes are especially important in controlling the quantity and quality of water infiltrating into the unsaturated zone, available for recharging the aquifer.

The investigation reported herein uses small bore drill holes to access the near surface fractured rock environment. The study was conducted in northern Nevada at the north end of the Pah Rah range, east of Pyramid Lake as an analog to Yucca Mountain. The results of this study will be used to better understand the chemistry and flow of the near surface flow regime of Yucca Mountain and to evaluate proposed techniques for use in future investigations.

GEOLOGY

The Pyramid District is located thirty miles north-northeast of Reno, Nevada, in the extreme northern portion of the Pah Rah Range. The dominant rock type of the study area is ash-flow tuffs of the Hartford Hill Rhyolite which has undergone propylitic alteration. Mineralized veins occur in the area with an advanced argillic assemblage haloing the veins and an encompassing sericitic envelope adjacent to the propylitic tuffs (Wallace, 1975).

Figures 1 and 2 show maps of the study area (Figure 2 is a 1:1000 map from Wallace, 1975; the area can also be located as follows: SW1/4, Sec.15, T23N, R21E, MDM, Moses Rock Quadrangle) and Figure 3 shows cross section A-A'. The clay zone indicated on the cross section is a mineralized vein area with water seeping from the walls and ceiling. The outcrops of vein rock on the ridge above the adit are steeply dipping to the southwest and are assumed to be the surface expression of the adit vein rock. The surrounding rock is propyliticly altered Hartford Hill Rhyolite (Wallace, 1975).

Numerous fractures were present in the propyliticly altered tuff. Coatings on the fractures ranged from reddish brown residues (iron oxide?) to well-indurated black linings. The vein rock rarely exhibited any fracturing, if fractures were present they were usually very irregular and not of great extent.

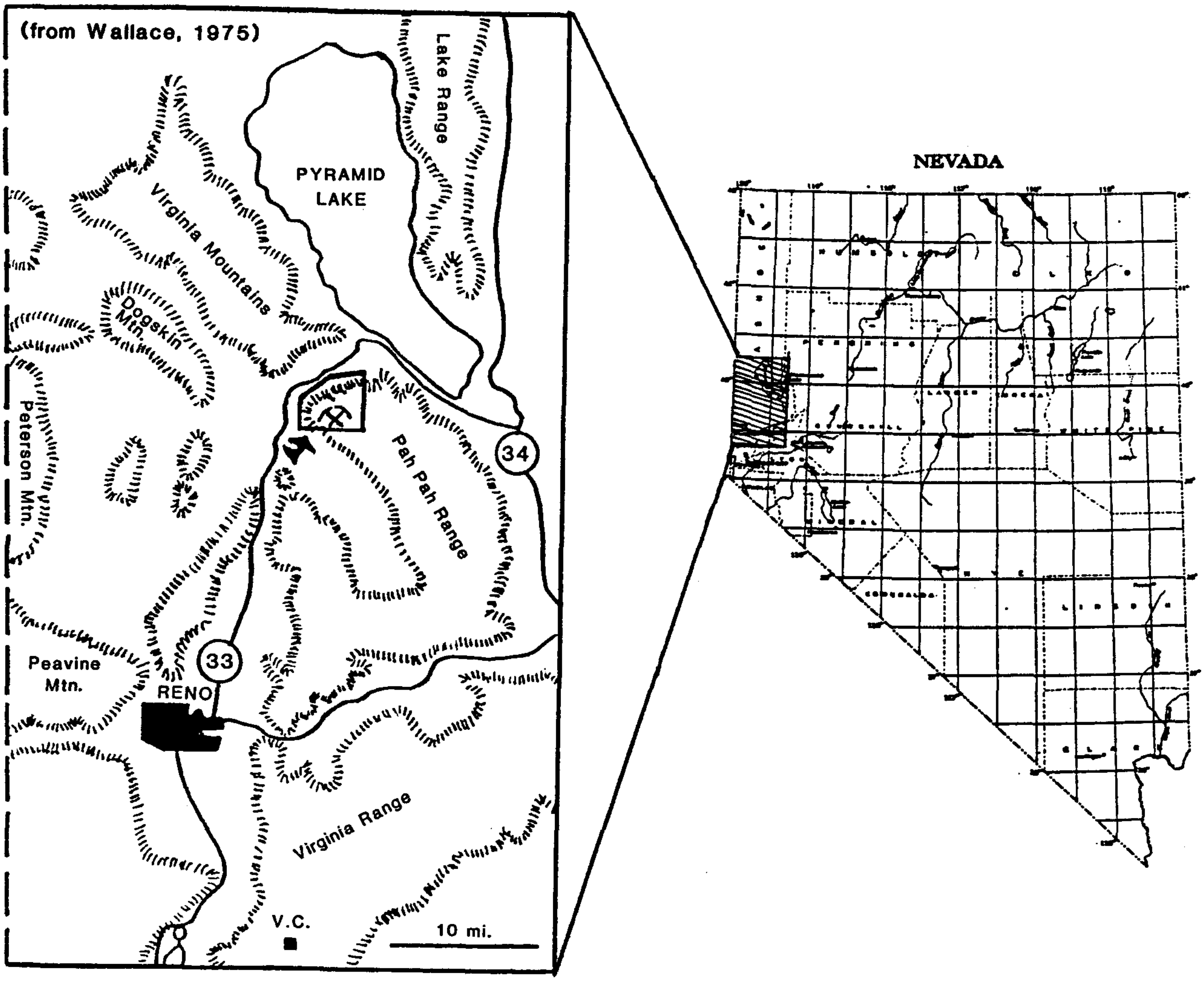

Figure 1. Index map to Pyramid District and vicinity.

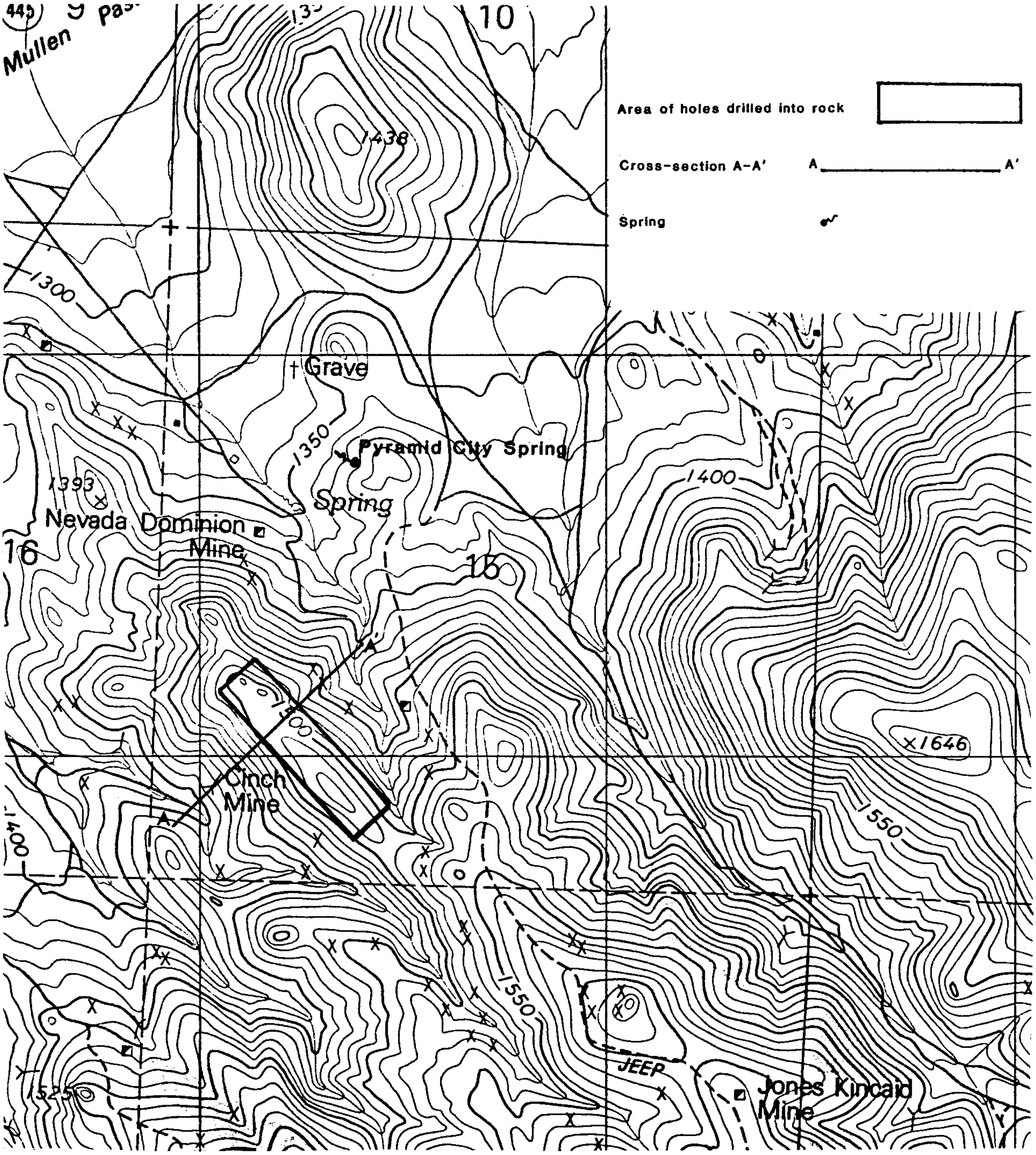

Figure 2. Map of study area (from Moses Rock, Washoe County, Nevada, 7.5 min. quadrangle, 1980).

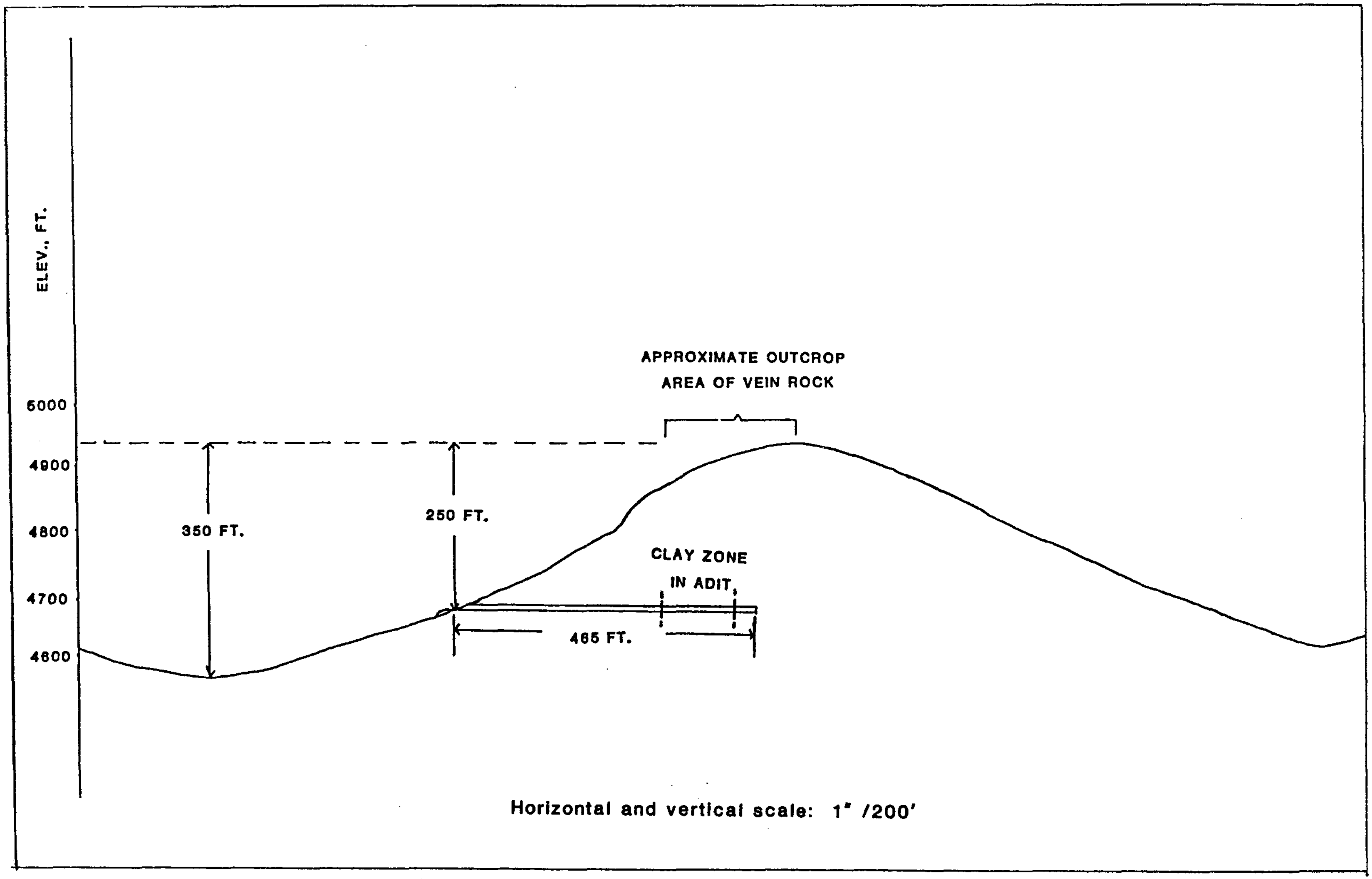

Figure 3. Cross section through New Eldorado Mine and study area.

EXPERIMENTAL PROCEDURE

Drilling

Drilling was done using a JKS 10 drill, a small hand-held drill made by JKS Industries, LTD, Golden, Colorado. Two-foot aluminum drill stem was used with steel couplings connecting the pieces. On the end of the drill stem was a 12 inch core barrel with an attached AEX diamond studded drill bit. Distilled, deionized water was used as a lubricant, gravity fed from a five gallon container through plastic tubing attached to the drill transfer housing. Although the use of water as a drilling fluid posed the possibility of contamination of the desired water chemistry, the threat was diminished by using distilled water and allowing a drying period after drilling. Disruption of the system also probably occurred due to flushing of fracture fillings by the circulating water.

All holes were drilled a few degrees below horizontal, and were drilled into both the propyliticly altered tuff and the vein rock. The propylitic tuff, being well-indurated, required approximately one to two gallons of water per foot of rock drilled. The softer vein rock required less water, about one gallon per foot of rock drilled. Occasionally a higher flow was required to ensure proper flushing of the bit to prevent clogging.

Once a section of rock the length of the core barrel was drilled, the drill was turned off and the drill stem pulled from the hole. The core was then extracted, keeping it in proper order, allowed to dry, and logged for fractures. Orientation of fractures was not possible.

Drilling along a fracture was preferred over drilling across fractures only because a larger fracture area and, therefore, more water could be intercepted. Drilling along a fracture was not always feasible though, for the following reasons: 1) if the fracture was very wide, the pieces comprising the core were small enough to jam the bit; 2) for a large fracture, debris falling from the fracture at the roof of the hole could cause the bit to jam; 3) it was difficult to keep the drill oriented along the fracture due to inherent lack of control in orienting a hand-held drill; 4) fractures would sometimes deviate from their original strike.

Eight holes were drilled altogether. Six were 9 feet deep, one was 3.5 feet, and one was 2 feet deep. Only one 9-foot hole, hole 5, was successfully completed along a fracture for any reasonable length. Hole 5 was used for the artificial infiltration experiment and holes 1,4, and 5 were monitored during the winter precipitation events of 1986. Descriptions of these three holes are given below.

Hole 1: Drilled at an angle of approximately 20 degrees below horizontal and 37 inches long. The opening is about 12 inches below the top of the outcrop. The end of the hole is about 24 inches below the top of the outcrop and ends at a wide fracture. Several fractures intersect the hole, providing access to percolating waters. The surface of the outcrop is fractured bedrock with a thin (1-2 inch) covering of loose pieces of bedrock intermixed with soil. Vegetation in the immediate area is limited to one juniper tree with its trunk approximately three feet from the hole and its branches extending just to the area above the hole. Numerous small roots were encountered in the fractures while drilling. Hole 1 was emplaced into the west facing side of an outcrop at the top of the ridge.

Hole 4: Drilled at an angle of approximately 5 degrees below horizontal and 108 inches long. The opening is about 3.5 feet below the top of the outcrop, as is the end of the hole. The hole intersects numerous fractures, but is not bisected longitudinally by any fractures. The surface above the hole is composed of bare rock outcrop for the first 3-4 feet, then is covered by approximately 10 inches of unconsolidated soil and loose rock fragments. The ground surface above the hole dips approximately 15 degrees roughly perpendicularly to the strike of the hole. The hillslope levels out about 20 feet upslope from the hole area. Vegetation is sparse in the area. The area upslope from the hole area is essentially devoid of any trees and schrubs. Hole 4 was also emplaced into the west facing side of an outcrop at the top of the ridge.

Hole 5: Drilled at an angle of approximately 5 degrees below horizontal and 108 inches long. The opening is about 3.5 feet below the top of the outcrop, as is the end of the hole. The hole intersects numerous fractures, but is not bisected longitudinally by any fractures. The surface above the hole is composed of bare rock outcrop for the first four feet, then is covered by approximately 10 inches of unconsolidated soil and loose rock fragments. The ground surface above the hole dips approximately 15 degrees roughly perpendicularly to the strike of the hole. The outcrop is approximately 200 feet downslope from the top of the ridge. Vegetation is sparse in the area. Approximately 25 feet upslope from the hole area is a large juniper tree. There are also occasional small shrubs upslope from the hole area. Hole 5 was emplaced into the west facing side of an outcrop, approximately 200 feet downslope from the top of the ridge, on the west facing slope.

Sampling Procedure

Two methods were employed for extracting water from the drilled holes. The first method involved wrapping small cellulose kitchen sponges around a plastic rod and inserting them into the hole. This method had serious drawbacks resulting from unavoidable problems of water extraction from the sponges and contamination of the water by materials in the sponge itself.

Due to the drawbacks of the first method, a second, more direct, method of water extraction was formulated. Materials required for the collection apparatus included:

1. One 7 dram snap cap vial.
2. 1.0 mm peristaltic pump hose 2-3 feet longer than the hole.
3. 2.0 inch-wide teflon tape the length of the hole.
4. Electrical tape.
5. One paper clip.
6. An inflatable packer, as shown in Figure 4, was also needed to position the collection apparatus (for a more detailed setup see Evans, 1983, pp 237).

The inside and outside of the lip of the snap cap vial was shaved down for about one-fourth the circumference so that the leading edge was sharp and the transition from the teflon tape to the vial was as smooth as possible. The teflon tape was then molded around the vial and securely taped into place with electrical tape. Next, one end of the tubing was attached to the top or side of the vial using a paper clip so that the end was pointing down at a 90 degree angle toward what would be the bottom of the vial once it was placed in the

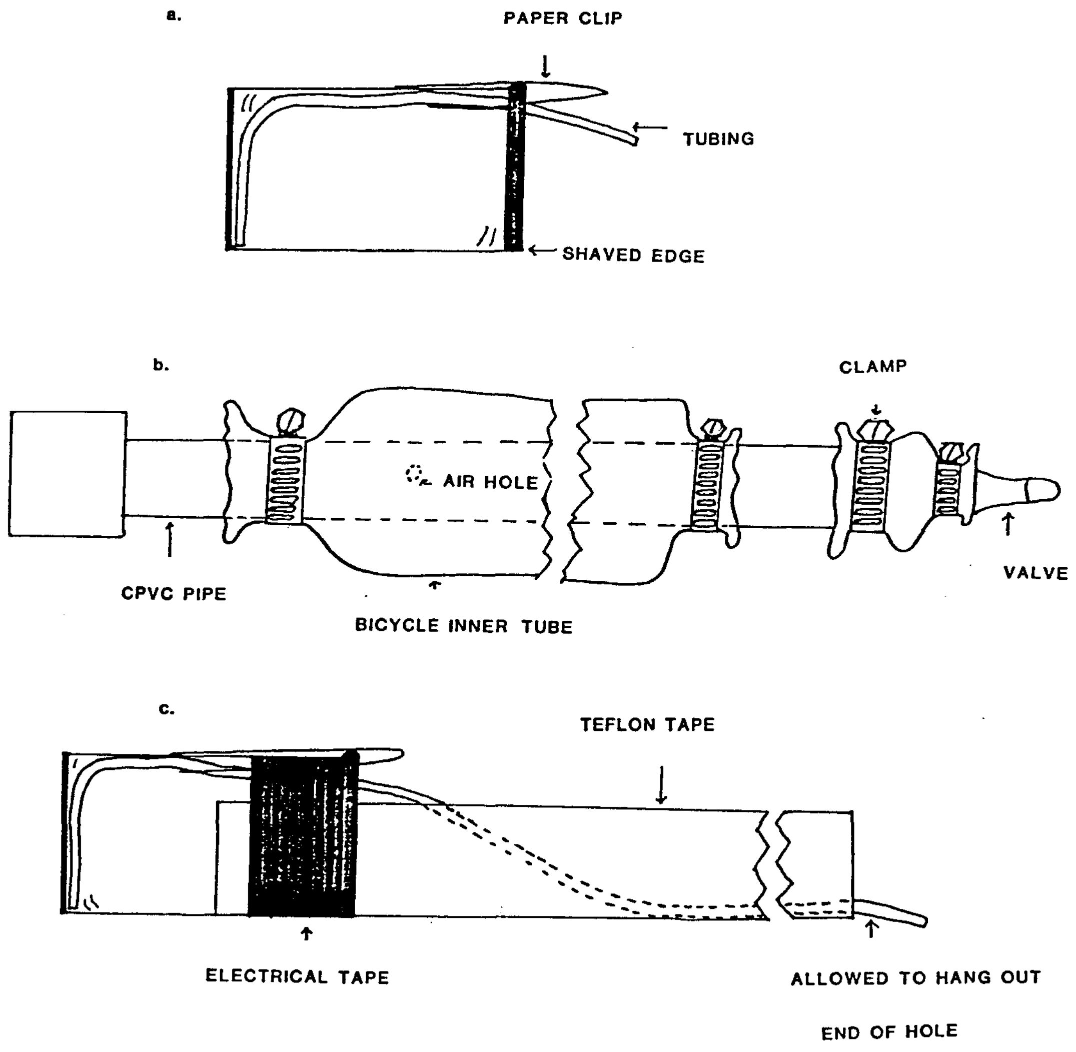

Figure 4. a. Snap cap vial. b. Packer. c. Collector ready for insertion.

hole (see Figure 4). Once assembled, the vial was placed onto the end of the packer and directed down into the hole. With the vial at the end of the hole the packer was inflated in order to form the teflon tape to the sides of the hole. The packer was deflated, pulled out the length of the inflatable part, and reinflated, the process being repeated over the entire length of the hole.

Finally, a short piece (about 5 inches) of water pipe small enough in diameter to slide into the hole was placed into the opening of the hole, with an inch or two sticking out. The pipe was then caulked into place using silicone caulking. A cork with a hole in the center was placed into the pipe to seal off the hole, allowing the tubing to run through the hole in the cork. This setup allowed the cork to be removed to provide access to the hole. As water moved down through the fracture to the hole, it would either drip onto the teflon tape or, if the tape was tight against the side of the hole, run down along the side of the hole and onto the tape. Suction was then applied to the tubing using a modified suction filtration device and the water was collected. This method provided for direct sampling of water without any intermediate step involved.

Since there is no seal between the tape and the rock, water dripping down the sides of the hole most likely would not flow onto the tape, providing false volume measurements. Using a stiffer collection medium than tape such as plastic water pipe cut longitudinally, sealed between the cut edge and the side of the hole, could prevent water from being lost down the side of the hole. Insuring a complete seal and possible contamination from the sealer could be inherent problems.

Another possible source of error would result from allowing the collection device to overflow. For flux measurements, sampling would have to be taken before water overflowed the collection device to prevent leakage or modification of the flow regime surrounding the hole.

Artificial Infiltration

Since the above described method was not developed until June, 1985, sample collection of infiltration from rainfall could not be expected until the fall of 1985. Alternatively, an artificial rainfall experiment was set up using a 2 by 2 foot rainfall simulator (Figure 5, Meeuwig, 1971).

The hole utilized, hole 5, was nine feet long, but only the interval from four to nine feet was considered usable due to the shape and bareness of the first four feet. The surface zone of the five foot interval was covered with approximately ten inches of soil. The surface slope averaged fifteen degrees. The log of the hole indicated a near vertical fracture running down the center of the hole from 4.5 to 9 feet. The rainfall simulator was placed on the surface of the ground at approximately the center of this 4.5 foot section, and about one foot up slope from the fracture bisecting the hole, allowing water to infiltrate down to bedrock upslope of the fracture. In leveling the simulator, the leading edge was adjusted so as to be at an angle to the fracture trace (see Figure 6).

On the first day of the experiment, July 18, 1985, rainfall simulation was begun and proceeded at 0.5in/hr for 2.5 hours then was changed to 2.5in/hr for another 40 minutes at which time it was then stopped. No infiltrated water was collected due to problems with the water collector.

On the second day (7/19/85) the water collector was successfully placed into the hole and water from the previous day was immediately collected. Simulated rainfall was then begun at a rate of 0.5in/hr. After 3 hours the last of the water was collected for the first sample which included the water collected from the previous day's infiltration. All subsequent water collected was designated as sample 2. Sampling frequency was every one-half hour with volumes of 250 ml. The total artificial rainfall when sample 1 was taken was 4.4 inches and that for sample 2 was an additional 1.75 inches. These depths and rates are probably not reflected in the samples taken due to the lag time for the water to move through the system.

Soil water was collected at the downslope end of the rainfall simulator by digging away the soil and sliding a piece of flat metal into the soil close to the bedrock. Water was

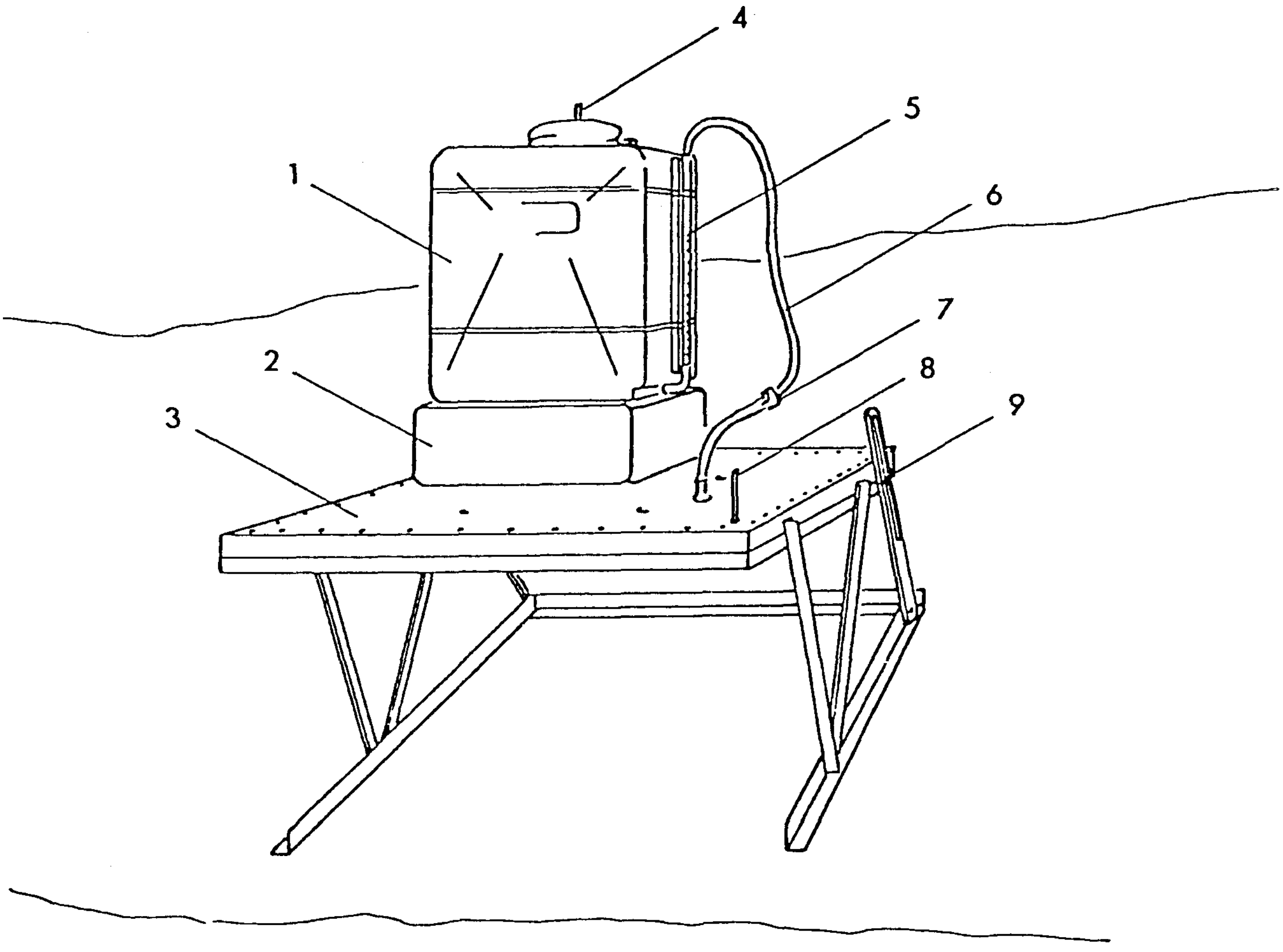

Figure 5. Diagram of rainfall simulator (Meeuwig, 1971).

1. 5-gallon polyethylene bottle with 1/2" tubulature.
2. 4-inch-high styrofoam block.
3. Water chamber.
4. 16-inch-long, 1/8 inch i.d. acrylic tube passes through the bottle cap and allows air to enter at a point about 1 inch above the bottom of the bottle. This helps maintain a relatively constant head.
5. Manometer to measure flow.
6. 3/8-inch i.d. plastic tubing.
7. Screw-type tubing clamp used to control flow rate.
8. 6-inch-long 1/8-inch i.d. acrylic tube connected to water chamber. This allows air to excape the water chamber during filling, indicates water pressure withing the chamber, and facilitates draining.
9. Leveling adjustment bolt.

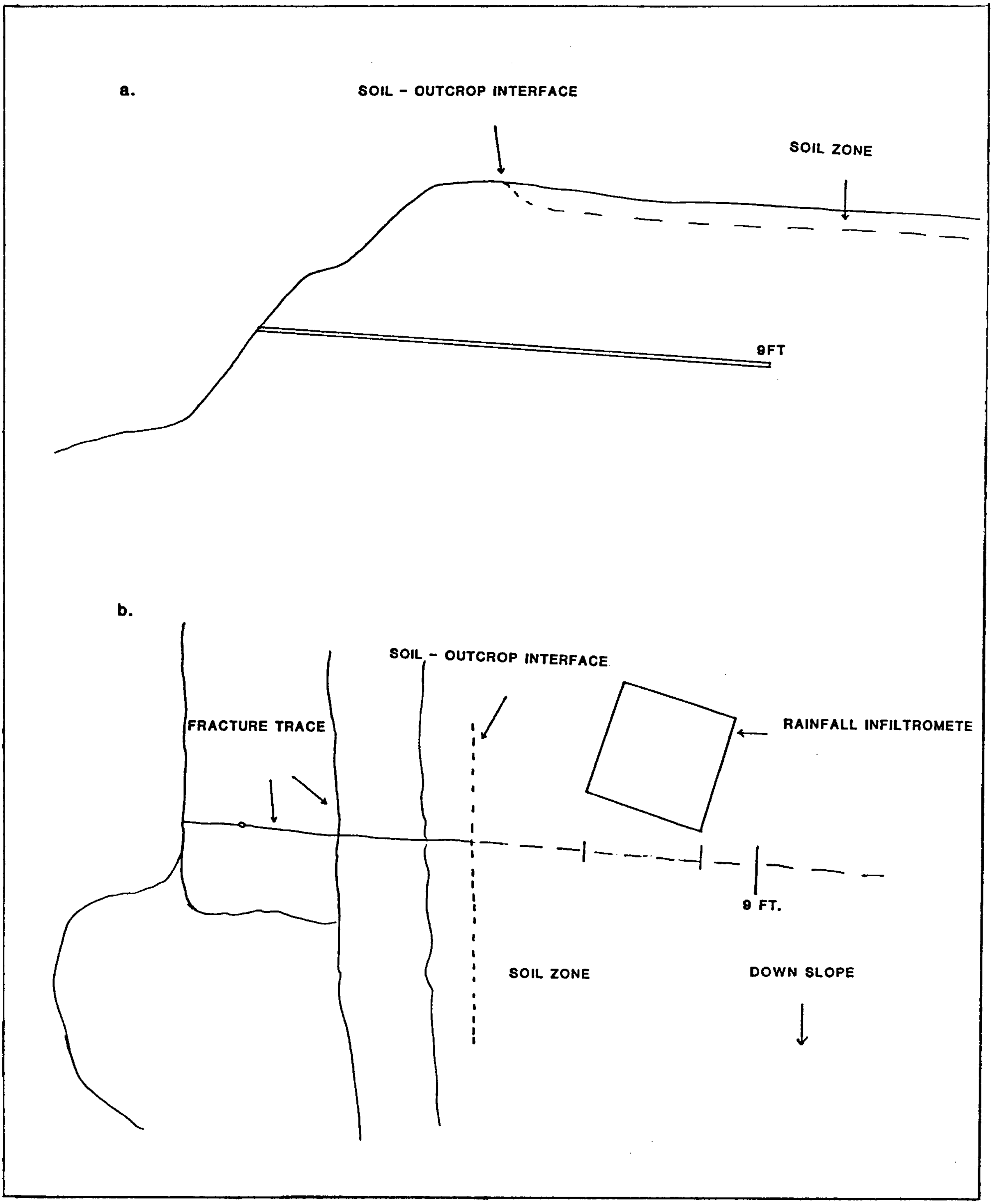

Figure 6.a. Cross section of outcrop through Hole 5. b. Top view of Hole 5 site.

collected as it dripped off the end of the upturned edge of the metal sheet. In order to not disturb the soil directly over the hole, and to get a sample of water from unleached soil, the simulator was moved downhill approximately one foot. Water was then collected for a period of two hours at a precipitation rate of 0.5in/hr. It should be noted that there was never any surface runoff present during the entire artificial precipitation experiment.

Natural Infiltration

Precipitation during the winter of 1986 produced infiltration into the soil and the fractures in the bedrock, some of which was collected in Holes 1, 4, and 5. Due to the orientation of Hole 1 and the fact that it ended at a wide fracture, only 32 ml of water could be collected at one time since any overflow would flow to the end of the hole and down the fracture. Holes 4 and 5 were more reliable in collecting true volumes, yet there was nothing preventing water from leaking out along fractures once water filled above the tape. During periods of high precipitation the flux into the holes was high and Holes 4 and 5 were seen to fill up. Water could then leak out the fractures intersecting the hole not only causing loss of water but also possibly affecting the flow regime surrounding the hole. Still, with this in mind, it is believed that general comparisons of volume between Holes 4 and 5 can be made.

Water was collected from the holes during the morning hours following a precipitation event. An exception to this was the sampling done on 2/26. Instead of this one sample, samples should have been taken daily starting on 2/17 and continuing until drainage ended, but access to the field site was cut off due to flooding of access roads.

Other Chemistry Sampling

Other data collected included a sample taken from Pyramid City spring on the east side of the hill and a sample taken from a seep located in the New Eldorado Mine. The New Eldorado Mine runs perpendicular to and under the ridge on which the holes were drilled. This sample was collected by tapping a piece of tin, with an attached funnel to collect the water, into the softer parts of the wall. A piece of tubing containing a gooseneck was attached to the funnel at one end and to a collapsed one gallon cubitaner at the other end, all connections being sealed with silicon caulking. The water was collected at a rate of about 2 liters every two weeks.

Isotope Sampling

Isotope samples were collected from the New Eldorado adit and Pyramid City Spring. Isotope samples were also collected during the artificial infiltration experiment. These include a sample of the simulator water, soil water, and water extracted from the hole. At the time of this report, the isotope samples were not yet analyzed.

RESULTS

The following discussion compares and contrasts the information obtained under this study for both the natural and simulated precipitation events. Flux values for Holes 1, 4, and 5 are given in Table 1. Chemistry results for Pyramid City Spring, New Eldorado mine, the artificial infiltration samples, and Holes 1, 4, and 5 are given in Table 2. Average values along with spring discharge values are given in Table 3. As mentioned in the geology section, the tuffs in and around the field area have undergone propylitization and mineralization which adds heterogeneity to the system. Therefore, relationships between recharge chemistries and discharge chemistries may not be direct.

Flux

Table 1 shows the precipitation depths and sample volumes collected during both parts of the study. As previously discussed, the water collected in the holes may not accurately represent true fluxes through the fractures in the bedrock. By inspection, Hole 1, having little soil covering on top of the rock to act as a catchment, could be expected to have less water flowing down to it. But without a better collection technique, a comparison between the volumes collected in Hole 1 and the other holes was not possible.

Holes 4 and 5 are similarly oriented and of the same length, so comparisons can be made between volumes collected. From Table 1, it can be seen that Hole 5 collected water sooner after precipitation started and longer after precipitation stopped, than did Hole 4. It

TABLE 1: PRECIPITATION AND MEASURED FLUX FOR HOLES 1, 4, AND 5

DATE(1986) PRECIP(cm)[1]	2/14 0.3	2/15 0.5	2/16 0.5	2/26 2.7	3/7 0.0	3/11 0.3	4/11 0.4	7/24 0.9
VOLUME(l)[2]								
Hole 1	0.03	0.03	0.03	0.03	0.00	0.01	0.00	0.03
Hole 4	0.0	0.56	1.47	0.25	0.0	0.00	0.00	0.00
Hole 5	0.64	1.80	2.33	1.35	0.17	0.83	0.11	0.36

(1) Values for precipitation represent the precipitation which fell during the preceding 24 hours. The precipitation reported for 2/26 represents the precipitation which fell from 2/16 to 2/19 due to inaccessibility of the field site. The sampling at 3/7 was to check for continuing drainage.

(2) Volumes may not represent true volumes for the period of time of collection due to possible leakage from the hole after it had filled up with water.

appears that Hole 5 also collected higher volumes not only during times when Hole 4 was dry, but also during the rest of the sampling. These phenomena could be attributable to the orientation of the fracture in Hole 5 which bisected the hole longitudinally for 5 feet. They could also be attributable to soil thickness variations, differences in precipitation above the two holes (since Hole 4 is closer to the top of the ridge than Hole 5), differences in area contributing to drainage, and the mechanics of water movement into the hole for fractures of varying orientation.

Chemistry

Chemistry data for samples collected from Holes 1, 4, and 5 are shown in Tables 2 and 3. The data in Table 2 was analyzed for spatial and temporal variations. The average chemistry for each hole was also compared to the spring discharge chemistry (Table 3). Since only small amounts of water were collected for certain samples, complete chemical analysis was not always possible. This was especially true for Hole 1 which lacked any pH and TOC data.

The data fall into two main categories, that collected as a result of winter (2/14/86-4/11/86) precipitation and that collected as a result of summer (7/24/86) precipitation. The majority of the data was collected during the winter of 1986 with only one sample collected during the summer of 1986.

TABLE 2: CHEMISTRY OF SAMPLES FROM NATURAL AND SIMULATED PRECIPITATION EVENTS

	1985		Hole 5 - 1985			Hole 1 - 1986						Hole 4 - 1986			Hole 5 - 1986							
DATE	6/19	7/1	7/22	7/22	7/22	2/14	2/15	2/16	2/26	3/11	7/24	2/15	2/16	2/26	2/14	2/15	2/16	2/26	3/7	3/11	4/11	7/24
SAMPLE	ADIT(1)	SPRING	SH5-1	H5-1	H5-2	H1-1	H1-2	H1-3	H1-4	H1-5	H1-6	H4-1	H4-2	H4-3	H5-3	H5-4	H5-5	H5-6	H5-7	H5-8	H5-9	H5-10
PRECIP(cm)(2)	-(4)	-	A	A	A	0.3	0.5	0.5	2.7	0.3	0.9	0.5	0.5	2.7	0.3	0.5	0.5	2.7	0.0	0.3	0.4	0.9
VOLUME(l)(3)	-	-	-	-	-	0.03	0.03	0.03	0.03	0.01	0.03	0.56	1.47	0.25	0.64	1.80	2.33	1.35	0.17	0.83	0.11	0.36
pH(5)	4.12	7.65	8.06	8.20	7.73	-	-	-	-	-	-	-	7.85	-	6.51	7.13	6.94	6.57	-	6.48	-	-
SP. COND.(umhos/cm)	516.	1130.	253.	242.	145.	97.	-	97.	78.	167.	133.	109.	117.	219.	64.	182.	169.	160.	181.	102.	-	177.
ANIONS(mg/l)																						
HCO3	-	250.0	129.0	89.0	74.1	-	-	-	-	-	-	53.1	53.3	120.0	23.2	56.9	58.7	78.8	92.9	50.6	-	87.3
CL	4.00	15.00	11.90	13.30	3.50	1.70	5.10	1.70	0.78	-	2.70	2.40	3.20	3.80	1.40	10.10	8.00	10.50	4.70	2.31	-	6.60
SO4	236.00	436.00	8.00	23.90	6.50	6.00	7.60	5.20	3.90	-	5.00	8.20	8.10	13.40	2.70	23.00	20.40	10.50	10.20	4.80	-	7.60
F	0.69	0.13	0.52	0.25	0.28	-	-	-	-	-	-	0.10	0.09	-	0.08	0.14	0.16	0.16	0.16	0.14	-	-
NO3	<0.04	3.01	12.80	6.63	0.96	7.10	24.80	4.60	3.30	-	21.00	0.31	3.50	0.44	6.70	4.20	3.00	<0.04	<0.04	1.24	-	<0.04
CATIONS(mg/l)																						
NA	19.10	45.50	36.10	16.70	11.50	1.68	2.20	7.21	0.85	-	2.38	7.18	7.04	11.40	4.50	10.80	11.60	11.40	12.70	7.79	-	12.30
K	3.64	1.42	7.81	1.14	0.92	2.19	3.80	2.28	1.74	-	3.46	0.30	0.40	0.35	0.52	1.01	1.01	0.52	0.52	0.44	-	2.62
CA	19.10	164.00	13.90	31.30	17.70	14.80	18.80	15.30	12.50	-	20.30	15.20	16.10	33.80	8.07	24.70	22.60	22.40	24.60	13.00	-	24.90
MG	4.86	32.60	1.75	1.79	1.12	4.86	1.18	0.95	0.71	-	1.00	0.64	0.68	1.54	0.47	1.66	1.56	1.36	1.47	0.83	-	1.40
SILICA(mg/l)	64.0	29.0	46.0	41.0	39.0	-	-	6.0	-	-	-	13.0	14.0	-	7.0	20.0	26.0	30.0	30.0	15.0	-	14.0
SR	0.06	2.24	0.07	0.15	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	-	-	-	-	-	0.08	0.10	0.06	0.04	-	-	0.09	0.08	0.07	0.10	0.12	0.07	0.12	-	0.09	-	-
TOC	-	-	-	-	-	-	-	-	-	-	-	2.1	3.2	5.3	14.9	11.9	12.2	12.4	11.0	11.1	22.7	-

(1) The anion/cation ratio (epm) was 1.691. This included attempts to balance the ratio by analyzing for Fe, Mn, and Li. Aluminum may be present in high concentrations (Wallace, 1975), but was not analyzed for.

(2) Values for precipitation represent the precipitation which fell during the preceding 24 hours. The precipitation reported for 2/26/86 represents the precipitation which fell from 2/16/86 to 2/19/86 due to inaccessibility of the field site. The sampling at 3/7/86 was to check for continuing drainage. The 'A' indicates artificial precipitation, further explanation in text.

(3) Volumes collected for Hole 1 were limited to 32ml. The spring sample was not limited in volume. The procedure for sampling of artificial precipitation and adit waters is described in the text.

(4) Dashes, '-', indicate no data available due to either no sample collected, too small of a sample to be analyzed for a particular constituent, or as in the case of the adit and spring sample, the precipitation measurement does not apply.

(4) Dashes, '-', indicate no data available due to either no sample collected, too small of a sample to be analyzed for a particular constituent, or as in the case of the adit and spring sample, the precipitation measurement does not apply.

(5) All pH values are laboratory values.

pH: The highest pH level recorded from Holes 4 and 5 for natural precipitation was 7.85 for Hole 4 on 2/16/86. This was in between the two values recorded for Hole 5 from the artificial infiltration experiment (Table 2). The pH values for Hole 5 taken after natural infiltration were all lower than the values recorded for the artificial infiltration experiment also done on Hole 5.

Specific Conductivity: The specific conductivity for Hole 4 reached a maximum value of 219. on 2/26/86, which was a maximum value for all of the samples taken during the winter and summer of 1986. The specific conductivity values for the two artificial infiltration samples (Table 2) were a little higher than this, though not by much. Hole 1 showed a maximum on 3/11/86, and a minimum on 2/26/86, while Hole 5 showed the reverse, a low value for 3/11/86 and a fairly high value for 2/26/86.

Trends in the specific conductivity values are also apparent when looking at the winter sampling period. Hole 1 showed a late increase, Hole 4 showed a middle increase, and Hole 5 showed an early increase in specific conductivities. The reasons for the discrepancies may have been due to different flow paths associated with each hole relative to the given precipitation conditions.

The summer precipitation events produced values that are higher than expected when compared to the winter values. The antecedent moisture condition (AMC) present prior to the samples being taken on 2/14/86 and 7/24/86 was low, probably lower during the summer sampling, yet for both Holes 1 and 5 the summer sample EC values are higher. Differences between the two sampling dates may have been present in the temperatures of the soil, air, and precipitation, the amounts of precipitation, and the amounts of eolian deposits. The difference between the summer and winter values is probably not due to differences in the AMC since the winter moisture content was probably the same or higher than that in the summer, and the first winter values are quite low and increase with continued precipitation. With more summer precipitation samples, discrepancies between the two types of infiltration could be examined more closely.

Chemical Constituents: The samples taken on 7/24/86 have values all fairly close to the mean values (calculated from the winter precipitation samples) of each constituent for the respective holes. When comparing the summer values for Hole 1 to the respective winter values taken at low AMC on 2/14/86, the summer values were higher for all of the constituents except for two, magnesium and sulfate. For Hole 5, the values of the summer sample were higher than the respective values on 2/14/86 for all constituents. Again, as explained for specific conductivity, differences in the environment between the two sampling dates were the air, soil, and precipitation temperatures, the amounts of eolian deposits, and the amounts of precipitation.

Trends of values taken for each hole were also noted for the winter sampling period. Hole 1 shows a maximum on 2/15/86 for all the anions and potassium and calcium. Magnesium showed decreasing concentrations with time, while sodium increased until 2/16/86, then decreased to a minimum at 2/26/86. Hole 4, with only three samples, showed increasing concentration with time for all constituents except boron, nitrate, and potassium. Silica and fluoride were incomplete analyses.

Samples from Hole 5, taken during the artificial precipitation experiment, showed higher concentrations initially. This would indicate eventual leaching following large volumes of infiltration. The samples from Hole 5 for natural infiltration show low initial values (2/14/86) for all constituents except nitrate and TOC. A general decrease in values was also seen for the last sample taken on 3/11/86. In between the first and last samples, no general trend could be discerned for all of the constituents as a whole except to note they were higher and fairly constant in most cases.

There may be some significance related to the first and last samples from Hole 5 being low and the in-between values being high. The antecedent moisture condition was extremely low prior to the sample being taken on 2/14/86. The AMC was also low prior to the sample taken on 3/11/86, i.e. after 3 weeks of drainage and drying. The AMC for samples taken on 2/15/86, 2/16/86, and 2/26/86 was high. The sample collected on 3/7/86 was a result of drainage from the series of storms ending on 2/19/86 which represented infiltration occurring during a high AMC. Averages for both a low and high AMC for Hole 5 are given in Table 3. It appears that with a low AMC and with the amount of precipitation recorded, infiltrating waters produce lower concentrations of most constituents. For Hole 5, this appears to be true for all constituents except TOC and nitrates, both of which are controlled by processes other than dissolution alone. Hole 1 also showed this pattern for the first four samples, with the exception of magnesium, and nitrates which resembled concentrations in Hole 4 more than Hole 5.

Hole 4 data was difficult to compare to since only three of the in-between samples were collected. Most constituents and the specific conductivity were either constant or showed a slight increase from 2/14/86 to 2/15/86 and 2/16/86. Samples taken on 2/26/86 showed for most constituents (except silica, fluoride, boron, nitrate and potassium) a fairly significant increase in concentration. This is different than Holes 1 and 5 which showed equal or slightly lower concentration on 2/26/86 than on preceding dates. The reason for this difference could be that flow paths above Hole 4 are different than for Holes 1 and 5 for the same precipitation event.

Nitrates: For the winter sampling, Hole 5 showed a continuous decrease in nitrates from 2/14/86 to 3/7/86, indicating leaching. The increase on 3/11/86 is most likely due to further nitrate production and buildup during the three weeks between storms. Holes 1 and 4 showed similar trends in their nitrate concentrations for winter samples. Both showed an initial low concentration for the first sample, a large increase for the second sample, then a decrease back to low levels again. The main difference between Holes 1 and 4 is the magnitude of the concentrations. Hole 1 had much higher concentrations than did Hole 4, especially for the sample on 2/15/86 which was 24.80 mg/l. This was also much higher than any of the values recorded for Hole 5, for both the natural and artificial infiltration events. Also, Hole 1 values do not indicate rapid leaching. This suggests that large amounts of organic matter, possibly provided by a nearby tree, contributed to the high recorded nitrate concentrations.

The samples taken on 7/24/86 show further distinction between Holes 1 and 5. As can be seen in Table 2, the values for nitrate are 21.00 and <0.04 mg/l for Holes 1 and 5, respectively. Again Hole 1 shows high nitrate values, much higher than the corresponding low AMC winter value on 2/14/86 of 7.10 mg/l. The value for Hole 5, below the lower detectable limit, is curiously low since some nitrate would be expected in the soil after only one precipitation event. The anion/cation ratio for Hole 5 on 7/24/86 was 0.906.

Nitrate values taken from Hole 4 indicate a different pattern of dissolution than seen in Holes 1 and 5 for the winter sampling. If the nitrates are assumed to reside mostly in the soil zone and not in the fractures, and it is assumed that the soil zone was at least partially saturated from the initial storm on 2/14/86 (although no water was collected in the hole itself), it seems reasonable to expect the nitrate values to be higher for the 2/15/86 sample, perhaps more like the value on 2/16/86. In comparison, Hole 5 had high nitrate concentrations initially on 2/14/86, and Hole 1 showed an increase after only two precipitation events, whereas Hole 4 took three precipitation events to show an increase, 48 hours longer than Hole 5, and 24 hours longer than Hole 1.

Several factors may have caused the observed variation in nitrate movement between Hole 5 and Holes 1 and 4. Since there is not significant vegetation above Hole 4, the initial amount of nitrates present in the soil may be quite small compared to other locations. Also, since vegetation is sparse and the organic content of the soil is low, the microbial population may be extremely low initially, creating a longer lag time for the production of nitrates.

TOC:. TOC samples were taken for Holes 4 and 5. Concentrations were higher for Hole 5 than Hole 4, as would be expected considering existing vegetation differences. Hole 5 concentrations started higher on 2/14/86, then lowered slightly to a fairly constant value until 4/11/86 when it reached a maximum of 22 mg/l. Hole 4 showed an increase in concentration with time. The TOC trends were similar to the nitrate trends for the respective holes, except the nitrates leached out with time. Since concentrations of dissolved organic acids are partially controlled by microbial action, as are nitrates, the increase of TOC with time in Hole 4 would be acceptable in comparison with the nitrate concentrations in Hole 4. Looking at both nitrate and TOC concentrations for Holes 4 and 5, and also the relative flow characteristics of the two holes, it appears that the higher initial concentrations in Hole 5 could have been either a result of higher organics and microbial activity in the soil zone, or deep seated sources of nitrates and organics within the system, perhaps in the fractures where roots may be present present.

It is interesting to note that the pH and TOC values for Hole 5 show an inverse relationship. If sample H4-2 is also included in this analysis, it too maintains the trend showing a higher pH with a lower TOC. It should be noted, though, that the TOC trends for Holes 4 and 5 were reversed, and, unfortunately, only the one pH value for Hole 4 was available.

Infiltration/Discharge Comparison: Data from Pyramid City spring, which is close in proximity to the field site, and mean values for other spring chemistries located in rhyolitic tuffs are presented in Table 3 along with average chemistry values (arithmetic averages) from the three drill holes for natural precipitation samples. The hole water chemistries were all well within reasonable limits representing early flow path waters with respect to the spring waters. In certain instances, when infiltrating waters are similar in concentration to discharge waters, care should be taken when determining what a representative infiltration water looks like. For example, the potassium values for the holes and for Pyramid City spring (Table 3) are all low. Depending on where the infiltrating waters are sampled, potassium could be either increasing or decreasing along the flow path. Obviously, knowledge of infiltration chemistry values weighted for flux is desirable, but most likely would not be readily available.

SUGGESTIONS FOR FURTHER WORK

The preceding report describes only a first cut with respect to the method development and the application of these methods to actual flow problems. The drilling results were useful in outlining techniques and limitations. The artificial precipitation experiment also was useful in testing techniques for collecting water. Results from the samples collected during winter precipitation events indicated that variations in infiltration fluxes and chemistries do exist in both time and space. What follows are some suggestions for further application of the techniques based on this initial study.

As in all flow situations there are two main areas of investigation, physical and chemical. The physical aspects of flow in unsaturated fractured rock, using methods similar to those expressed in this paper, have been largely dealt with by Evans (1983). A short summary of his work is presented here for completeness. following this is a section of suggestions for application to chemical and isotopic investigations.

Physical Aspects

Evans (1983) utilized small boreholes in adits in order to evaluate physical flow parameters. Specifically, the boreholes were used to determine statistical distributions of fracture orientations, spacing, aerial extent, aperture, and aperture variation. Utilization of a

TABLE 3: COMPARISON OF WATER CHEMISTRIES

SAMPLE	AVERAGE WINTER VALUES			PYRAMID CITY SPRING	NEVADA SPRINGS[1]	AVERAGE's FOR H5:	
	H1	H4	H5			LOW AMC[2]	HIGH AMC
pH	-[3]	7.85	6.70	7.65	7.87	6.50	6.88
SP. COND.(umhos/cm)	90.	148.	143.	1130.	456.6	83.	173.
ANIONS(mg/l)							
HCO3	-	53.20	60.20	250.00	174.6	36.90	71.80
CL	2.32	3.10	6.20	15.00	20.6	1.86	8.33
SO4	5.70	9.90	11.93	436.00	38.2	3.75	16.03
F	-	0.09	0.14	0.13	0.33	0.11	0.16
NO3	9.95	4.25	2.52	3.01	4.01	3.97	1.8
CATIONS(mg/l)							
NA	2.99	8.54	9.80	45.50	40.6	6.15	11.63
K	2.50	0.35	0.67	1.42	4.00	0.48	0.77
CA	15.35	21.70	19.23	164.00	36.00	10.54	23.58
MG	1.93	0.95	1.23	32.60	7.3	0.65	1.51
SILICA(mg/l)	6.0	13.5	21.0	29.0	44.7	8.0	27.0
B	0.07	0.08	0.10	-	-	0.10	0.11
TOC	-	3.5	13.7	-	-	18.8	11.7

(1) Mean values for 40 high elevation springs discharging from predominately siliceous (rhyolitic) tuff in east central Nevada (Raker, unpublished data, 1986). The value for fluoride is from 20 samples.

(2) AMC = antecedent moisture condition. Low AMC values taken from samples H5-3 and H5-9, high AMC values taken from samples H5-4, 5, 6, 7, and 8.

(3) Dashes, '-', indicate no data available due to either no sample collected or too small of a sample to be analyzed for a particular constituent. If sampling of the type outlined in this paper were utilized, minimum values for spatially variable infiltration zones could be determined.

borehole television camera facilitated the measurement of these parameters.

Moisture content measurements were made in the boreholes using a neutron probe and earth resistivity meter. This data was used to plot time series moisture curves for individual boreholes which would be useful in determining travel times through overlying rock and to develop moisture profiles for a borehole at a given time respectively. Ultimately, seasonal changes in moisture content in the boreholes could be monitored.

Moisture potential measurements were made by Evans (1983) using a thermocouple psychrometer (an osmotic tensiometer was suggested for similar use). The thermocouple psychrometer measurements would be proportional to the average water potential of the surrounding rock. With potential a function of water content, travel times could be determined by comparing precipitation curves to time series psychrometer data. If non-fracture zones could be isolated from individual fractures or fracture zones, time series psychrometer data could indicate times and conditions under which flow through the two respective zones occurs.

Other possible uses for boreholes include: drilling parallel holes in order to run tracer and gas flow experiments, and investigations of heat and mass flow. Point dilution tracer tests were also conducted in two boreholes which contained standing water, but results were not reported (Evans, 1983). Cores could also be analyzed for physical flow parameters. By placing cores in teflon sleeves, permeability and aperture width could be determined (Heiken, 1982; Brace et al., 1968). Tracer and radionuclide migration tests could also be conducted using cores (Heiken, 1982).

Holes placed in zones representing different infiltration rates (ridges, washes, fault zones, etc.) could provide information on spatial distribution and variation of infiltration. Using artificial recharge, the dependence of fracture hydraulic conductivity on saturation could also be examined.

Chemistry

The chemistry results from this study exhibit spatial and temporal variations. By comparing time series chemistry data with precipitation and borehole flux data from individual holes, the variation of chemistry with time during a precipitation event could be examined. By also knowing respective flow path characteristics of several holes, the relation of various flow parameters (soil/bedrock thickness, fracture density, etc.) to the chemistry could be determined. Flux time series data could be compared to time series data for a particular constituent to determine zones and times of maximum and minimum input for that constituent.

Boreholes could also be used to determine the true contribution of fracture flow to chemistry by comparing chemistry from infiltration through fractures without a soil covering to infiltration through similar fractures with a soil covering. Also, the values of TOC observed suggest further study. The relatively high values reported are higher than expected and the flux of organic acids into the groundwater may be higher than previously thought. Further sampling of the adit waters and Pyramid Spring waters for TOC may be warranted.

Isotopes

Stable environmental isotopes are quite useful in determining origins and mixing of groundwater. Boreholes would allow sampling of water below the evaporation zone which would give a realistic isotopic recharge value. Spatial variations in isotope values could be present, as they are for chemistry values, for different soil thicknesses, slopes, or exposures due to differences in evaporation and infiltration rates.

Mixing within the unsaturated zone could also be analyzed by comparing isotope values for different precipitation events to the values recorded from the holes. Depending on the magnitude of mixing, information regarding the movement and velocity of water through the system could be obtained.

Temperature

Another area which could prove to be of some interest is the variation of temperature and its effect on the infiltration of water. Table 4 shows temperature readings taken during the rainfall simulation experiment and during the sampling period 1986. The most obvious result is the constant temperature of the water in the hole, regardless of the surface water or air temperature. As water infiltrates through the warmer surface layer in the summer (either rock or soil) it becomes cooled. During winter months, cooler infiltrating waters would be heated.

The presence of a relatively high heat source (compared to winter temperatures) in contact with snow at the surface could cause local melting of the snow at the snow-soil/rock

TABLE 4 - TEMPERATURE DATA

Date	Time	PI.Water	D.1/2"	D.2"	W.1/2"	W.2"	Air.S	H.Water
7/18/85	1045	26.5	32.5	-	38.0	31.0	30.0	-
7/18/85	1245	31.5	32.0	-	46.5	34.5	40.0	23.0
7/19/85	0915	25.0	24.0	-	29.0	26.0	25.0	-
7/19/85	1000	-	-	-	-	-	-	22.5
7/19/85	1030	-	-	-	-	-	-	22.0
7/19/85	1130	28.5	26.0	27.0	40.0	32.0	29.0	22.5
7/19/85	1345	29.0	24.5	24.5	35.0	31.0	32.0	22.5
1/3/86	1400	-	13.0	12.5	-	-	10.5	9.0
1/6/86	-	-	-	-	-	-	8.0	9.0
2/15/86	-	-	-	-	-	-	-	9.5

Table 4. Temperature data obtained during artificial experiment. Temperatures, in Celsius, were taken for: PI.Water = Pre-infiltration water; D.1/2", D.2", W.1/2", W.2" = Dry and wet soils at given depths; Air.S = Air-shade; H.Water = Hole water.

interface. This would be the case with a substantial snow layer effectively insulating the ground from freezing air temperatures. Boreholes would be especially useful in monitoring any infiltration occurring in this situation in conjunction with analysis of snow depth, surface temperatures, and borehole temperatures over time.

CONCLUSIONS

Characterization of the near surface unsaturated fractured bedrock zone was attempted using small bore drill holes. Six holes 9 feet long, one hole 3.5 feet long, and one hole 2 feet long were successfully drilled into fractured, welded rhyolitic tuffs. Water sampling devices were emplaced into three of the holes. Hole 5 was also instrumented with a thermister temperature probe.

Chemistry results showed spatial as well as temporal variations among the three holes sampled. Trends for most constituents varied with location. Nitrate readings for Hole 1 were surprisingly high. TOC values were higher than expected overall, and opposite trends in TOC values were seen for Holes 4 and 5. TOC values also showed an inverse relationship to pH values. Winter concentrations recorded for Hole 5 were lower when infiltration occurred during low antecedent moisture conditions. Summer concentrations were high in comparison to winter concentrations.

Average constituent concentrations for the three holes, compared to spring discharge values, were at appropriate levels for early flow path waters. Fluoride and potassium values for Pyramid City spring were similar in concentration to the values for the three holes. By knowing flux values for the holes, weighted chemistry averages of infiltrating waters could give more precise comparisons to discharge waters when infiltration and discharge values are close.

Flux values for Holes 4 and 5 were seen to vary. Due to an inadequate sampling device, Hole 1 fluxes could not be reliably included for comparison. More water was observed in hole 5, arriving sooner after precipitation started and discharging longer after precipitation finished.

Temperature data indicated the rock could act as a heat sink/source for infiltrating waters. Low temperature recorded for the winter was 9.0 degrees centigrade. Significant winter recharge could occur at these temperatures due to snow melt at the snow-soil/rock interface.

The small diameter boreholes used in this project provide an effective, inexpensive means for gaining access to water flowing through rock. The experimental techniques and results presented in this paper are a first step to demonstrate usefulness and application of the boreholes and further work on fractured rock using small diameter boreholes is warranted.

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