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

A Hydrogeochemical Survey for Mineralized Breccia Pipes--data from springs, wells, and streams on the Hualapai Indian Reservation, northwestern Arizona

By

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ABSTRACT

A 1982 water sampling survey on the Hualapai Indian Reservation delineated two areas as targets for possible clusters of mineralized breccia pipes. Samples were collected from all known flowing wells and springs on the Reservation--totalling 75. Statistical analyses, including mean, standard deviation, correlation coefficients, scatter plots, and R-mode factor analyses, were determined on the samples using 47 elements and other chemical parameters.

Silver, Hg, Mo, and Pb, elements associated with uranium in breccia pipes, appear to be effective pathfinders for hydrogeochemical surveys for uranium-rich breccia pipes. Eight springs were found to be anomalous, and their recharge areas should be thoroughly searched for mineralized breccia pipes: Travertine Falls Spring, Lost Travertine Falls Spring, two seeps at the mouth of Separation Canyon, Beecher Spring (south of the Ridenour Mine), Horsehair Spring, Mohawk Spring, Warm Springs, and Pumpkin Spring. Of these eight anomalous springs, the two providing the best targets for exploration are Mohawk Spring and Beecher Spring. As a result of the hydrogeochemical survey in 1982, both areas were searched in detail for mineralized breccia pipes with considerable success. Several mineralized breccia pipes have been located near Beecher Spring; likewise several pipes have been found in the vicinity of Mohawk Spring, including one (the Mohawk Canyon pipe) that was drilled in 1984 and determined to contain anomalous concentrations of U (ore grade), Cu, Zn, Pb, As, Ag, Co, Ni, and Mo.

Of the 75 sites, many are magnesium, calcium, bicarbonate waters which are within safe drinking standards for the inorganic chemical parameters tested in this report--these waters remain to be tested for organic compounds. Several spring sites located in the bottoms of canyons (such as Horsehair and Pumpkin) are sulfate and chloride waters, most of which are not potable. The aquifer providing water for the most sites sampled in this study was the Cambrian Muav Limestone. The next most common aquifers were the Tertiary and Quaternary gravels and conglomerates, particularly the Frazier Well gravel, and the Coconino Sandstone. It is also worth noting that one of the 5 springs (Upper Diamond Spring) with the greatest discharge on the Hualapai Reservation emanates from the Redwall Limestone.

INTRODUCTION

This study was originally part of a uranium resource assessment survey for the Hualapai Indian Tribe. The Hualapai Indian Reservation is located in northwestern Arizona, bounded on the north by the Colorado River as it flows through the Grand Canyon, and on the west by the Grand Wash Cliffs, the western margin of the Colorado Plateau (fig. 1). The original goal of this project was to delineate exploration guides for locating uranium- and base metal-bearing breccia pipes buried beneath the plateau surfaces of the Grand Canyon region. A consequent accomplishment of this study was an extensive baseline data set of the inorganic geochemistry (and organic carbon) of essentially all springs, wells, and perennial streams flowing in 1982 on the Reservation.

Hydrogeochemical sampling is one means of locating buried ore deposits. Because most of the Hualapai Reservation lies in a semi-arid climatic regime, ground water flowing through mineralized breccia pipes should reflect anomalous metal concentrations, as subsequent dilution by other waters would be minimal. Water on the Reservation is sparse so all available wells, springs and streams were sampled. Because of this paucity of water and the small diameter of the

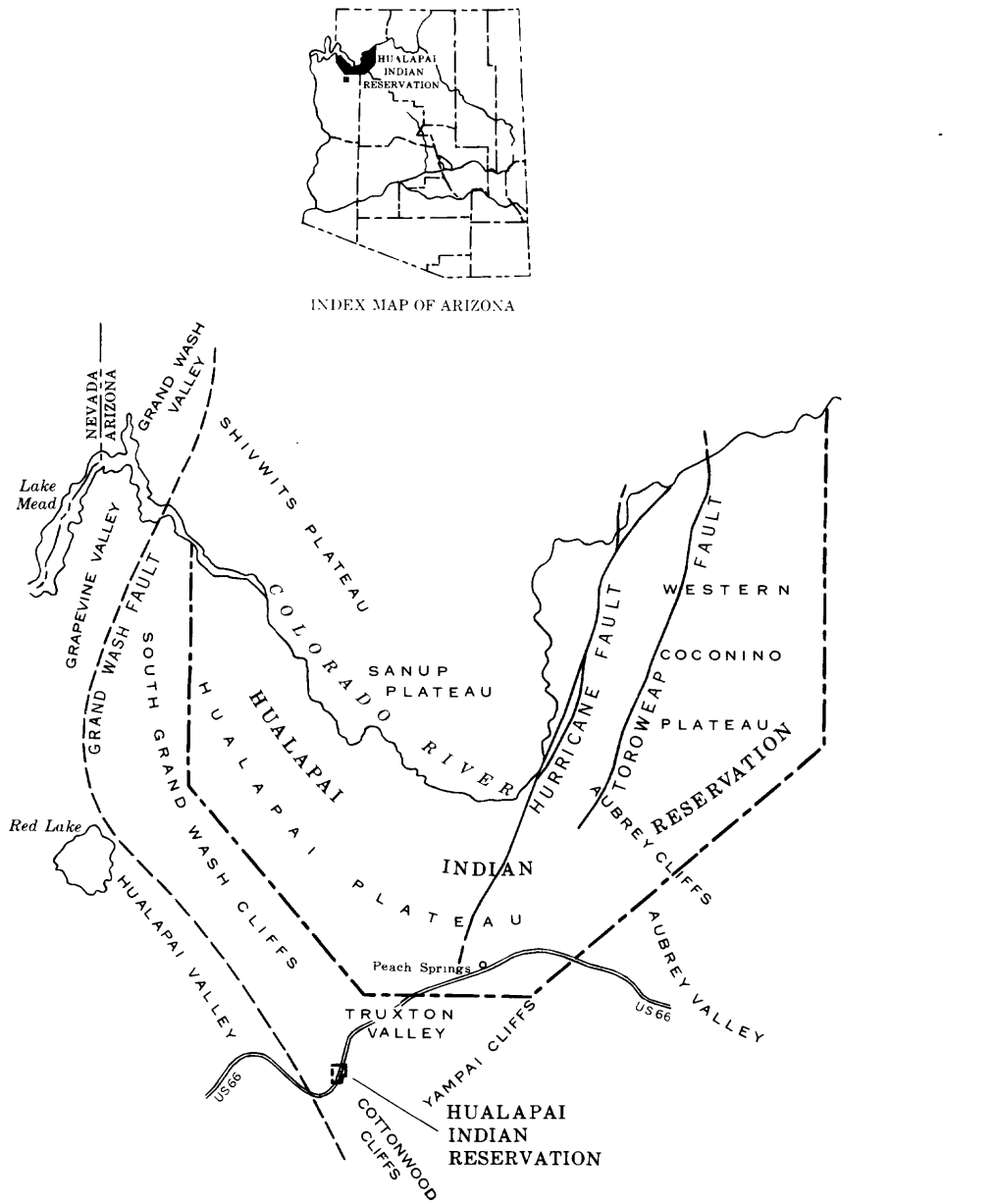


Figure 1. Index map of the Hualapai Reservation, Arizona (Twenter, 1962).

breccia pipes (<300 ft), the odds of sampling a spring which flowed through a pipe are reduced; nevertheless, the brecciated nature of the pipes provides an excellent conduit for rain water and snow melt to enter the aquifer system, increasing the probability of detecting an anomaly signature in the ground water.

The Colorado Plateau of northern Arizona is host to thousands of solution-collapse breccia pipes. Fluids precipitated over a hundred different Ag, As, Co, Cu, Mo, Ni, Pb, U, V, and Zn-bearing minerals within the matrix of the pipe breccia. Mining ventures in breccia pipes of the Grand Canyon region began during the late 1870's, at which time essentially all mining was for copper. During this period, development began on such mines as the Ridenour Mine, located on the Hualapai Reservation, (Wenrich and others, 1990). In 1951, uranium was discovered in the Orphan Mine breccia pipe. During the period 1956-1969, the Orphan Mine yielded 4.26 million lbs of U_3O_8 with an average grade of 0.42%. In addition to uranium, 6.68 million lbs of copper, 107,000 oz of silver, and 3400 lbs of V_2O_5 were recovered from the ore (Chenoweth, 1986). Apparently the mine was aptly named, because little successful exploration for other uranium-mineralized breccia pipes ensued, and this uranium mine remained an orphan (Dan Hogan who discovered and developed the Orphan in 1893, named it such because he himself was an orphan) until 1976, when a newly discovered breccia pipe adjacent to the old Hack Canyon Mine, also a breccia pipe, was found to be economic for uranium. By 1976 the high price of uranium had stimulated exploration activity in northern Arizona, particularly along the sparsely populated Arizona Strip (the land north of the Grand Canyon). Despite depressed uranium prices during the 1980's, exploration activity for mineralized breccia pipes in northern Arizona remained high due to the high-grade nature of the ore. Nevertheless, the long distance to the nearest uranium mill and environmental constraints within the Grand Canyon area did not improve the economic situation. Around 1990 the price of uranium fell to a record low since the 1960's, and in 1992 the remaining breccia pipe mines were placed on stand-by status.

The breccia pipes are easily recognized within canyons where their third dimension is exposed. In addition, the vertical cross section permits visual mineralogical and lithogeochemical studies. Unfortunately, large expanses of northern Arizona are comprised of undissected high plateaus where breccia pipe orebodies are buried more than 1000 ft (330 m) below the surface. Recognition of pipes in these areas is particularly important because mining access to the plateaus is far better than to the canyons. The small size of the pipes, generally less than 300 ft (100 m) in diameter, and limited rock outcrop on the plateaus, compound the recognition problem. Consequently, various geochemical and geophysical exploration methods, such as this hydrogeochemical survey, are required in the search for these unusual, deeply-buried deposits.

Commonly, stream-sediment surveys are done in conjunction with hydrogeochemical surveys. A stream-sediment survey was not conducted during this study because (1) the authors believe it would have been of little assistance in locating buried deposits, as stream sediments mostly reflect surface exposure, and (2) the anomaly signature from such localized ore deposits would be severely diluted by the large volume of sediments contributed by the remainder of the drainage basin, unless sampling was nearly adjacent to the breccia pipe. Hence, to reliably locate a significant number of breccia pipes would have required an exceptionally high sample density. This is in contrast to hydrogeochemical sampling in such terrane, where little water is available to dilute that which flows through a breccia pipe. Stream-sediment surveys conducted by J.C. Antweiler (Billingsley and others, 1983, and Billingsley and others, 1986) in the

Grand Gulch and Kanab Creek areas of the Arizona Strip (both areas contain known breccia pipe orebodies) show no anomalies, except those that can be directly related to past mining activity. Antweiler believes that the breccia pipe dispersion halo in stream sediments is so small that it can rarely be detected at distances in excess of a few hundred feet. This is probably caused in part by the circular, closed basin nature of many of the pipes that prevents significant transport of mineralized material downstream.

In contrast to the absence of good stream-sediment halos around breccia pipes, hydrogeochemical halos are more likely to develop because the breccia pipes act as conduits for fluid movement between aquifers. Because mineralized breccia pipes do tend to cluster, a hydrogeochemical survey was considered for reconnaissance exploration to delineate regions of greatest mineral potential.

GENERAL GEOLOGY

The Hualapai Indian Reservation encompasses about 4000 km^2 (1500 mi^2) along the southwestern edge of the Colorado Plateau. It can be divided into two physiographic provinces: the Hualapai Plateau and the western Coconino Plateau. The Hualapai Plateau is lower in altitude and more arid, with vegetation restricted primarily to cacti and shrubs, particularly members of the juniper family, in contrast to the Coconino Plateau, where ponderosa pines are abundant at the higher elevations.

Except for the deeply dissected canyons of the Grand Canyon along the northern boundary of the Reservation, where Precambrian schist, gneiss and granite are exposed, the surface exposures on the Hualapai Reservation are restricted to Paleozoic and Tertiary rocks which lie on the Precambrian erosional surface (fig. 2). In general, the Coconino Plateau is capped by the uppermost Paleozoic unit, the Kaibab Limestone, while surface exposure on the Hualapai Plateau is restricted to lower Paleozoic formations, particularly the Mississippian Redwall Limestone and the Cambrian Muav Formation (fig. 2). Some southern areas on both plateaus are covered by unconsolidated and consolidated Tertiary to Quaternary silt, sand, and gravel, along with lavas and ash-flow tuffs. The structure of these two plateaus is one of nearly flat-lying to gently dipping beds (rarely exceeding 5°), broken by a number of major normal faults and monoclines.

The breccia pipes are formed by solution collapse into the Redwall Limestone and upward stoping of the overlying upper Paleozoic sediments. The pipes crop out in Mississippian to Permian strata; none of the pipes (those related to orebodies) were observed during mapping of the Hualapai Reservation (Wenrich and others, 1987, in press; and Billingsley and others, 1986, 1990) to occur in rock below the base of the Thunder Springs Member of the Redwall Limestone. The higher parts of nearly all pipes in the Grand Canyon region have been eroded away; younger Mesozoic rocks that may have been penetrated by pipes are not preserved on the Hualapai Reservation. Pipes which have been mineralized with any of the previously mentioned metals are best located by searching for the ubiquitous, and easily recognized, uranium and secondary copper minerals. The Ridenour Mine is the only breccia pipe which produced uranium ore within the boundary of the Hualapai Reservation; 14 tons of uranium-vanadium ore averaging 0.15% U_3O_8 and 2.36% V_2O_5 were shipped in 1961 (Chenoweth, 1988).

Detailed discussion of the geology, mineralogy, petrography, and genesis of the pipes and ore-forming fluids can be found in Wenrich and Sutphin (1989), and Wenrich, Chenoweth, and others (1989). Descriptions and photographs of

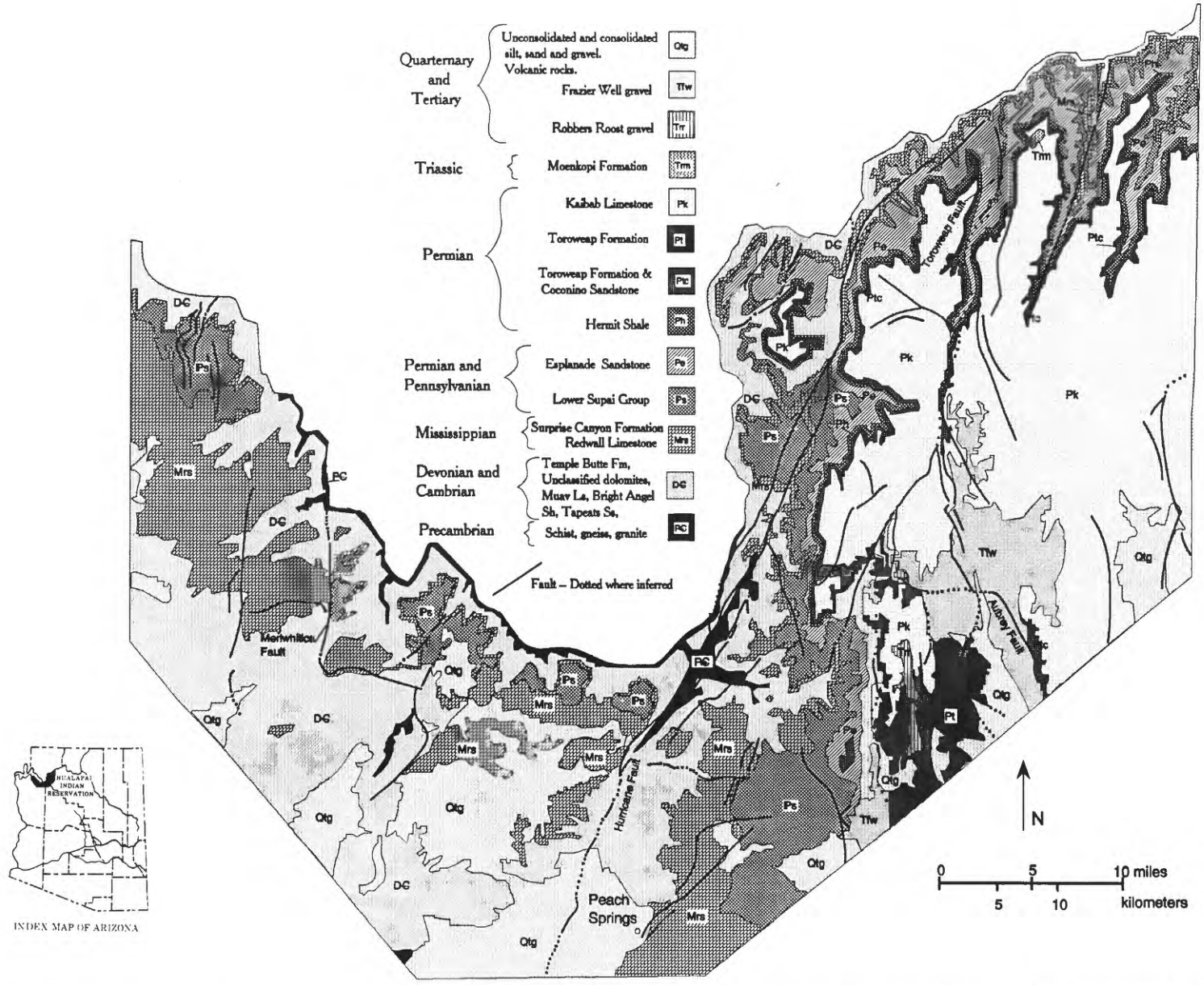


Figure 2. Geologic map and stratigraphic section of the Hualapai Reservation, Arizona. Geology compiled from Wenrich and others (in press), Billingsley and others (1986), Wenrich and others (1987), and Billingsley and others (1990). The Lower Supai Group includes the Wescogame, Manakacha, and Watahomigi Formations.

specific breccia pipes on the Hualapai Reservation can be found in Wenrich and others (1988, 1992), and Wenrich, Billingsley, and others, (1989). Discussions of uranium occurrences on the Reservation and specifically in the Ridenour Mine can be found in Miller (1954), Miller and Lovejoy (1954), Billingsley (1974), Chenoweth (1988), and Wenrich and others (1990).

PREVIOUS WATER SAMPLING ON THE HUALAPAI RESERVATION

Descriptions of the ground water for this area were done by Twenter (1962), Devlin (1976), Huntoon (1977), Boyer (1977), and Young (1987). Geochemical analyses of 13 springs are provided by Twenter (1962) in his summary of the geology and its relationship to the occurrence of ground water throughout the Hualapai Reservation. Boyer (1977) provided analyses for an additional 20 springs, tanks, wells, and streams. Johnson and Sanderson (1968) collected five spring/surface water samples at Lava Falls (Warm Spring), 205-Mile Canyon, Diamond Creek, Travertine Falls, and Spencer Canyon; two spring samples were collected along the south side of the Colorado River, at Pumpkin Springs and Lava Falls, by Peterson and others (1977). Several water samples from the Reservation were analyzed as part of the National Uranium Resource Evaluation hydrogeochemical and stream-sediment reconnaissance: 1) 1 sample from the Grand Canyon 2° quadrangle (Koller, 1980) and 2) approximately 20 samples from the Williams 2° quadrangle (Wagoner, 1979).

HYDROGEOLOGY

The Colorado River, which delineates the 108-mile northern boundary of the Hualapai Reservation, is the only non-spring fed perennial stream on the Reservation. Spring-fed perennial streams include Diamond and Spencer Creeks. Streams that are not fed by springs on the Hualapai and Coconino Plateaus are ephemeral and flow only during or after precipitation.

Ground water on the Hualapai Reservation lies primarily within perched water tables that are supported by aquicludes (Twenter, 1962). The most effective of these aquicludes is the Bright Angel Shale (Twenter, 1962). The downward movement of ground water is retarded at its upper contact with the Muav Limestone, producing what Twenter (1962) believes is the best aquifer on the Reservation, as well as throughout the Grand Canyon; this ground water occurrence is largely controlled by the irregular unconformity zone between the Bright Angel Shale and the base of the Rampart Cave Member of the Muav Formation (Huntoon, 1977). Many of the springs sampled in this hydrogeochemical survey were issuing from the Muav Limestone, which is the next formation beneath the bottom of the breccia pipes. On the Hualapai Plateau, many of the largest springs in the deep canyons along the Colorado River, such as Meriwhitica, Quartermaster, Spencer, and Columbine, issue from the Rampart Cave Member of the Muav Limestone. The Muav Limestone caps much of the Hualapai Plateau, providing good recharge to the aquifer, and dips generally to the northeast at <4°. A large part of the ground water moves downdip toward the Colorado River, issuing as springs along the Colorado River and its tributaries. On the Coconino Plateau, the Toroweap fault (fig. 1) forms a natural barrier that retards the northeastward-flowing ground water west of the fault, causing the water to collect and flow along the fault (Twenter, 1962). East of the Toroweap fault, the ground water in the Muav Limestone moves northeastward toward the Colorado River. Because the water flow on the Reservation is interrupted by canyons and faults, many areas of the

plateaus are well-drained and contain only meager supplies of ground water (Boyer, 1977).

Many of the most productive wells on the Reservation are located in the southern part and in the Frazier Wells area in Tertiary gravel beds. Cenozoic geology research by Young (1966, 1987, and 1989) has greatly aided in our understanding of these aquifers. The Tertiary stratigraphy and channeled erosion surfaces control water occurrence in the less-consolidated Cenozoic sediments and volcanics (R.A. Young, written commun., 1992). A complex series of deep, interconnected Tertiary channels converge on the Hurricane fault zone (Young, 1989) from both east and west; some of these channels have excellent ground water potential and explain a number of the large springs in Peach Springs and Milkweed Canyons (R.A. Young, written commun., 1992).

Despite the great potential of the Muav Limestone as a source of ground water, the capacity of the Redwall Limestone to yield water should not be overlooked. The two largest springs in northwestern Arizona, Blue Spring along the Little Colorado River, and Havasu Spring in Havasu Canyon on the Coconino Plateau, issue from the Redwall Limestone. On the Hualapai Plateau, most of the surface is stripped to the Redwall Limestone or below, resulting in a greatly reduced recharge area for the Redwall Limestone (fig. 2). Hence, Twenter (1962) and Huntoon (1977) are probably correct that the Muav Limestone provides the best ground water potential on the Hualapai Plateau. The Coconino Plateau is different--the recharge area for the Redwall Limestone is good, as indicated by the discharge from the Redwall Limestone at Havasu Spring, located less than 25 mi east of the Hualapai Reservation boundary (fig. 1). In addition, Diamond Creek Spring (site #28--also known as Upper Diamond Spring), one of the 5 springs with the greatest discharge (Boyer, 1977) on the Hualapai Reservation, issues from the Redwall Limestone and contributes a significant amount of the water in Diamond Creek. Hence, the potential for ground water to issue from the Redwall Limestone on the Coconino Plateau is good. Despite all the discussion revolving around which stratigraphic units might be the best producing aquifers, it should be noted that faults, joints and monoclines have the greatest influence on water movement in this part of Arizona.

SAMPLING PROCEDURE

Northern Arizona is semi-arid, with an average spring or well density of less than one per 20 mi^2 (53 km^2). Hence, grid sampling is not feasible--every spring or well must be sampled. Water samples were collected during June and July, 1982 from almost every known flowing well, spring, or creek on the Hualapai Reservation (table 1). Although it is possible that a few may have been missed, it is unlikely, because members of the Hualapai Tribe led the authors to several previously unmapped springs. A total of 74 locations (predominantly wells and springs) were sampled during this period; one additional sample in Hindu Canyon, with exceptionally difficult access, was collected during July, 1984. The only spring known by the authors, but not sampled, was Honga Spring--an unsuccessful attempt was made to reach this difficult to access spring. Ten percent of the samples were replicated in order to test analytical precision. Sampling locations are shown in Figure 3, and photographs of several of the sites are shown in Figure 4.

In situ measurements were made of specific conductivity, pH, temperature, helium, and radon. Samples were filtered in the field through 0.45 μm millipore membranes. All water was stored in polyethylene bottles, except samples

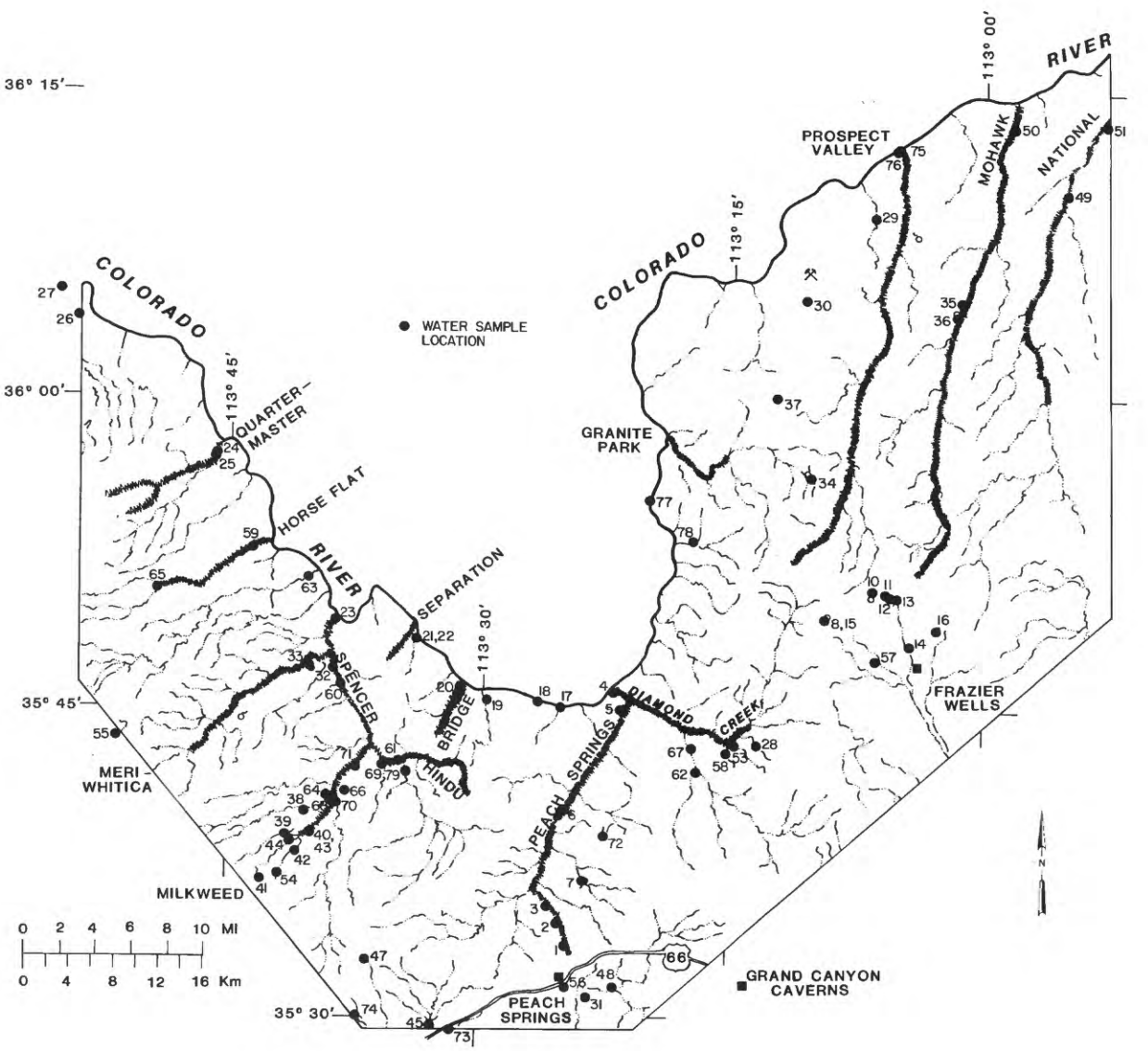


Figure 3. Sample location map showing site numbers (Tables 1 and 3).

Figure 4a. Pocomate Spring--sample #15-W82. This spring issues from the base of the Coconino Sandstone. Lyman Beecher (Hualapai Tribal Member) assisted with the sampling.

Figure 4b. Travertine Falls Spring--sample site 18-W82. The sample was collected at the base of the falls from the water flowing over the cliff just to the right of the travertine deposit.

Figure 4c. Hells Hollow Seep--sample #29A-W82. Seep emanates from the Esplanade Sandstone. Water from this seep apparently flows all year, although the flow is so minor that it either evaporates in pools or seeps back into the sandstone rather than forming a perennial stream. Sampling crew includes Susan Boundy, Stephen Whitaker, and Gregory Grounds (Hualapai Tribal Member).

Figure 4d. Horsehair Spring--sample #49A-W82. The spring is located in Mohawk Canyon and issues from the Esplanade Sandstone. This spring is one of the 8 sites considered to be anomalous in uranium and associated metals and its upstream drainage is considered favorable for uranium-mineralized breccia pipes.

Figure 4e. Mohawk Spring--sample #50A-W82. The amount of water discharging from this Muav Limestone spring provides adequate water for a swim, which is in contrast to many springs and seeps, such as Hells Hollow, on the Reservation. This spring, like Horsehair Spring, is one of the 8 sites found to be anomalous in uranium and metals associated with uranium in breccia pipe orebodies.

Figure 4f. Pumpkin Spring--sample #77A-W82. The spring, located at mile 212.9 along the Colorado River, forms a colorful orange travertine bowl around its warm spring orifice issuing from the Tapeats Sandstone. Pumpkin Spring is also one of the 8 anomalous sites.

collected for carbon determination, which were filtered through 0.45 μm Ag membranes into glass bottles. Samples collected for determination of elements whose preservation requires a low pH (table 2), were acidified in the field to a pH <1.

CHEMICAL ANALYSES

Table 3 is a list of analytical results for waters collected from the Hualapai Reservation. Table 2 lists the variables presented in table 3, the analytical method used, and the corresponding detection limit. All water samples were analyzed by the U.S. Geological Survey.

Two methods of fluorimetry were used for uranium determinations: (1) direct fluorimetry with a detection limit of 0.4 and (2) extraction fluorimetry with a detection limit of 0.01. The second method was used only on those samples with a uranium concentration less than 0.4 μg/ℓ. A second column for uranium is shown in table 3: uranium/conductivity X 100. The use of this parameter permits better comparison of uranium in samples collected from different drainage basins or during different time periods. Normalization with conductivity reduces the effects of seasonal variation and evaporation. Fluctuating discharge was probably not a serious problem for this study as the samples were all (except one) collected within a 6 week period, and more than 90% were ground water. Nevertheless, samples with a greater conductivity (a relative measure of the total dissolved solids) generally have relatively higher trace elements, so it is necessary to reduce these false anomalies by normalizing with conductivity (Wenrich-Verbeek, 1977). Figure 5 is a map showing uranium concentrations of all sample sites and figure 6 shows the normalized uranium concentrations. In general, because of the above mentioned reasons, the anomaly distribution does not change significantly between the two figures, although enough influence on uranium by conductivity exists to justify use of the normalized data rather than the raw uranium concentrations.

STATISTICAL ANALYSIS

The population statistics for each element or chemical parameter are presented in table 4; replicate samples were not included. Sixteen of the metals had more than 50% of their data below the detection limit; any element in this category received no further statistical treatment, but will be discussed later in the data interpretation. Except for the means and standard deviations shown in table 4, all qualified data with "less than values" (table 3) were replaced with 3/4 of the qualified value for statistical analysis. The histograms for both the logs and the raw data for each element distribution were plotted; from these histograms each element was determined to be either log-normally or normally distributed. The results are shown in table 4. Along with the data transformation used, table 4 also provides the mean, standard deviation, and number of samples less than or greater than the detection limit (qualified data) for each variable. All further statistical tests used the appropriate data transformation.

An analysis of variance was made on all variables to determine whether the analytical precision was acceptable. All elements but helium showed that at the 99% confidence limit, the analytical variance was negligible in contrast to the total population variance. Helium was therefore eliminated from any further statistical analysis. The replicate samples were removed from the data set prior to further statistical analysis.

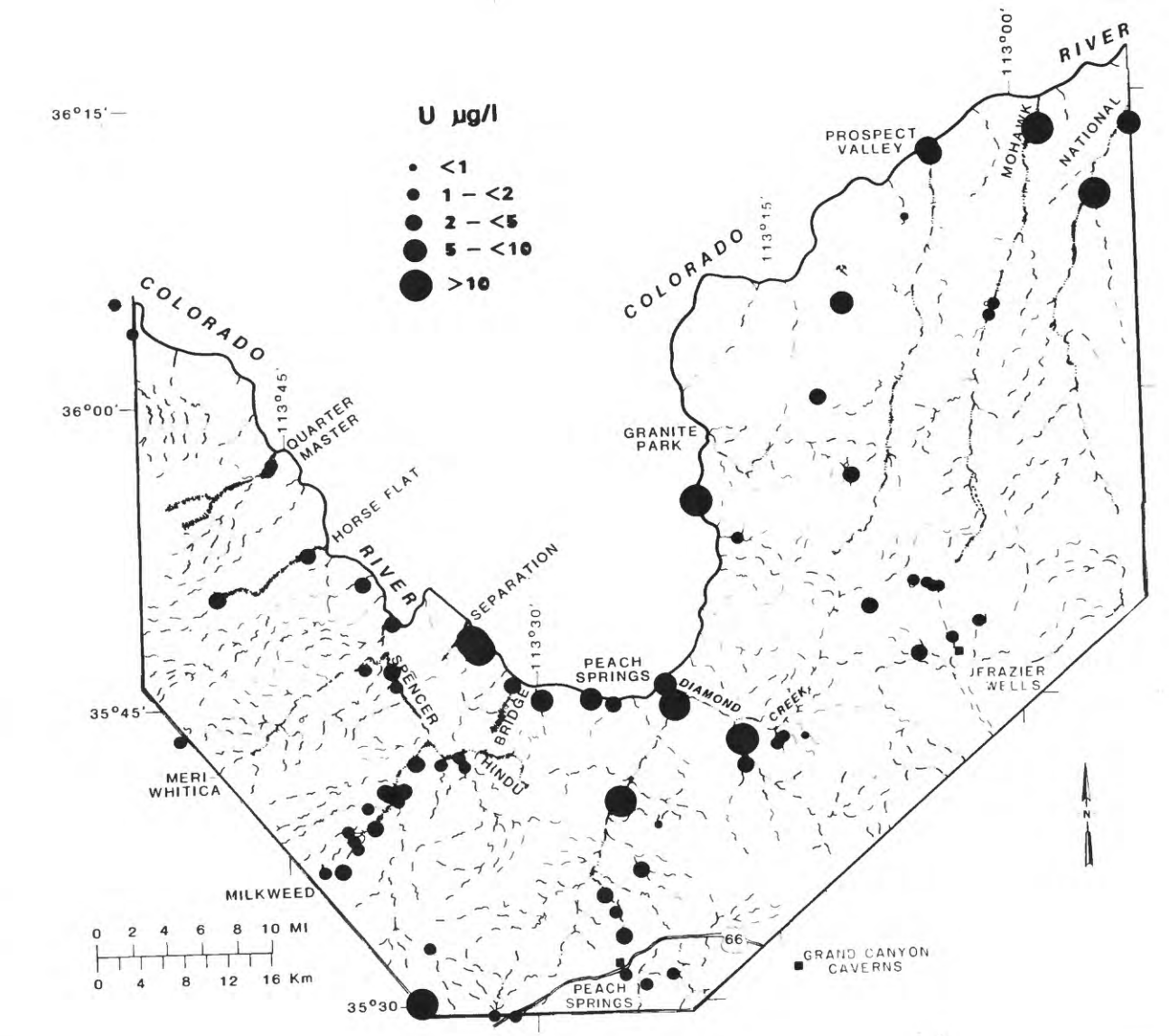


Figure 5. Sample location map showing uranium concentrations.

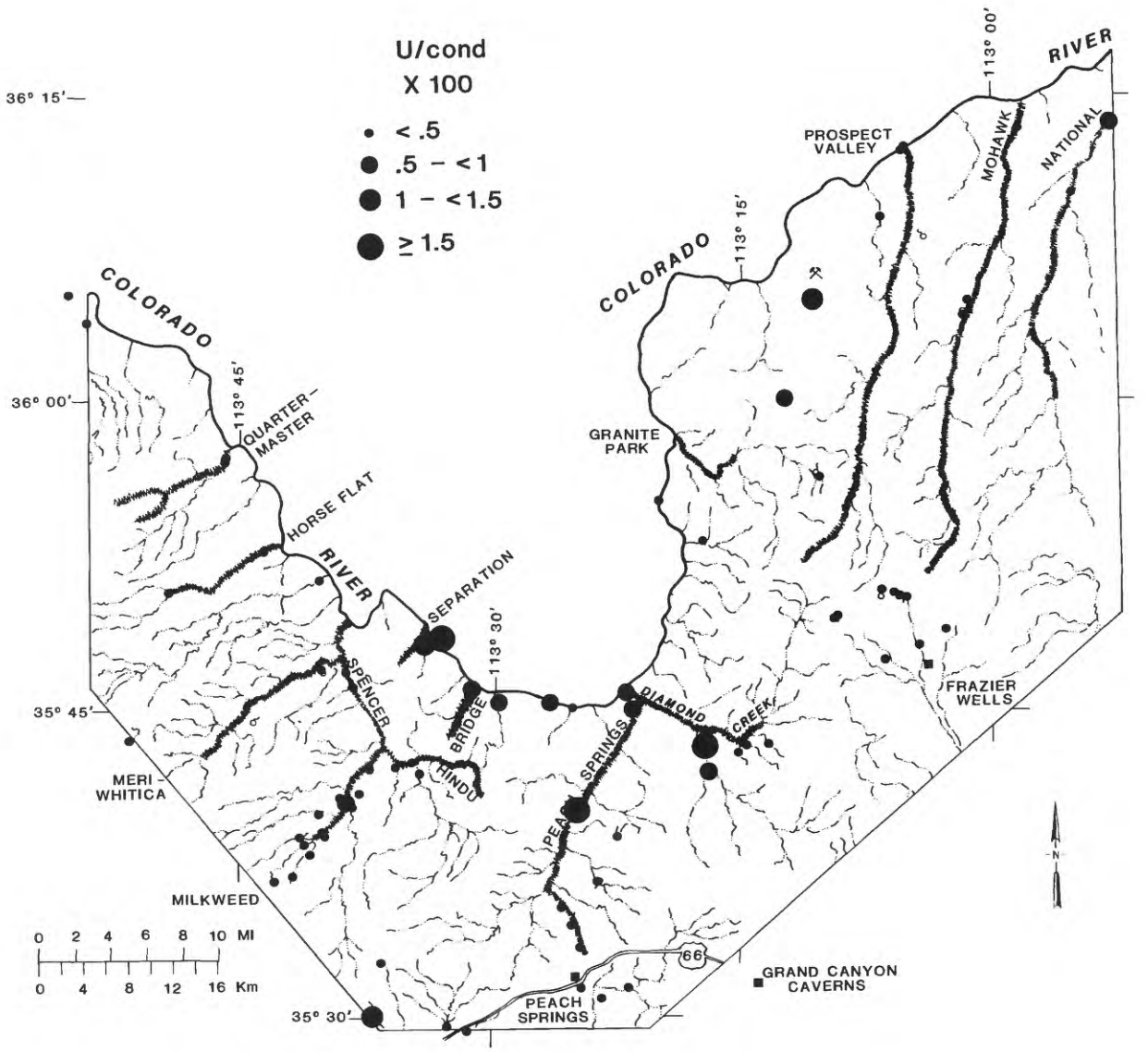


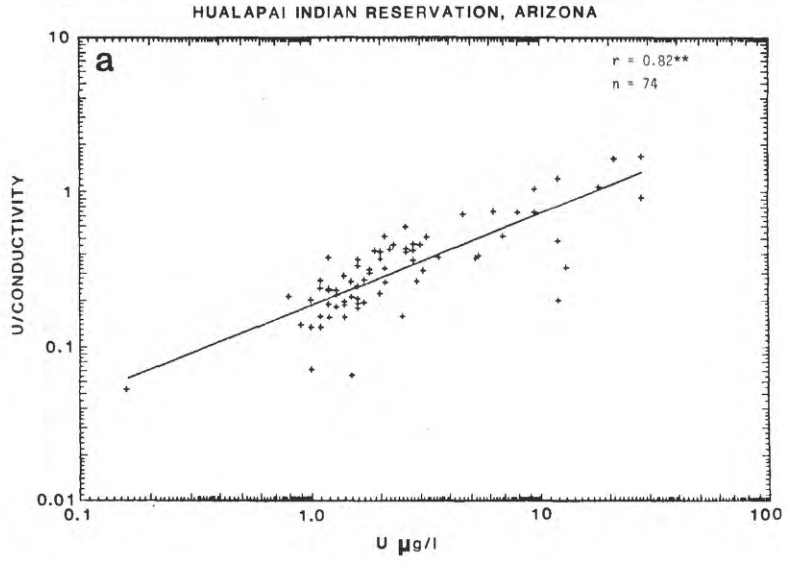
Figure 6. Sample location map showing uranium concentrations/conductivity.

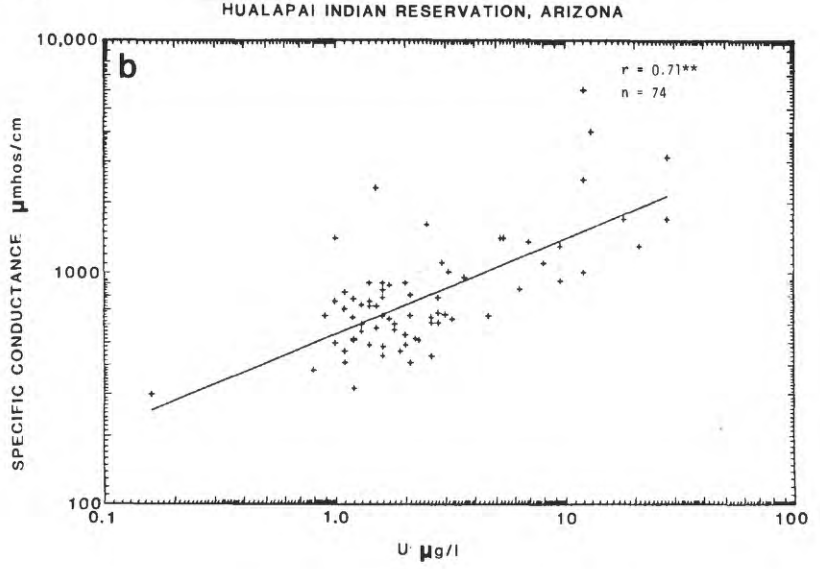
A correlation matrix for all chemical parameters determined is shown in table 5. The number of samples used to determine the correlation for each two elements was always 75 because the qualified values were replaced. Normalized data were not used in the calculations because fluctuating discharge and dissolved solids content do not affect intrasample analyses. Because correlation coefficients must be interpreted carefully to assure that one or two extreme values aren't forcing a significant correlation, scatter plots have been provided for all elements that show a significant correlation with uranium at the 95% confidence level (figs. 7-a through 7-t). On all of these scatter diagrams the element concentrations are plotted on the ordinate against uranium on the abscissa, and in most cases on a log-log scale (depending on whether or not the element was log-normally distributed). The correlation coefficient (r) appears on each diagram along with the number of samples (n). Linear regression lines were plotted on each diagram. Significance at the 99% confidence level is indicated by ** on the diagram next to the value of r, and significance at the 95% confidence level is indicated by *.

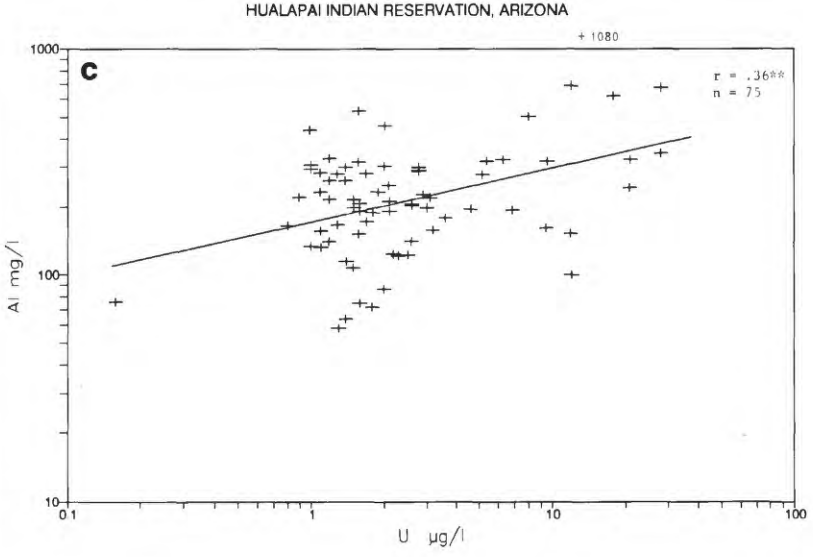
Scatter plots or further discussion of other individual correlation coefficients are not included here because such interpretations involve over 400 correlation coefficients--a rather unwieldy group of data. Instead, multivariate R-mode factor analysis of all chemical parameters was used to place correlating parameters into a small number of groups. Choosing the number of groups (factor rotations) can be somewhat subjective, although the number of factor rotations does not influence the inter-element correlation, but rather affects the strength of the relations among the group parameters. The larger the number of groups, the higher are the factor scores in each group (more strongly the parameters in the group correlate with each other). For purposes of this study, 8 rotations (groups) were chosen (table 6). This decision was based on the following: (1) The eigenvalues show a break at this point--increasing the number of rotations does not increase the cumulative variance at the same rate it did for the first 7 groups; (2) for fewer than 8 groups many of the parameters, such as Ba, Fe, N, Sr, and temperature, had factor scores that were low--less than 0.5; (3) for fewer than 8 groups some parameters, such as uranium and conductivity, had equally high factor scores for more than one group; and (4) for more than 8 groups some of the groups reduced to only one parameter. With such a large number of groups, it is sometimes difficult to identify the geochemical or geological factors controlling each group. Despite this problem, and the added problem that many elements had to be eliminated from the multivariate statistical analysis because too many values were below the detection limit, many of the 8 groups do contain parameters that can be linked by geochemical or geological processes. Factor scores were calculated for each factor group for all sites--these scores weight each site for its contribution to the respective factor group. The results are plotted in figures 8a-8c.

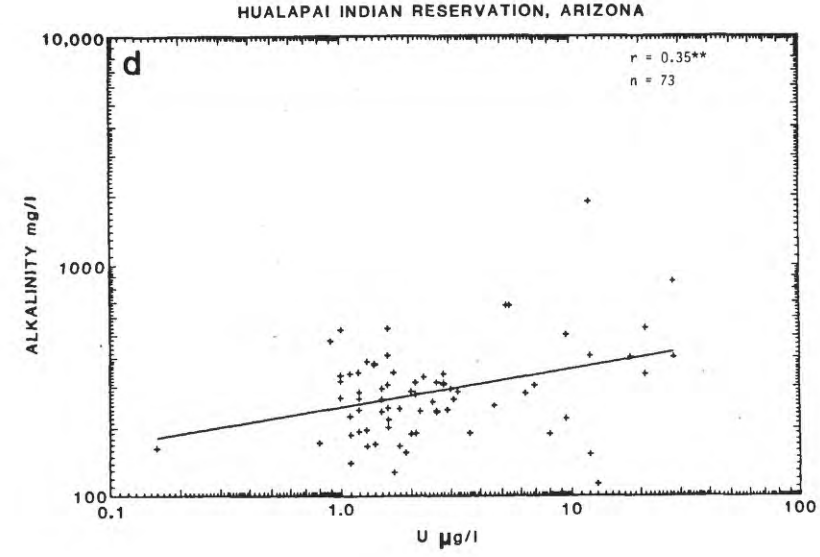
As can be seen from table 6, no factor group could be called a strong "breccia pipe mineralization factor", although perhaps metal mineralization created the association of U and Rn in group 5 (fig. 8b). Unfortunately, most of the breccia pipe metals were not included in the factor analysis because >50% of their values were below the detection limit. Of those metals enriched within breccia pipes that had an adequate number of unqualified values, As, Fe, and Zn should also occur in such a mineralization factor group, but do not. Instead Fe and Zn occur together with Mn in Group 7 (fig. 8c). All 3 of these metals commonly form spring precipitates (oxides). Apparently, the geochemical process of Fe and Zn removal from the water by precipitation is a dominant process in these waters over the influence on these metals by breccia pipe mineralization.

Figure 7a-t. Scatter diagrams of uranium versus elements correlating significantly with uranium at the 99% confidence level (**) or the 95% confidence level (*). r=correlation coefficient; n=number of samples used in the correlation. Samples with values below the detection limit are not plotted on the scatter diagram. Regression lines are plotted for each diagram.









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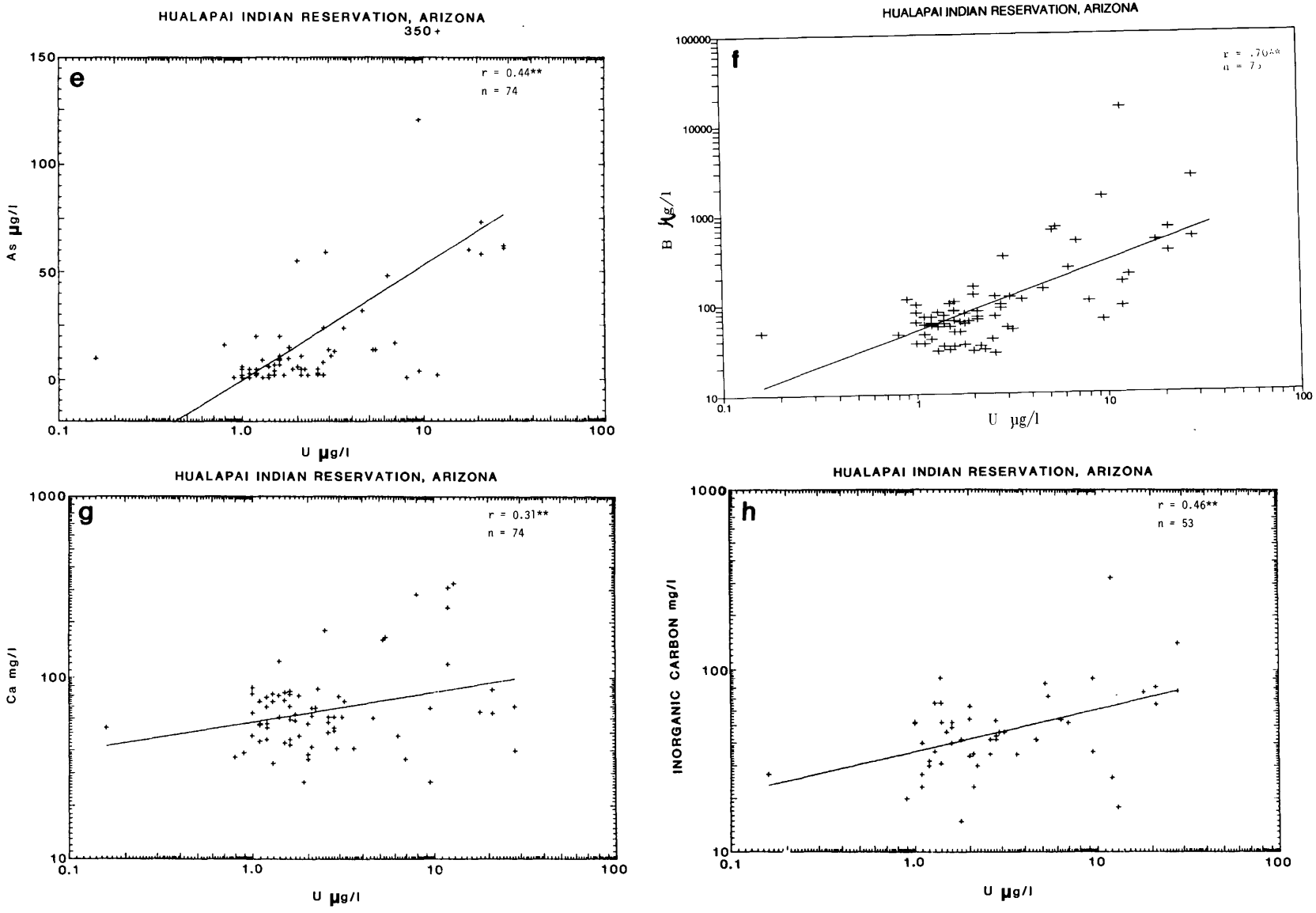

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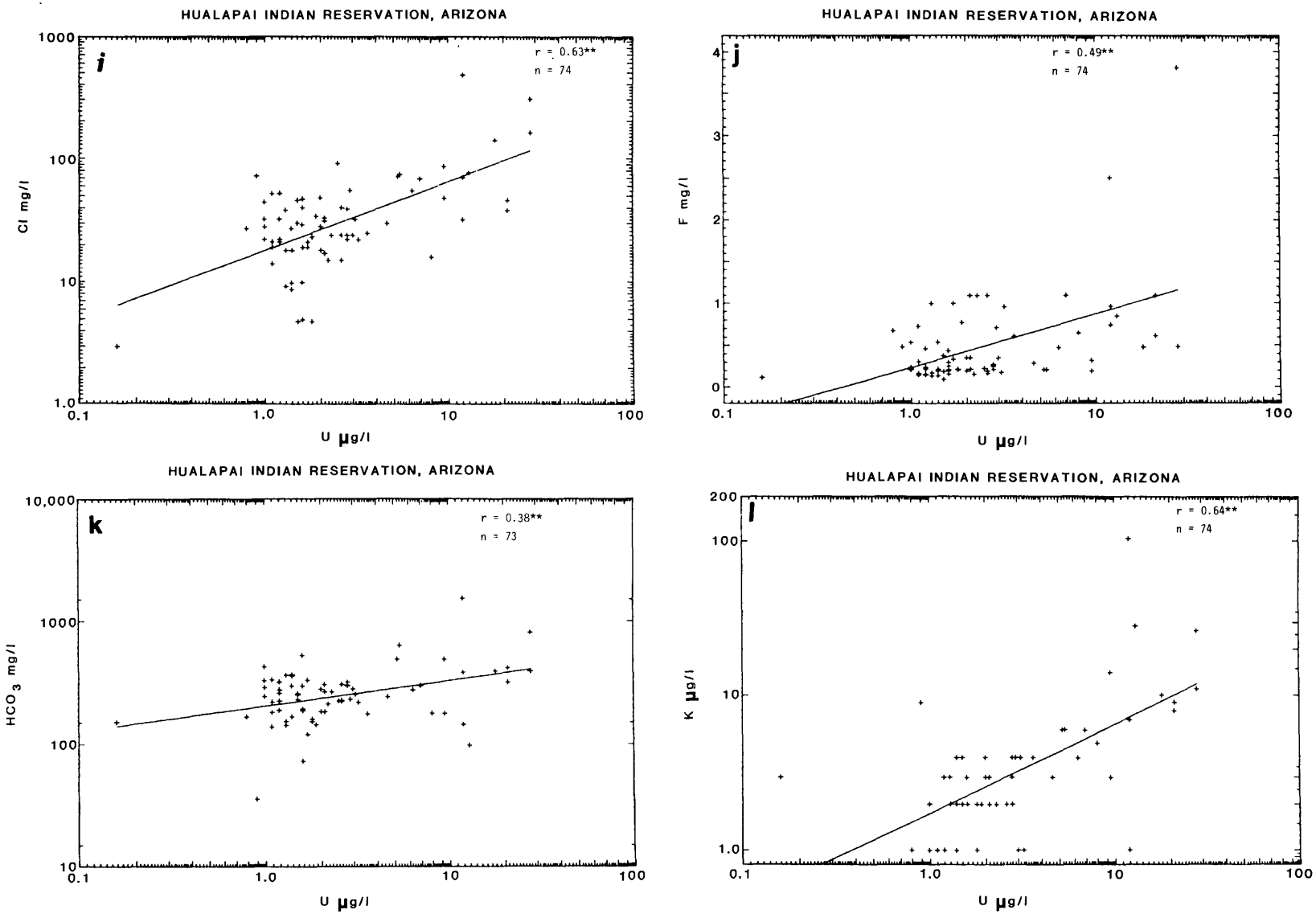

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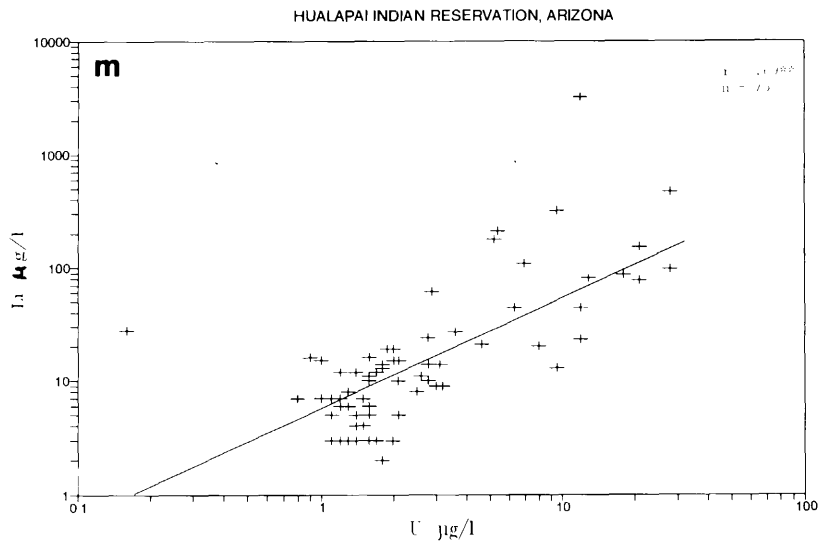

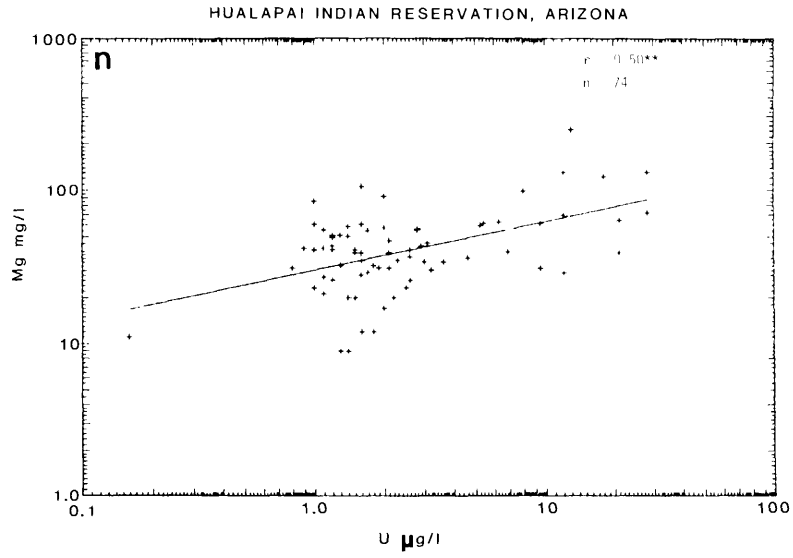

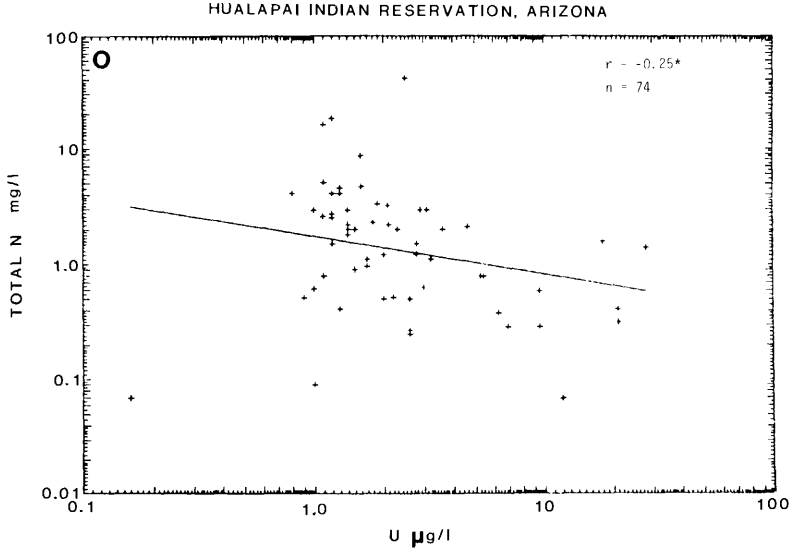

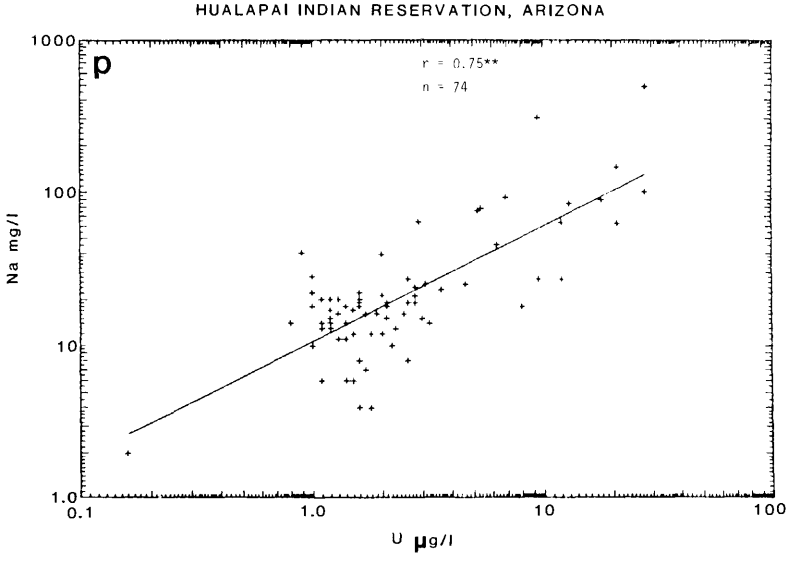

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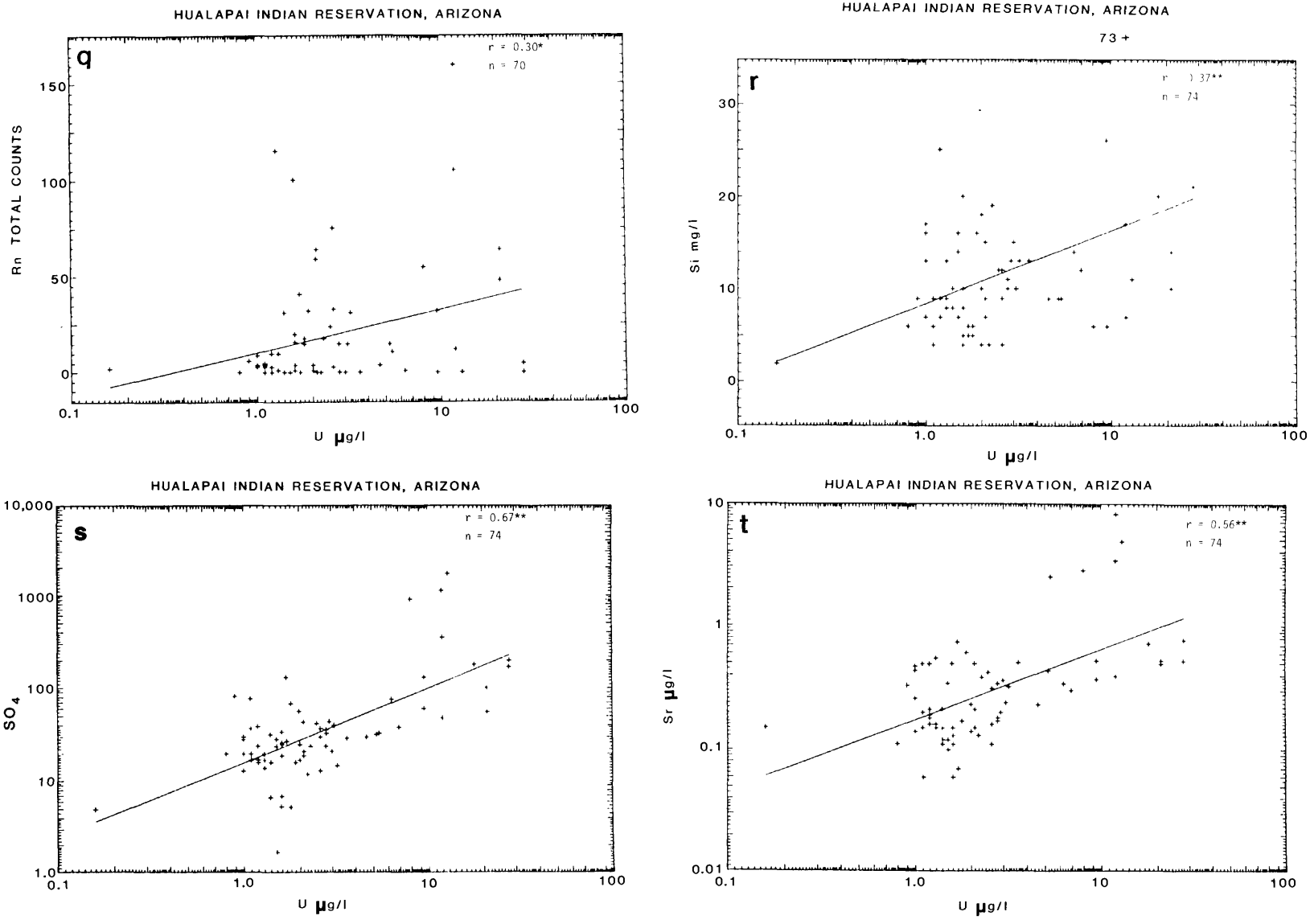

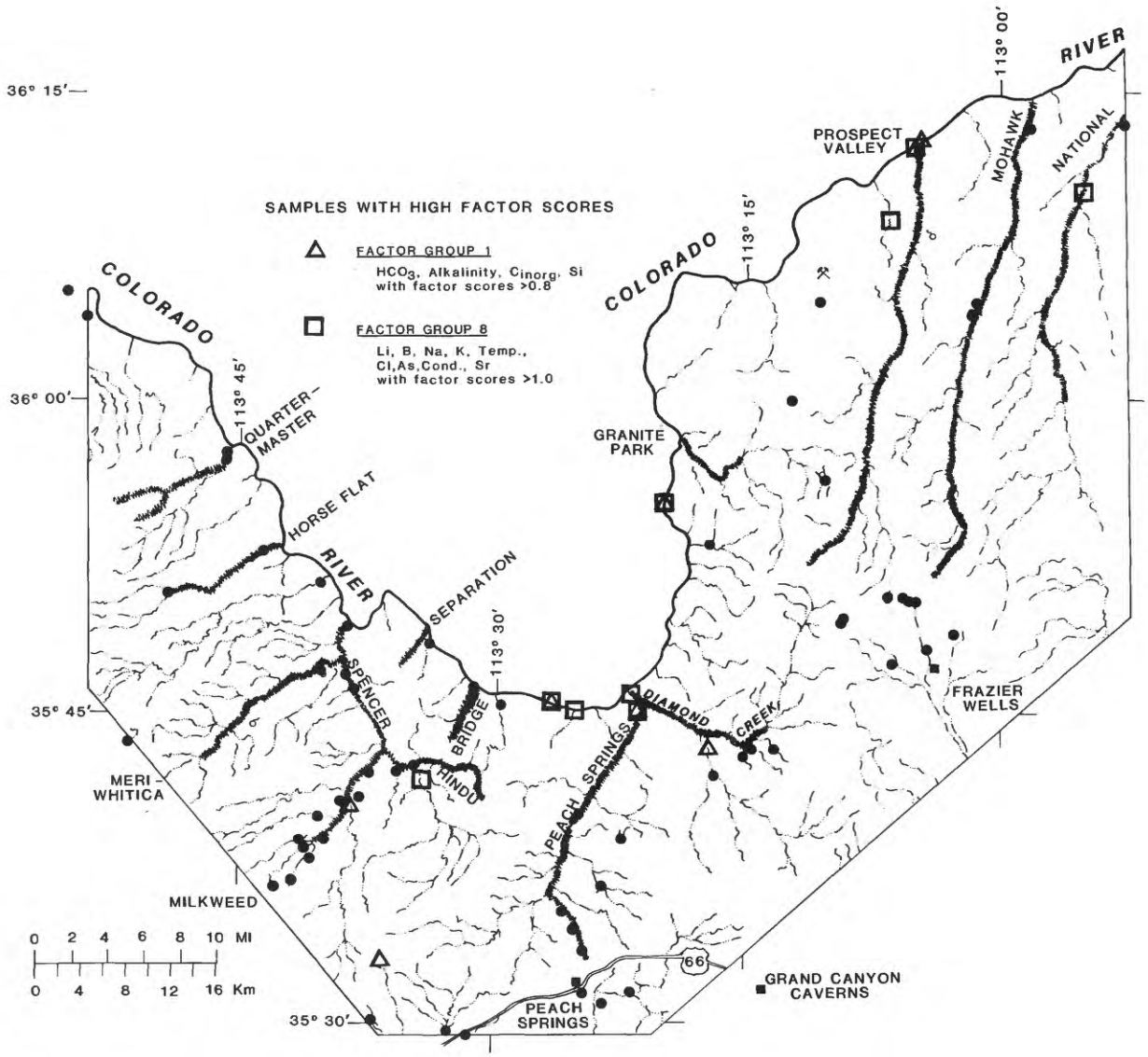

Figure 8a. Sample location map showing sites with high factor scores for factor groups 1 and 8.

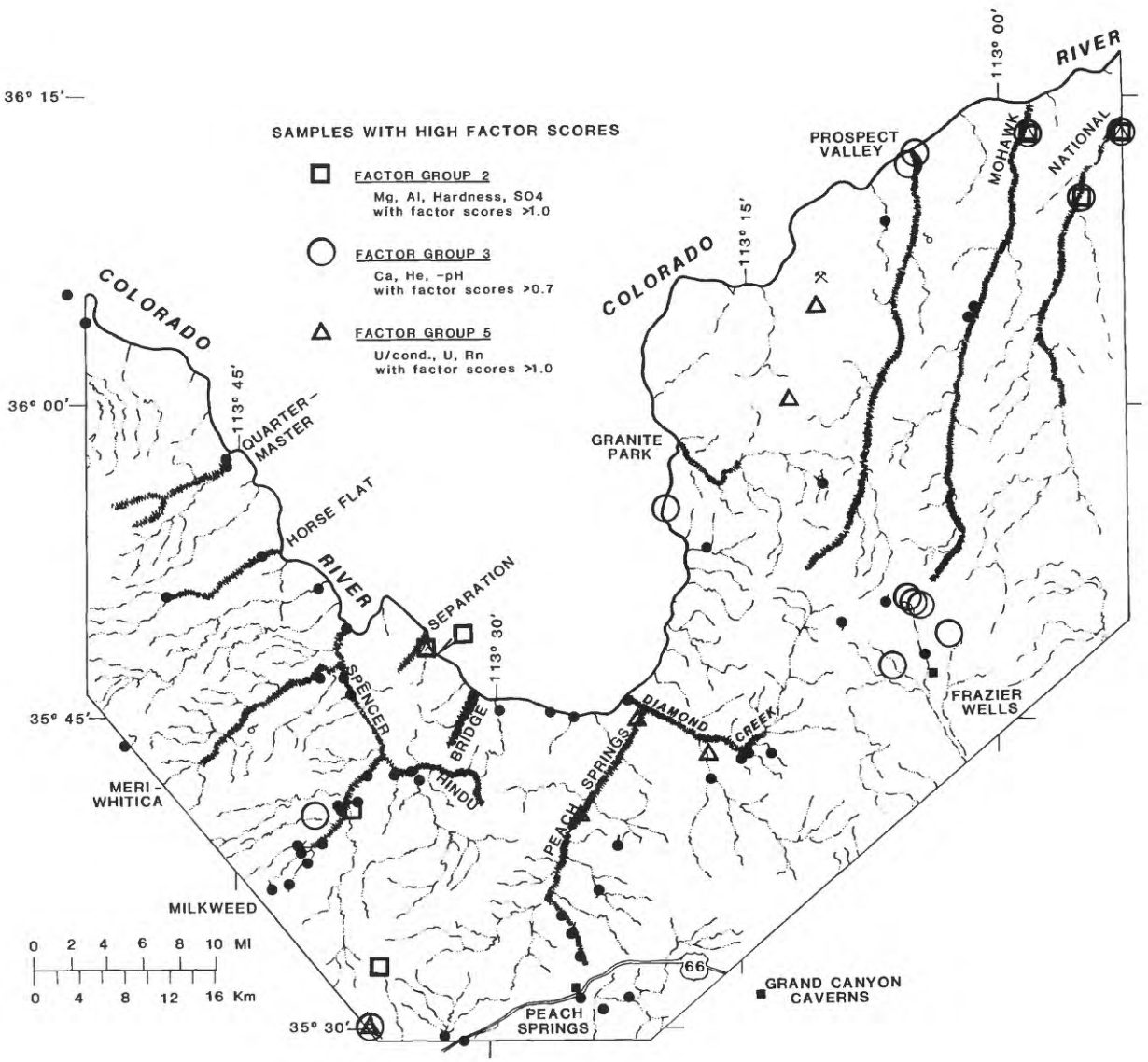

Figure 8b. Sample location map showing sites with high factor scores for factor groups 2, 3, and 5.

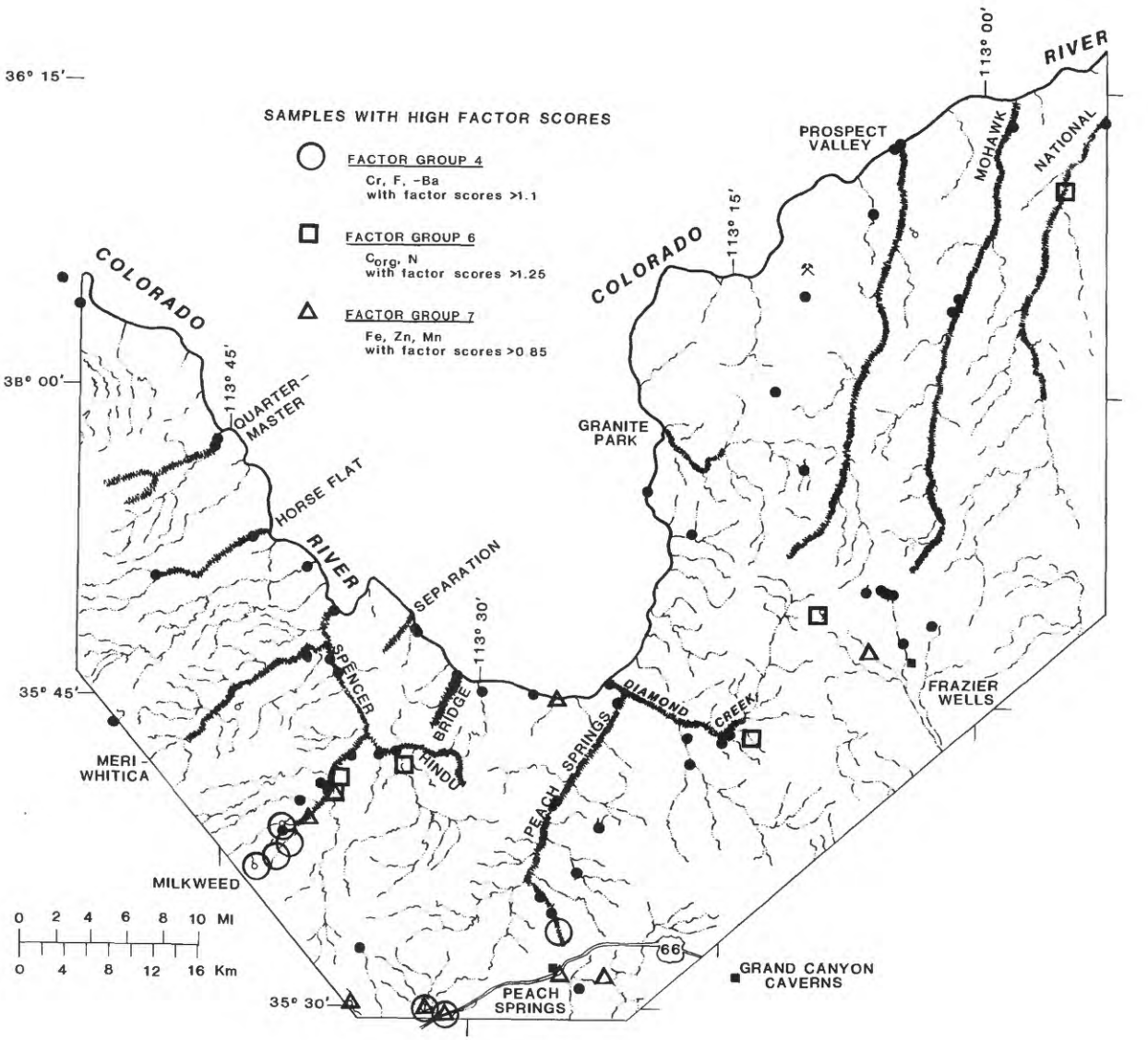

Figure 8c. Sample location map showing sites with high factor scores for factor groups 4, 6, and 7.

Group 1 (bicarbonate, alkalinity, inorganic carbon, and Si; fig. 8a) appears to be predominantly parameters related to the carbonate complex and silica, perhaps controlled by weathering of carbonate-cemented sandstones; inorganic carbon is probably tied up primarily in the HCO_3 complex. Group 6 (fig. 8c) contains organic carbon correlating negatively with total nitrogen; this group is probably controlled by the geochemical process of organic matter decay (loss of organic carbon), which produces ammonia (increase in total nitrogen). Group 8 is probably controlled primarily by higher temperature waters--most of the elements that are concentrated in this group are ones that are commonly enriched in hot springs (fig. 8a). The other 3 groups are not readily explainable on the basis of geochemical parameters, but most likely are controlled by aquifers. For instance, samples with high factor group 4 scores (Cr, F, and -Ba) are distinctly restricted to Milkweed, uppermost Peach Springs, and Truxton Canyon areas (fig. 8c). All are samples from springs and wells that emit from aquifers that occur within Cenozoic sedimentary and volcanic rocks.

The factor analysis has provided a mechanism to reduce a multidimensional statistical problem into a manageable size that gives some insight into the processes that control the geochemistry of ground water on the Reservation. Apparently, in most ground water sampled on the Reservation, the bulk of the major and minor elements that occur in concentrations above the detection limit are controlled by geochemical processes other than the leaching of metals from breccia pipe orebodies.

DISCUSSION

Much of the water collected on the Hualapai Reservation issues from springs, wells, and streams that can be categorized as magnesium, calcium bicarbonate water, and would be suitable for drinking purposes. Those sites that contain inorganic chemical constituents below the maximum recommended concentrations (Davis and DeWiest, 1966), are marked in table 1 with a "+". These sites may be suitable for drinking purposes if they are tested for organic compounds. Note that those samples containing high organic carbon may be rendered unpotable by organic contamination. Many springs located in bottoms of canyons, particularly along and near the Colorado River, are not simple bicarbonate waters, but rather calcium, magnesium sulfate waters as at Horsehair Spring (fig. 4d) or sodium, bicarbonate, chloride waters as at Pumpkin Spring (fig. 4f). The variation in types of water on the Reservation can best be seen on a Piper trilinear diagram (fig. 9). Percentages of anions and cations are based on total equivalents per million of the major ions. Compared to the "average potable ground water" (Davis and DeWiest, 1966, fig. 3.9) the bulk of the data are about 15% higher in Ca+Mg on the Piper diagram, but similar in SO_4+Cl and HCO_3+CO_3 concentrations.

Most of the metals associated with U in breccia pipe orebodies, Ag, As, Ba, Cd, Co, Cu, Hg, Mo, Ni, Pb, Sb, Sr, V, and Zn (Wenrich and Sutphin, 1983), with the exception of As, Ba, Sr, and Zn, had more than 50% of their data below the detection limit, and hence, could not be statistically treated. Nevertheless, the few data for this large suite of elements that are above the detection limit proved very useful. Figures 10-14 show locations of all samples with data above the detection limit for 15 elements (including Ag, Co, Cu, Hg, Mo, Pb and V from the above list). It is interesting to note that half of the water sample copper anomalies are located in the area of the old (pre 1960's) copper prospects (Van Gosen and Wenrich, in press) on the Reservation. An additional geochemical

Hualapai Water Data

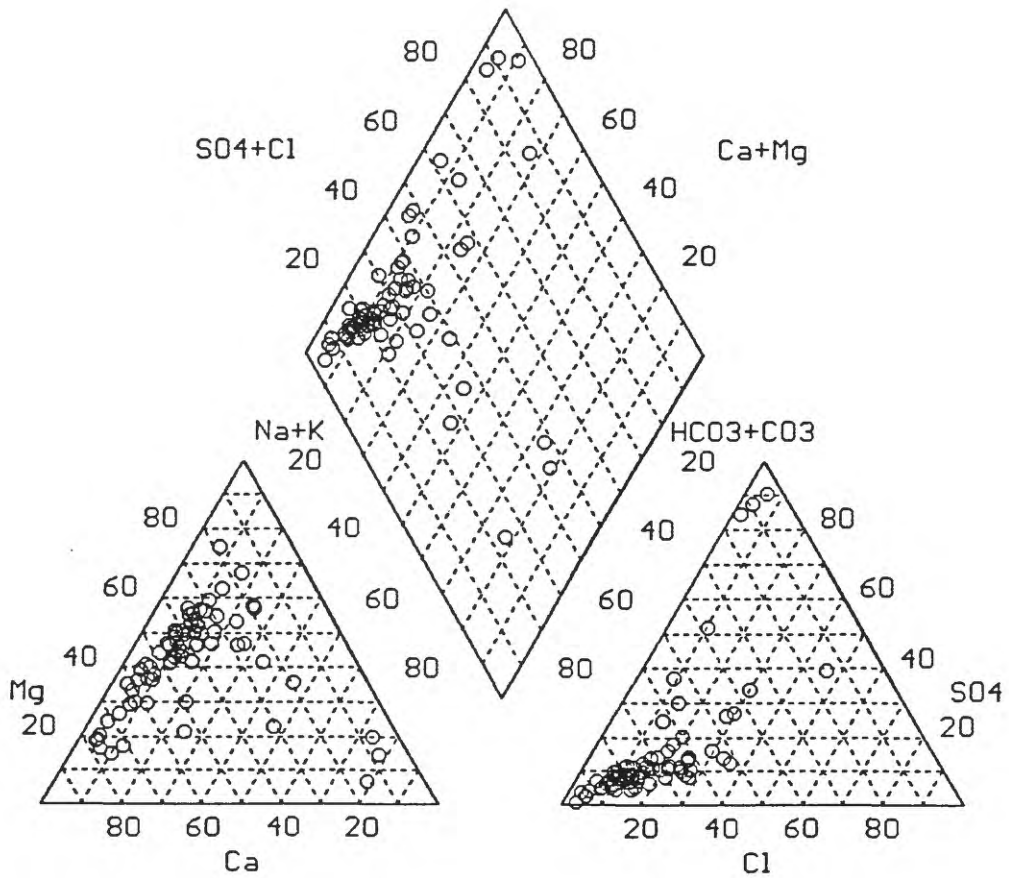

Figure 9. Piper trilinear diagram permits a comparison of the water chemistry from the various samples collected from the Hualapai Reservation. Percentages of anions and cations are based on total equivalents per million of the major ions.

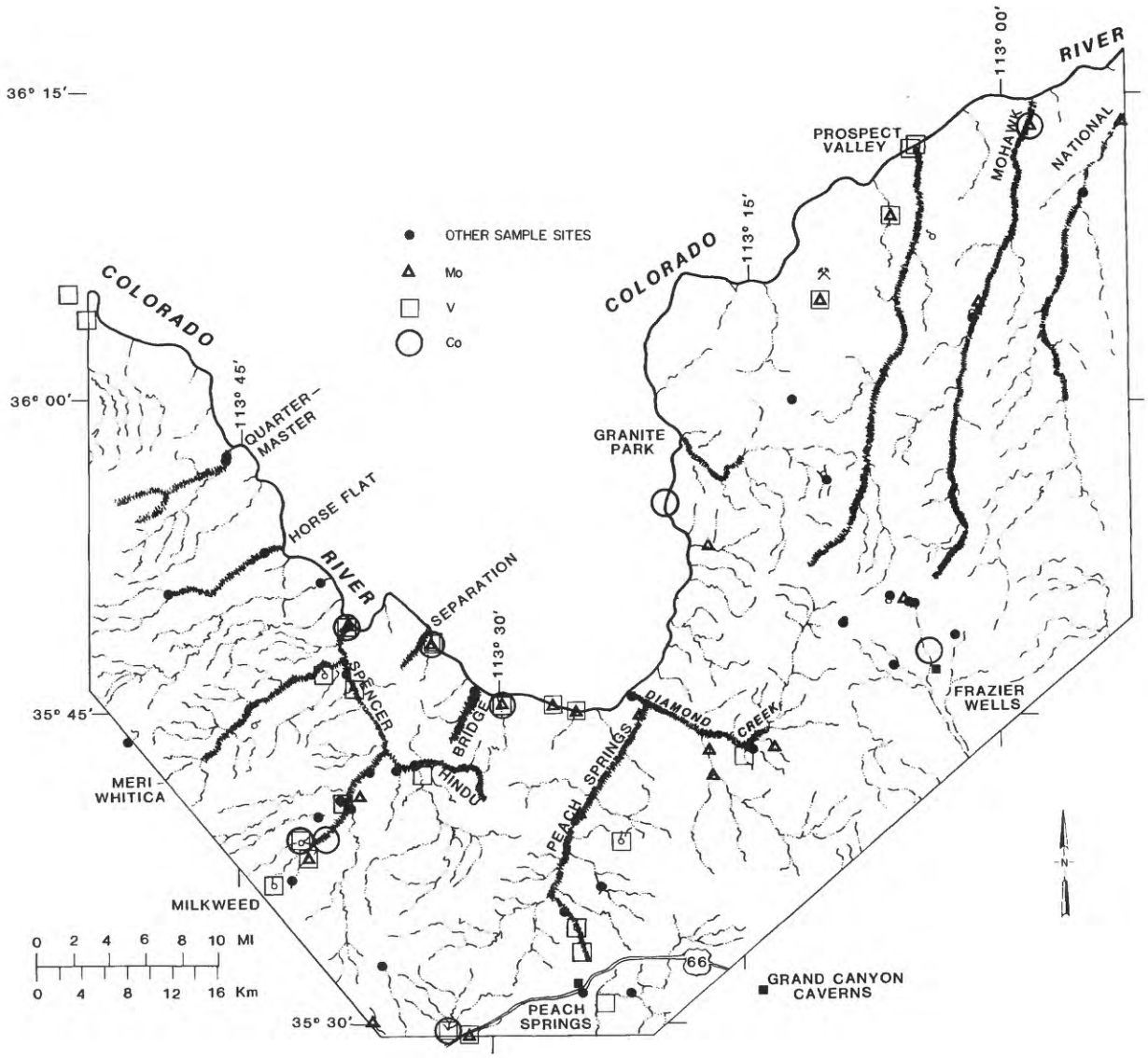

Figure 10. Sample location map showing sites with values above the detection limit for Co, above 6 $\mu g/\ell$ for V, and above 2 $\mu g/\ell$ for Mo.

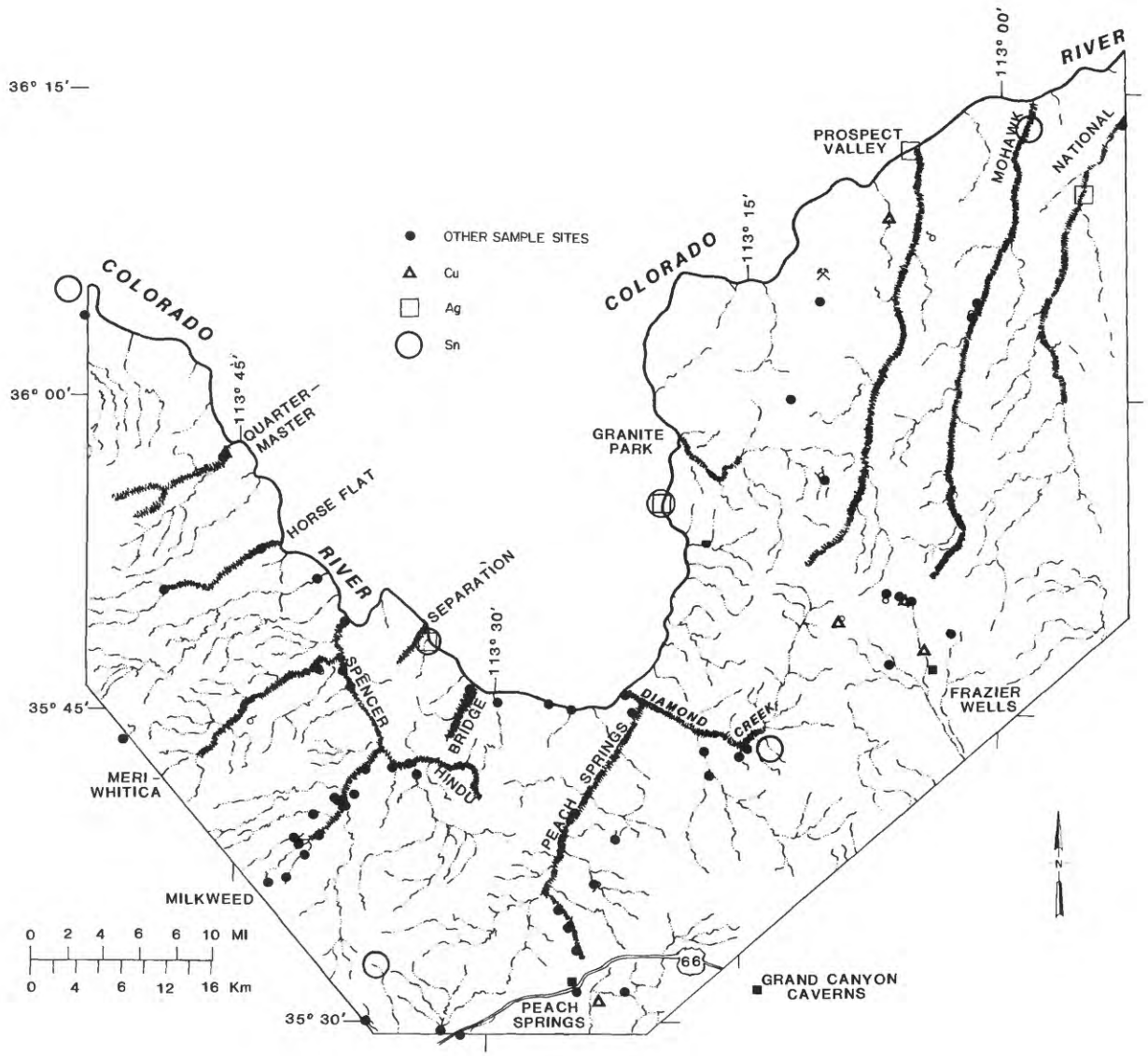

Figure 11. Sample location map showing sites with values above the detection limit for Cu, Ag, and Sn.

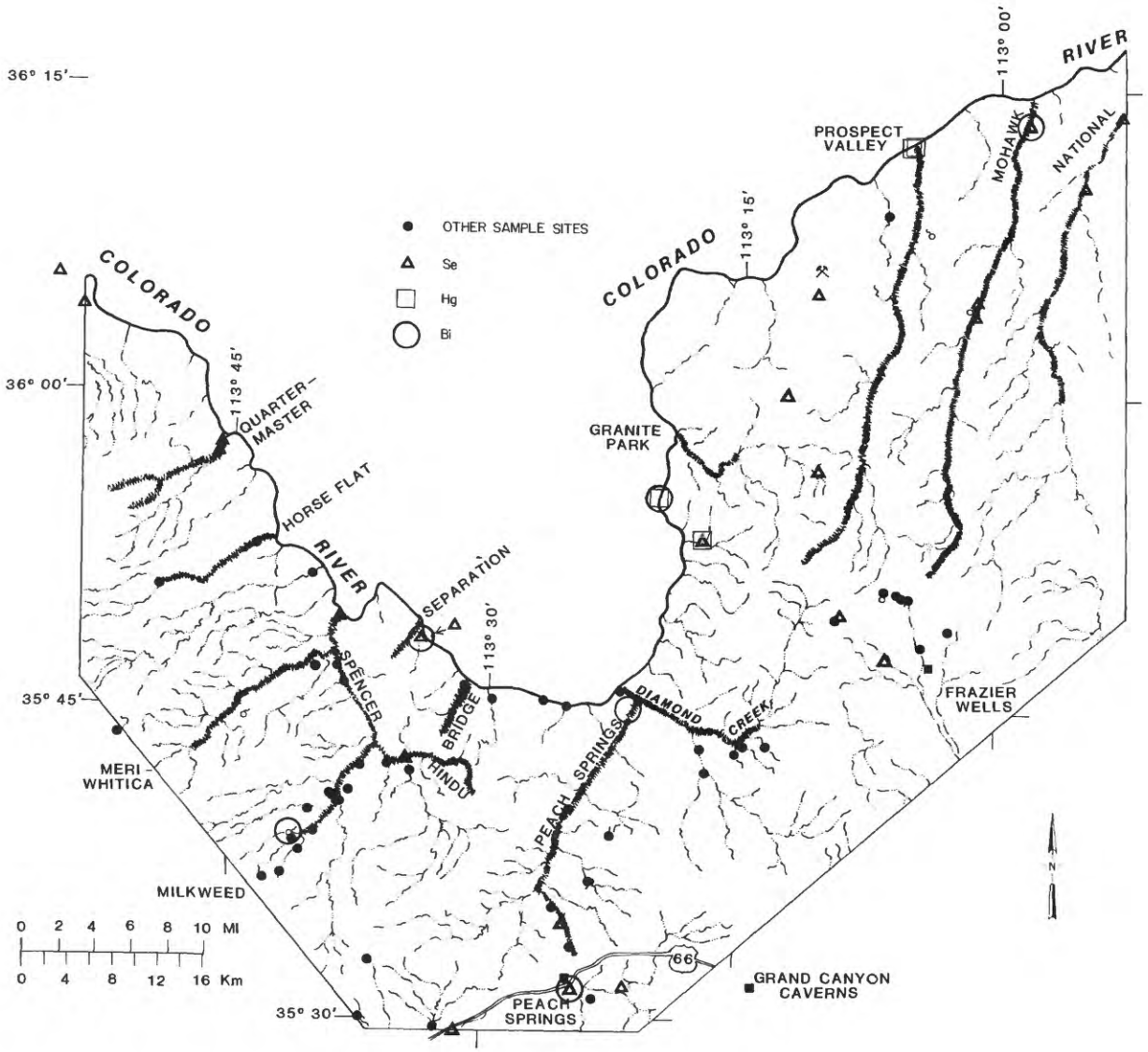

Figure 12. Sample location map showing sites with values above the detection limit for Hg and Bi, and above 2 $\mu g/\ell$ for Se.

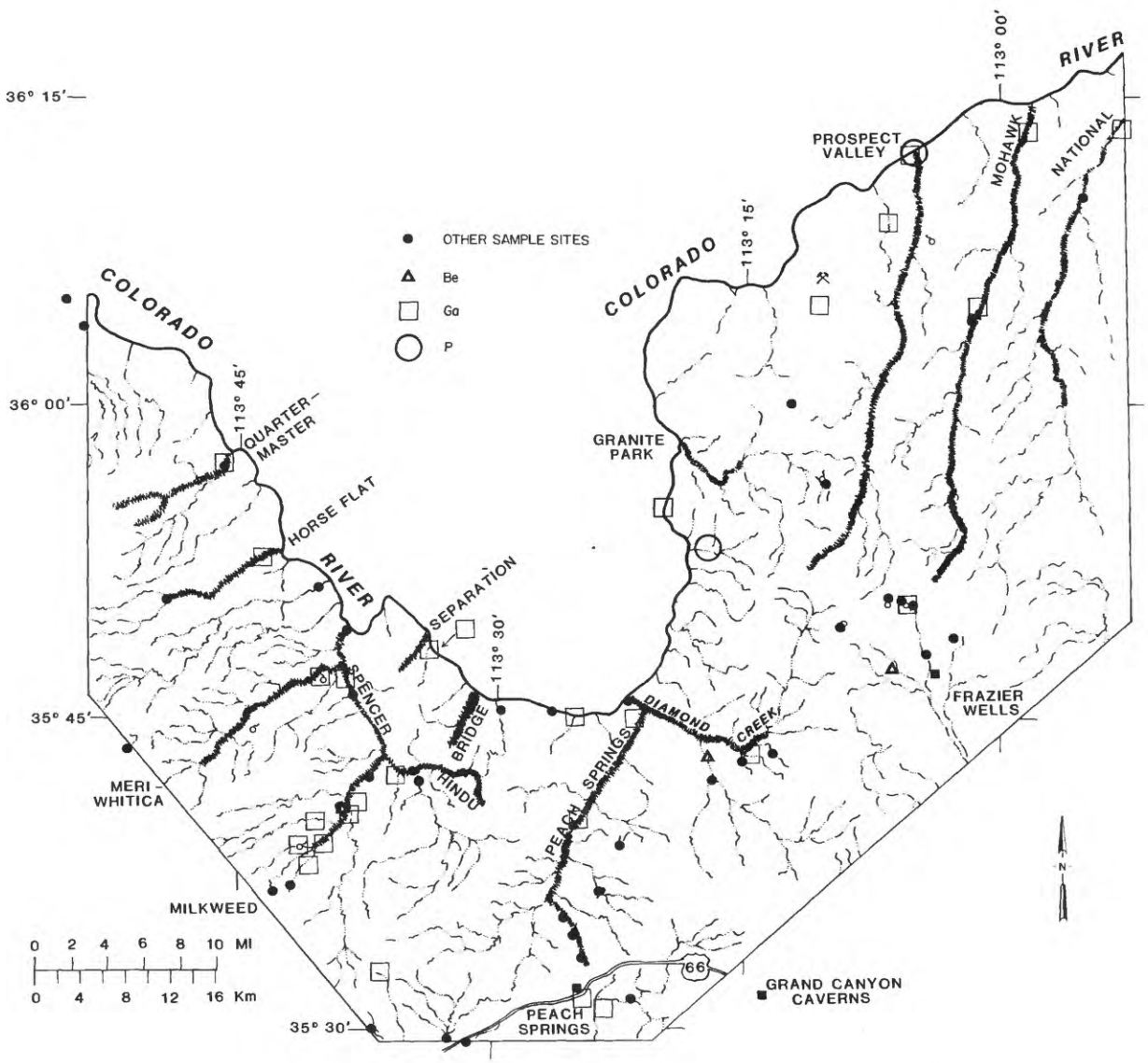

Figure 13. Sample location map showing sites with values above the detection limit for Be, Ga, and P.

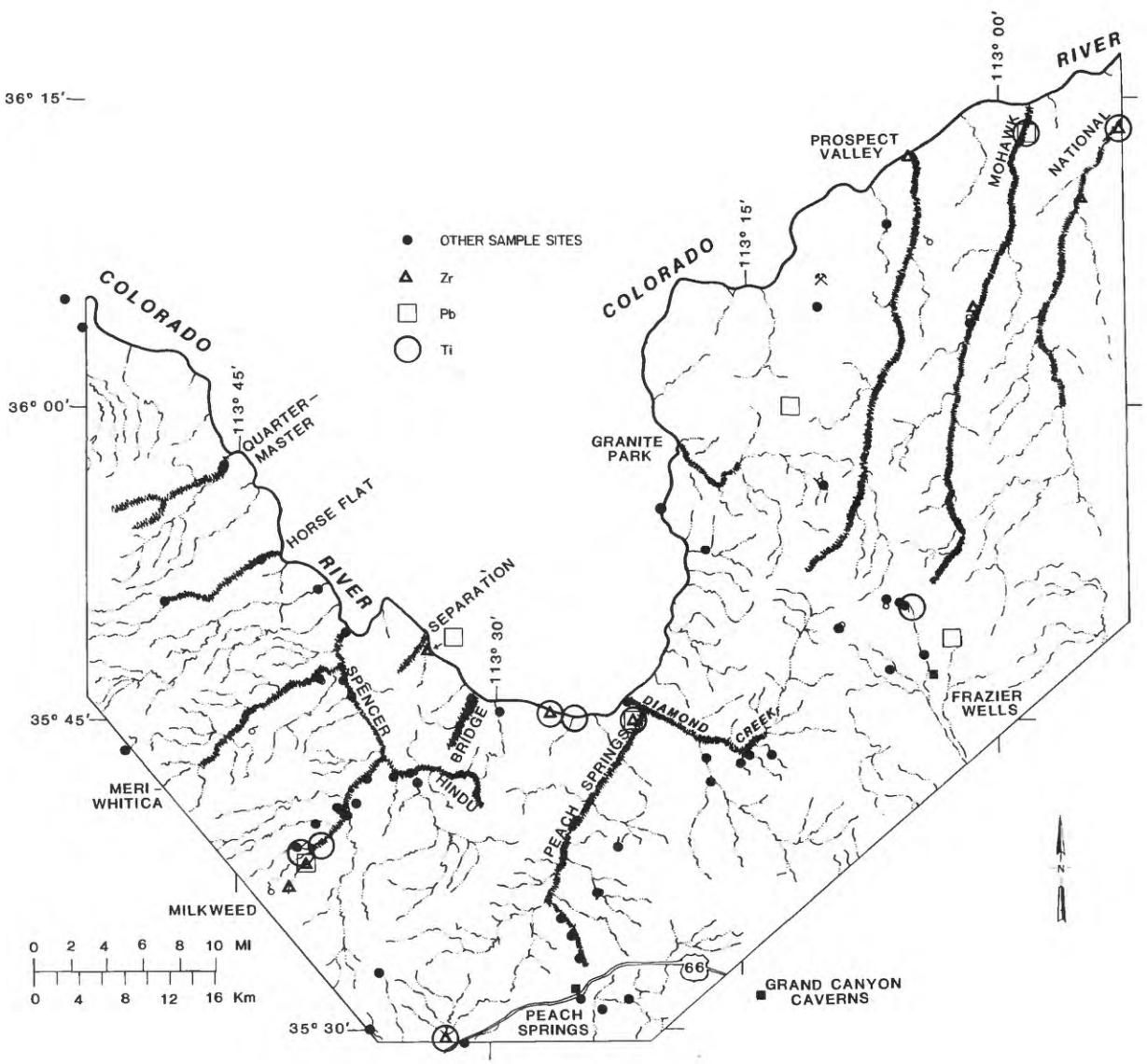

Figure 14. Sample location map showing sites with values above the detection limit for Pb, Ti, and Zr.

process, other than ore deposit mineralization, needs to be considered--many of the metals commonly associated with uranium in the breccia pipes have different solubilities and complex with different anions, and hence do not necessarily occur together in water as they do in ore deposits. This perhaps explains why Fe, As, and Zn do not occur in the same factor group with uranium, as might be expected if the uranium factor group represented an ore deposit mineralization factor. Those metals with 50% or more of their anomalous concentrations occurring in samples also containing anomalous uranium are Ag, Bi, Hg, Mo, Pb, Sn, Ti and Zr. Of these elements, Ag, Hg, Mo, and Pb, which occur with uranium in breccia pipes, should make excellent pathfinders in water for uranium-rich breccia pipes.

As can be seen from the scatter plots (figs. 7-a to 7-t), every parameter in factor groups 1, 2, and 8 shows a significant positive correlation with uranium at the 99% confidence limit (table 5 shows the complete correlation matrix). The correlation of uranium with the alkalies, alkaline earths, and major anions (HCO_3, SO_4--fig. 15, Cl, F) is common in spring and surface waters (Wenrich-Verbeek, 1977). Their influence, and possible resulting false anomalies, need to be considered and removed when interpreting the data. The additional contribution to the SO_4 content of the water from the sulfide-bearing uranium orebodies is important to the data interpretation and needs to be isolated from the "expected SO_4 content". A simple close approximation is, of course, normalization with conductivity.

Most of the anomalous uranium concentrations appear to be clustered along the Colorado River between Diamond Creek and Separation Canyon, and up Diamond Creek and Peach Springs Canyon (fig. 5). Samples near the mouths of Mohawk Canyon, National Canyon, and Prospect Valley are also anomalous in uranium, but do not remain anomalous when normalized by conductivity. In contrast, the R-mode factor analysis and factor scores for group 5, (U, U/cond, and Rn--fig. 8b) suggest that the Mohawk Canyon, National Canyon, and Diamond Creek samples are the most anomalous. More insight can be gathered in solving this conflict by (1) determining which water sites might be down drainage from breccia pipes, (2) verifying that sites that have high uranium do not lie along the linear trend of the correlation between uranium and many of the major cations and anions, as shown on the scatter plots, (3) observing the other factor groups to see which sites might be anomalous, and (4) most importantly, determining which sites are anomalous in the metals, not treated by multivariate statistical analysis, that are associated with uranium in the breccia pipes.

Sample sites (sample numbers are shown on fig. 3) containing four or more anomalous metals in addition to uranium (fig. 16), are Travertine Falls Spring (#18--fig. 4b), Lost Travertine Falls Spring (#19), seeps at the mouth of Separation Canyon (#21 and #22), Beecher Spring (#30), Horsehair Spring (#49--fig. 4d), Mohawk Spring (#50--fig. 4e), Warm Springs at Lava Falls (#75 and #76), and Pumpkin Springs (#77--fig. 4f). Of these eight anomalous locations (fig. 16), the two providing the best, and in fact, excellent, target areas for a nearby mineralized breccia pipe(s) are the two that are also anomalous in factor group 5 (containing Rn and U--fig. 8b). These two are samples #50 and #30, Mohawk and Beecher Springs respectively. Mohawk Spring is about 2 mi (3.3 km) from the mouth of Mohawk Canyon and contains the most anomalous elements: U, Co, Mo, Pb, Rn, Se, and Sr. The Mohawk Canyon drainage contains several mineralized breccia pipes (Wenrich and others, in press); one was drilled in 1985, and found to contain high U, Cu, Zn, Pb, As, Ag, Co, Ni, and Mo concentrations (Wenrich and others, 1988). Beecher Spring, the second site, is located just south of the

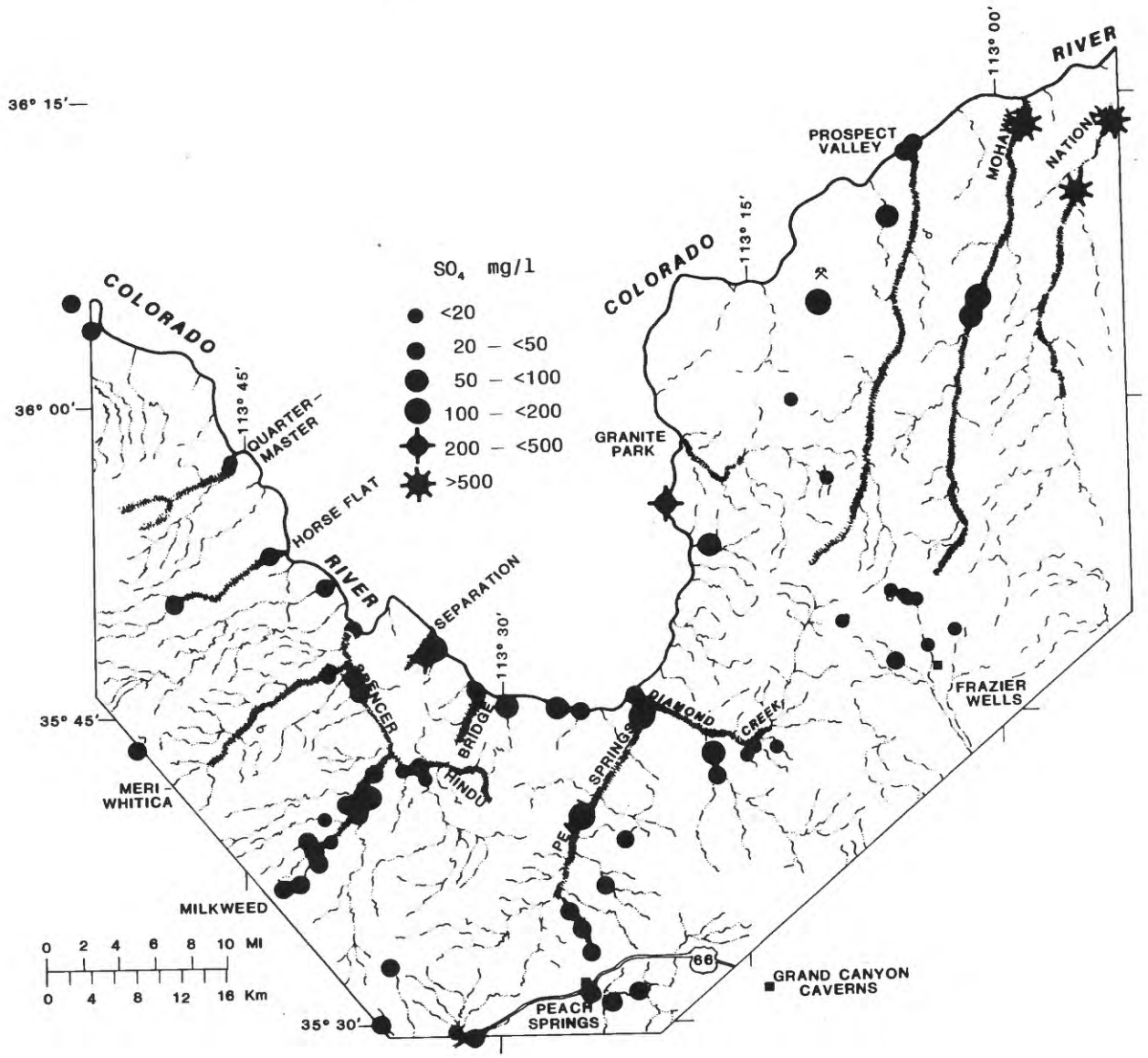

Figure 15. Sample location map showing SO_4 concentrations.

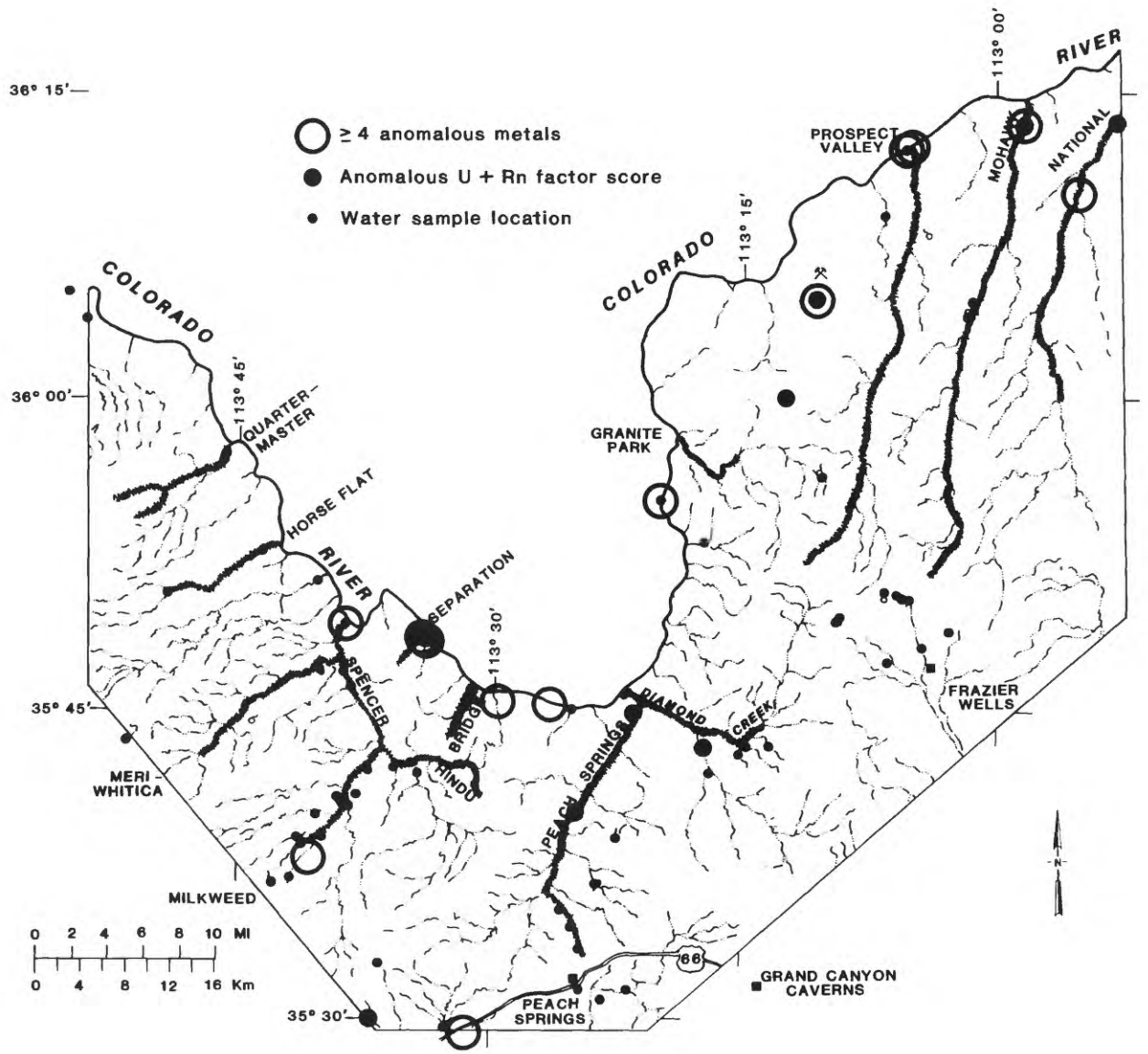

Figure 16. Sample sites considered anomalous and target areas for future exploration.

Ridenour Mine (a breccia pipe, shown on figure 16 by the mine symbol) where three other mineralized pipes (Wenrich and others, in press) are also clustered. This spring yielded anomalous concentrations of U, Ba, Mo, Rn, Se, V, and Sr. In addition to the metals, both springs contain anomalous SO_4 concentrations, which would be expected were the waters draining a breccia pipe. In the case of Mohawk Spring, the 1100 $\mu g/\ell$ SO_4 concentration renders the water unpotable. All of the above elements, except U, are present within pipes as sulfides. So, this hydrogeochemical survey, done in 1982, focused attention on Mohawk Canyon and the Ridenour Mine area, where several mineralized breccia pipes were later discovered.

A water survey conducted by J.C. Antweiler (Billingsley and others, 1983) also indicated that hydrogeochemical sampling might be useful in breccia pipe exploration. Antweiler found that water from Pigeon Spring contained 44 ppb U, the highest U concentration found in the Kanab Creek Roadless Area, and higher than the maximum of 28 ppb found on the Hualapai Reservation. Although Pigeon Spring is only 0.5 mi (1 km) from the Pigeon Pipe (a breccia pipe orebody mined in the late 1980's) it is topographically higher. Thus, a good possibility exists, particularly because mineralized pipes occur in clusters, that this spring is emitting water that has flowed through one or more other mineralized pipes.

CONCLUSIONS

Three problems are associated with hydrogeochemical surveys for breccia pipes: (1) Due to the low density of springs and wells, each water site drains such a large area that the anomaly may be proportional to the size of the recharge area. Additionally, there is a vector effect and mineralized pipes closer to the spring will contribute more metals to the sample site than will more distant pipes; (2) Collectively, the springs drain several totally different aquifer systems, such as the Cambrian Muav Limestone, the Mississippian Redwall limestone, or Cenozoic gravels and volcanic rocks. The 75 springs and wells emanate from over 15 different host rocks. This has resulted in several water populations, as well as one representing contributions from mineralized breccia pipes; and (3) The analytical detection limits for the metals are so low (generally 1 $\mu g/\ell$ for most of the metals), particularly for low conductivity samples, that very careful analyses are required. Nevertheless, even with good analytical sensitivity, such as the uranium analyses provided in this study (table 3), the sample density is so low that a hydrogeochemical survey is probably only capable of delineating clusters of mineralized pipes, or a single mineralized pipe if it is in close proximity to, and directly up the hydraulic gradient from, the sampled spring. This appears to be the case near Mohawk and Beecher Springs. Here hydrogeochemical sampling was successful at delineating target areas for mineralized breccia pipes, which were subsequently located through detailed geologic mapping of these areas.

ACKNOWLEDGEMENTS

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Table 1. List of sample numbers and sample names (w=well, s=spring, st=stream, *=site from stream just below spring, which was relatively inaccessible). Note that sites 1 and 35 are both named Red Spring, but are unrelated springs from distant geographic locations. In contrast, sites 8 and 15, both labeled Pocomate Springs, are from separate but related seeps located in close proximity to each other. Those sites containing water with inorganic chemical constituents "low" enough to render the water suitable for drinking are marked with an "+". "Low" is defined here as below the "quality criteria" listed in Table 4.5 of Davis and DeWiest (1966). Note that none of these samples have been tested for organic compounds, other than organic carbon; organic contamination could render some of these water sites as unpotable, particularly those with a high organic carbon content.

Sample number	Host Rock	Type of water	Location name
1A-W82+	Muav Ls	s	Red Spring
2A-W82+	Muav Ls	s	Peach Springs
3A-W82+	Muav Ls	s	Lower Peach Springs
4A-W82+	Diamond Creek Gravels	st	Diamond Creek (at mouth)
5A-W82	Bright Angel Sh	s	Rocky Spring
6A-W82	Bright Angel Sh in landslide block adjacent to Hurricane Fault	s	Mesquite Spring
7A-W82+	Muav Ls	s	Mulberry Spring
8A-W82+	Coconino Ss	s	Pocomate Springs
10A-W82+	Kaibab Ls	s	Upper Pine Spring
11A-W82+	Kaibab Ls	s	Unnamed spring 1/3 mi from Pine Tank
12A-W82+	Tertiary Frazier Well gravels	s	Pine Spring
13A-W82+	Tertiary Frazier Well gravels	w	Unnamed well
14A-W82+	Tertiary Frazier Well gravels	w	fed by Frazier well
15A-W82+	Coconino Ss	s	Pocomate Springs (fig. 4a)
16A-W82	Tertiary Frazier Well gravels	w	Unnamed well
17A-W82	Vishnu Schist	st*	Travertine Falls
18A-W82	Precambrian granite	s	Travertine Falls Spring (fig. 4b)
19A-W82+	Tapeats Ss	st*	Lost Travertine Falls Spring
20A-W82+	Vishnu Schist	st*	1/4 mile below Bridge Canyon Spring
21A-W82	Precambrian granite	s	seep south of Separation Canyon
22A-W82	Precambrian granite	s	seep south of Separation Canyon
23A-W82+	Spencer Canyon gravels	st	mouth of Spencer Canyon
24A-W82+	Travertine	s	Quartermaster Springs - NE
25A-W82+	Travertine	s	Quartermaster Springs - SW
26A-W82+	Muav Ls	s	Rampart Springs
27A-W82+	Muav Ls	st*	base of Columbine Falls - 1/2 mi from spring
28A-W82+	Redwall Ls	s	Diamond Creek Spring (Upper Diamond Spring)
29A-W82+	Esplanade Ss	s	Hells Hollow Spring (fig. 4c)
30A-W82	Hermit/Esplanade contact	s	Beecher Spring
31A-W82+	Redwall Ls	s	Surprise Springs
32A-W82+	Muav Ls & Spencer Canyon Gravels	s	Spencer Springs
33A-W82+	Muav Ls	s	Meriwhitica Springs
34A-W82+	Contact of Hermit Sh and Coconino Ss	s	Hockey Puck Spring
35A-W82	Coconino Ss	s	Red Spring
36A-W82	Coconino Ss	s	Moss Spring
37A-W82+	Coconino Ss	s	Big Spring
38A-W82+	Music Mt. congl.	s	Unnamed Spring
39A-W82+	Hualapai volcanics	s	Willow Spring

Table 1. continued

Sample number	Host Rock	Type of water	Location name
40A-W82+	Bright Angel Sh	s	Lower Milkweed Spring duplication of 43A-W82
41A-W82+	Hualapai volcanics	s	West Water Spring (upper)
42A-W82+	Music Mt. congl.	s	Unnamed spring
43A-W82+	Bright Angel Sh	s	Lower Milkweed Spring
44A-W82+	Music Mt. congl.	s	Lower West Water Spring
45A-W82+	Quaternary & Tertiary gravels	w	PMG Well (Truxton)
47A-W82	Muav Ls	s	Horse Trough Spring
48A-W82	Muav Ls	w	Shipley Well
49A-W82	Wescogame Fm	s	Horsehair Spring (fig. 4d)
50A-W82	Muav Ls	s	Mohawk Spring (fig. 4e)
51A-W82	Redwall Ls	s	National Canyon Spring
53A-W82+	Muav Ls	s	East Diamond Spring
54A-W82+	Hualapai volcanics	s	Milkweed Spring
55A-W82+	Muav Ls	s	Clay Springs
56A-W82+	Muav Ls	w	Santa Fe #5 Well
57A-W82	Tertiary Frazier Well gravel	w	XI Well
58A-W82+	Muav Ls	s	Diamond Spring
59A-W82+	Precambrian granite	s	Reference Point Spring
60A-W82+	Bright Angel Sh	s	Wild Horse Spring
61A-W82+	Muav Ls	s	Hindu Spring
62A-W82+	Bright Angel Sh	s	Blue Mtn Seep
63A-W82+	Contact between Precambrian granite and Tapeats Ss	s	Lost Creek Spring
64A-W82+	Precambrian granite	s	Unnamed spring in Milkweed Canyon
65A-W82+	Temple Butte Fm	s	Sheep Spring
66A-W82	Bright Angel Sh	s	Unnamed spring in Milkweed Canyon
67A-W82	Vishnu Schist	s	Robbers Roost Spring
68A-W82+	Precambrian granite	s	Unnamed spring in Milkweed Canyon
69A-W82+	Muav Ls	s	Hindu Seep
70A-W82+	Bright Angel Sh	s	Buck and Doe Spring
71A-W82+	Tapeats Ss	s	Tilted Spring
72A-W82+	Muav Ls	s	Metuck Springs
73A-W82+	Quaternary & Tertiary gravels	w	Truxton Well
74A-W82+	Vishnu Schist	s	Dewey Mahone Spring
75A-W82	Muav Ls	s	Warm Springs
76A-W82+	Muav Ls	s	Lava Falls (by cliff)
77A-W82	Tapeats Ss	s	Pumpkin Spring (fig. 4f)
78A-W82+	Muav Ls	s	Three Springs
79A-W84+	Muav Ls	st*	Hindu Canyon

Table 2. Analytical procedures, detection limits, and sample collection procedures

Chemical parameter	Analytical procedure	Lower detection limit	Units	Sample collection procedure
U	Direct and extraction fluorimetry (see text)	0.01	µg/ℓ	Filtered, acidified with HCl
Sp cond	Beckman conductivity probe	--	µmhos/cm	In situ field measurement of specific conductance
U/cond	Uranium/conductivity X100	--	--	-----
Ag	ICP	2	µg/ℓ	Filtered, acidified with HNO_3
Al	ICP	--	µg/ℓ	" " " "
Alkalinity	Direct titration with hydrochloric acid	--	mg/ℓ	Raw
As	Hydride generation atomic absorption	1	µg/ℓ	Filtered, acidified with HNO_3
B	ICP	--	µg/ℓ	" " " "
Ba	ICP	--	µg/ℓ	" " " "
Be	ICP	1	µg/ℓ	" " " "
Bi	ICP	10	µg/ℓ	" " " "
C-inorg	Persulfate oxidation and IR gas analyzer	--	mg/ℓ	Filtered through a Ag membrane into a glass bottle
C-org	Persulfate oxidation and IR gas analyzer	--	mg/ℓ	Filtered through a Ag membrane into a glass bottle
Ca	ICP	--	mg/ℓ	Filtered, acidified with HNO_3
Cd	Graphite furnace atomic absorption	1	µg/ℓ	" " " "
Cl	Ion chromatography	--	mg/ℓ	Filtered
Co	ICP	2	µg/ℓ	Filtered, acidified with HNO_3
Cr	ICP	1	µg/ℓ	" " " "
Cu	ICP	2	µg/ℓ	" " " "
F	Ion chromatography	--	mg/ℓ	Filtered
Fe	ICP	2.0	µg/ℓ	Filtered, acidified with HNO_3
Ga	ICP	5	µg/ℓ	" " " "
Hardness	Calculated from Ca, Mg values	--	mg/ℓ	-----
HCO_3	Titration	--	mg/ℓ	Raw
He	Mass spectrometer	--	ppb W.R.T. air	In situ field measurement
Hg	Flameless atomic absorption	0.2	µg/ℓ	Filtered, acidified with HNO_3
K	ICP	1	mg/ℓ	" " " "
Li	ICP	2	µg/ℓ	" " " "
Mg	ICP	--	mg/ℓ	" " " "
Mn	ICP	2	µg/ℓ	" " " "
Mo	ICP	2	µg/ℓ	" " " "
Total N	Ion chromatography	0.04	mg/ℓ	Filtered, preserved with $HgCl_2$ and chilled
Na	ICP	--	mg/ℓ	Filtered, acidified with HNO_3
Ni	ICP	5	µg/ℓ	" " " "
P	ICP	1	mg/ℓ	" " " "
Pb	ICP	6	µg/ℓ	" " " "
PO_4	Ion chromatography	0.20	mg/ℓ	Filtered, preserved with $HgCl_2$ and chilled
pH	Orion Ph meter	--		In situ field measurement
Rn	Alpha scintillometer	1	Total Counts	Raw, placed in Alpha scintillometer cell
Se	Hydride generation atomic absorption	2	µg/ℓ	Filtered, acidified with HNO_3
Si	ICP	--	mg/ℓ	" " " "
Sn	ICP	6	µg/ℓ	" " " "
SO_4	Ion chromatography	--	mg/ℓ	Filtered
Sr	ICP	0.05	µg/ℓ	Filtered, acidified with HNO_3
temp	Thermometer	--	°C	In situ field measurement
Ti	ICP	1	µg/ℓ	Filtered, acidified with HNO_3
V	ICP	5	µg/ℓ	" " " "
Zn	ICP	1	µg/ℓ	" " " "
Zr	ICP	1	µg/ℓ	" " " "

--	All data above the detection limit.
ICP	Inductively coupled argon plasma atomic emission spectrosopy.
W.R.T. air	With respect to air.

Table 3 -- Hualapai Water Data

Sample #	Latitude	Longitude	U µg/ℓ	sp cond µhos/cm	U/cond x100	Ag µg/ℓ	Al µg/ℓ	alkalinity mg/ℓ	As µg/ℓ	B µg/ℓ
1A-W82	35°33'31"	113°25'20"	3.6	950	.38	<2	179	190	24	109
2A-W82	35°34'42"	113°25'49"	1.6	780	.21	<2	190	218	9	65
3A-W82	35°35'31"	113°26'22"	2.6	640	.41	<2	203	237	5	72
4A-W82	35°45'58"	113°22'14"	6.9	1350	.51	<2	193	306	17	476
5A-W82	35°44'58"	113°21'47"	28	3100	.90	<2	343	854	62	2490
6A-W82	35°40'13"	113°25'16"	21	1300	1.62	<2	323	342	73	363
7A-W82	35°36'42"	113°24'09"	3.1	1000	.31	<2	219	267	11	118
8A-W82	35°49'25"	113°09'35"	1.5	2300	.07	<2	107	267	4	56
10A-W82	35°50'31"	113°06'48"	1.6	650	.25	<2	152	307	20	49
11A-W82	35°50'23"	113°06'11"	1.4	900	.16	<2	114	373	6	60
12A-W82	35°50'12"	113°05'52"	1.8	570	.32	<2	72	243	10	35
13A-W82	35°50'09"	113°05'33"	1.6	480	.33	<2	75	245	10	34
14A-W82	35°47'48"	113°04'38"	1.4	490	.29	<2	64	172	2	34
15A-W82	35°49'19"	113°09'39"	2	490	.41	<2	87	189	6	30
16A-W82	35°48'37"	113°03'01"	1.3	560	.23	<2	58	196	1	30
17A-W82	35°45'02"	113°25'30"	2.9	1100	.26	<2	227	239	59	331
18A-W82	35°45'21"	113°26'49"	9.5	1300	.73	<2	162	502	120	1520
19A-W82	35°45'22"	113°29'51"	6.3	850	.74	<2	324	283	48	243
20A-W82	35°46'09"	113°31'35"	4.6	650	.71	<2	195	250	32	142
21A-W82	35°48'28"	113°33'58"	18	1700	1.06	3	622	404	60	485
22A-W82	35°48'28"	113°34'01"	28	1700	1.65	<2	674	405	61	524
23A-W82	35°49'24"	113°34'01"	2	540	.37	<2	304	288	6	126
24A-W82	35°57'31"	113°45'56"	1.3	725	.18	<2	280	385	1	81
25A-W82	35°57'22"	113°45'58"	1.4	750	.19	<2	262	381	1	74
26A-W82	36°08'42"	113°06'33"	1.6	440	.36	<2	207	203	7	105
27A-W82	36°05'32"	113°55'14"	1.5	575	.26	<2	199	235	7	101
28A-W82	35°43'12"	113°13'51"	.2	300	.05	<2	76	164	10	49
29A-W82	36°08'42"	113°06'33"	.9	650	.14	<2	222	474	1	112
30A-W82	36°04'34"	113°10'41"	9.5	920	1.03	<2	318	220	4	65
30B-W82	36°04'34"	113°10'41"	8.4	920	.91	<2	314	221	4	76
31A-W82	35°31'07"	113°24'04"	1	750	.13	<2	305	336	2	79
31B-W82	35°31'07"	113°24'04"	1.2	750	.16	<2	302	336	2	83
32A-W82	35°46'59"	113°39'00"	2.8	610	.46	<2	299	343	8	89
33A-W82	35°47'11"	113°40'30"	1.2	640	.19	<2	328	347	2	57
33B-W82	35°47'11"	113°40'30	1.2	640	.19	<2	257	348	2	66
34A-W82	35°56'01"	113°10'31"	2.2	520	.42	<2	124	238	5	34
34B-W82	35°56'01"	113°10'31"	2.1	520	.40	<2	115	238	5	38
35A-W82	36°04'14"	113°01'23"	1.7	630	.27	<2	172	128	2	49
36A-W82	36°03'42"	113°01'37"	1.1	460	.24	<2	133	141	3	36
37A-W82	35°59'59"	113°12'24"	2.6	440	.59	<2	141	234	2	28

Table 3. continued

Sample #	Latitude	Longitude	U µg/ℓ	sp cond µhos/cm	U/cond x100	Ag µg/ℓ	Al µg/ℓ	alkalinity mg/ℓ	As µg/ℓ	B µg/ℓ
38A-W82	35°40'11"	113°40'39"	1.6	840	.19	<2	315	410	11	85
39A-W82	35°39'02"	113°41'55"	1.5	720	.21	<2	215	296	2	31
39B-W82	35°39'02"	113°41'55"	1.3	720	.18	<2	228	294	2	47
41A-W82	35°37'05"	113°43'35"	1	500	.20	<2	134	271	1	36
41B-W82	35°37'05"	113°43'35"	.9	500	.18	<2	134	265	1	29
42A-W82	35°38'14"	113°41'20"	1.2	520	.23	<2	262	284	20	61
43A-W82	35°39'12"	113°40'20"	2.1	650	.32	<2	212	279	11	71
44A-W82	35°38'41"	113°41'40"	1	500	.20	<2	293	319	6	62
45A-W82	35°29'47"	113°33'23"	1.9	460	.41	<2	233	156	5	64
45B-W82	35°29'47"	113°33'23"	2.1	460	.46	<2	197	152	5	73
47A-W82	35°32'59"	113°37'05"	1.6	900	.18	<2	530	536	<1	83
47B-W82	35°32'59"	113°37'05"	1.4	900	.16	<2	529	510	<1	84
48A-W82	35°31'35"	113°22'26"	1.1	825	.13	<2	232	226	<1	71
49A-W82	36°09'25"	112°54'54"	13	4000	.33	5	1080	114	<1	201
50A-W82	36°12'47"	112°58'13"	12	2500	.48	<2	689	154	2	169
51A-W82	36°12'48"	112°52'43"	8	1100	.73	<2	501	189	1	104
53A-W82	35°43'08"	113°15'14"	1.1	410	.27	<2	157	187	5	46
54A-W82	35°37'06"	113°42'18"	2.3	510	.45	<2	122	332	2	31
55A-W82	35°43'51"	113°52'02"	1.7	880	.19	<2	280	346	<1	63
56A-W82	35°31'37"	113°40'39"	1.2	770	.16	<2	217	239	<1	71
56B-W82	35°31'37"	113°40'39"	1.2	790	.15	<2	222	241	<1	61
57A-W82	35°47'04"	113°06'48"	2.5	1600	.16	<2	123	261	<1	40
57B-W82	35°47'04"	113°06'48"	1.7	1600	.11	<2	117	266	<1	32
58A-W82	35°42'48"	113°15'37"	1.2	320	.38	<2	140	193	5	40
59A-W82	35°52'57"	113°43'52"	2.8	780	.36	<2	292	313	2	98
60A-W82	35°42'38"	113°38'40"	1.1	700	.16	<2	283	343	1	58
61A-W82	35°41'49"	113°35'05"	1.4	720	.19	<2	299	376	1	65
62A-W82	35°41'49"	113°17'31"	2.1	410	.51	<2	192	190	5	82
63A-W82	35°51'25"	113°40'36"	2.1	800	.26	<2	249	315	2	67
64A-W82	35°40'53"	113°39'24"	3	660	.45	<2	198	294	14	54
65A-W82	35°50'54"	113°49'31"	2.6	610	.43	<2	206	314	3	119
66A-W82	35°59'04"	113°38'23"	2	900	.22	<2	458		55	153
67A-W82	35°43'05"	113°17'44"	21	1300	1.62	<2	244	539	58	679
68A-W82	35°40'49"	113°39'14"	3.2	630	.51	<2	158	286	13	51
69A-W82	35°42'16"	113°36'08"	1.2	510	.24	<2	217	269	3	59
70A-W82	35°40'32"	113°38'48"	1	1400	.07	<2	437	528	5	98
71A-W82	35°42'21"	113°37'38"	2.8	670	.42	<2	287	307	24	89
72A-W82	35°38'48"	113°22'57"	.8	380	.21	<2	166	173	16	46
73A-W82	35°29'44"	113°32'07"	1.3	600	.22	<2	167	168	9	55

Table 3. continued

Sample #	Latitude	Longitude	U µg/ℓ	sp cond µhos/cm	U/cond x100	Ag µg/ℓ	Al µg/ℓ	alkalinity mg/ℓ	As µg/ℓ	B µg/ℓ
73B-W82	35°29'44"	113°52'07"	1.2	600	.20	<2	174	174	9	53
74A-W82	35°30'21"	113°37'40"	12	1000	1.20	<2	153	410	<1	91
74B-W82	35°30'21"	113°37'40"	12	1000	1.20	<2	157	375	<1	106
75A-W82	36°11'49"	113°04'54"	5.4	1400	.39	<2	319	674	14	696
76A-W82	36°11'46"	113°04'50"	5.2	1400	.37	2	279	674	14	641
77A-W82	35°55'00"	113°19'55"	12	6000	.20	2	100	1867	350	15000
78A-W82	35°53'08"	113°17'34"	1.8	600	.30	<2	189	167	15	77
78B-W82	35°53'08"	113°17'34"	1.6	600	.27	<2	184	176	16	81
79A-W84	35°42'11"	113°34'44"	1.8	453	.40	---	<10	186	9	60

Table 3. continued

Sample #	Ba µg/ℓ	Be µg/ℓ	Bi µg/ℓ	C-inorg mg/ℓ	C-org mg/ℓ	Ca mg/ℓ	Cd % µg/ℓ	Cl mg/ℓ	Co µg/ℓ	Cr µg/ℓ
1A-W82	20	<1	<10	35	.9	41	<1	25	<2	3
2A-W82	52	<1	<10	40	.5	59	<1	40	<2	<1
3A-W82	13	<1	<10	42	1.7	50	<1	40	<2	<1
4A-W82	77	<1	<10	52	2.6	36	<1	68	<2	<1
5A-W82	61	<1	10	140	2.9	40	<1	300	<2	2
6A-W82	52	<1	<10	65	2.2	64	<1	38	<2	<1
7A-W82	47	<1	<10	46	2.2	61	<1	32	<2	<1
8A-W82	49	<1	<10	46	9.4	83	1	4.8	<2	1
10A-W82	150	<1	<10	52	1.9	84	<1	9.8	<2	<1
11A-W82	225	<1	<10	66	4.5	122	<1	8.7	<2	<1
12A-W82	95	<1	<10	42	1.1	80	<1	4.8	<2	2
13A-W82	92	<1	<10	49	1.3	81	<1	5	<2	2
14A-W82	108	<1	<10	31	3	61	<1	9.8	3	3
15A-W82	29	<1	<10	34	.7	56	<1	18	<2	<1
16A-W82	133	<1	<10	36	.9	74	<1	9.2	<2	2
17A-W82	49	<1	<10	46	1.3	41	<1	55	<2	<1
18A-W82	91	<1	<10	90	1.7	27	<1	48	<2	4
19A-W82	88	<1	<10	54	2	48	<1	55	2	<1
20A-W82	113	<1	<10	42	1.1	60	<1	30	<2	2
21A-W82	71	<1	10	76	2.6	65	<1	140	2	3
22A-W82	75	<1	<10	77	1.8	70	<1	160	<2	<1
23A-W82	31	<1	<10	54	1.8	36	<1	28	4	1
24A-W82	47	<1	<10	66	1.5	81	<1	18	<2	2
25A-W82	45	<1	<10	90	2.1	80	<1	18	<2	2
26A-W82	39	<1	<10	40	1.8	46	<1	29	<2	1
27A-W82	21	<1	<10	46	.8	44	<1	30	<2	<1
28A-W82	100	<1	<10	27	9.8	53	<1	3	<2	1
29A-W82	103	<1	<10	20	17	39	<1	71	<2	<1
30A-W82	135	<1	<10	36	5.1	68	<1	86	<2	<1
30B-W82	102	<1	<10	35	5	66	<1	90	<2	1
31A-W82	42	<1	<10	51	1.7	48	<1	28	<2	1
31B-W82	43	<1	<10	51	1.6	48	<1	28	<2	<1
32A-W82	55	<1	<10	53	1.4	61	<1	39	<2	2
33A-W82	43	<1	<10	---	---	69	<1	22	<2	2
33B-W82	42	<1	<10	50	1.3	67	<1	20	<2	2
34A-W82	237	<1	<10	30	1.4	68	<1	15	<2	<1
34B-W82	238	<1	<10	33	1.7	71	<1	15	<2	1
35A-W82	38	<1	<10	---	---	63	<1	19	<2	3
36A-W82	55	<1	<10	23	2.2	55	<1	14	<2	2
37A-W82	132	<1	<10	35	2.6	57	<1	15	<2	<1

Table 3. continued

Sample #	Ba µg/ℓ	Be µg/ℓ	Bi µg/ℓ	C-inorg mg/ℓ	C-org mg/ℓ	Ca mg/ℓ	Cd % µg/ℓ	Cl mg/ℓ	Co µg/ℓ	Cr µg/ℓ
38A-W82	35	<1	<10	---	---	70	<1	47	<2	<1
39A-W82	14	<1	<10	---	---	75	<1	46	2	4
39B-W82	16	<1	20	---	---	75	<1	47	3	5
41A-W82	15	<1	<10	---	---	82	<1	22	<2	2
41B-W82	13	<1	<10	---	---	82	<1	24	<2	2
42A-W82	35	<1	<10	---	---	53	<1	32	<2	7
43A-W82	16	<1	<10	---	---	62	<1	31	<2	<1
44A-W82	23	<1	<10	---	---	64	<1	32	<2	<1
45A-W8	14	<1	<10	---	---	27	<1	34	2	30
45B-W82	14	<1	<10	---	---	27	<1	34	<2	29
47A-W82	25	<1	<10	---	---	43	<1	19	<2	<1
47B-W82	25	<1	<10	---	---	43	<1	18	<2	<1
48A-W82	73	<1	<10	---	---	74	<1	52	<2	<1
49A-W82	25	<1	<10	18	4.7	324	<1	76	<2	<1
50A-W82	29	<1	10	26	.5	306	<1	32	2	3
51A-W82	19	<1	<10	---	---	281	<1	16	<2	1
53A-W82	76	<1	<10	27	.4	45	<1	21	<2	3
54A-W82	3	<1	<10	---	---	87	<1	24	<2	2
55A-W82	37	<1	<10	---	---	58	<1	21	<2	1
56A-W82	77	<1	10	---	---	78	<1	52	<2	<1
56B-W82	78	<1	<10	---	---	78	<1	50	<2	2
57A-W82	327	<1	<10	---	---	178	3	91	<2	<1
57B-W82	260	1	<10	---	---	175	<1	84	<2	<1
58A-W82	77	<1	<10	30	.5	46	<1	22	<2	1
59A-W82	50	<1	<10	44	1.9	51	<1	24	<2	<1
60A-W82	42	<1	<10	40	1.5	56	<1	19	<2	<1
61A-W82	45	<1	<10	52	2.2	80	<1	27	<2	2
62A-W82	53	<1	<10	23	.7	42	1	33	<2	<1
63A-W82	85	<1	<10	35	.6	68	<1	17	<2	<1
64A-W82	170	<1	<10	---	---	79	<1	24	<2	2
65A-W82	55	<1	<10	42	2.2	61	<1	24	<2	3
66A-W82	162	<1	<10	63	4.8	38	<1	48	<2	<1
67A-W82	124	1	<10	81	.4	86	<1	46	<2	<1
68A-W82	149	1	<10	---	---	74	5	22	<2	2
69A-W82	53	<1	<10	32	.9	56	<1	21	<2	1
70A-W82	61	<1	<10	52	4.2	88	<1	44	<2	<1
71A-W82	184	<1	<10	42	1.2	53	<1	22	<2	<1
72A-W82	37	<1	<10	---	---	37	<1	27	<2	<1
73A-W82	11	<1	<10	---	---	34	<1	38	<2	19

Table 3. continued

Sample #	Ba µg/ℓ	Be µg/ℓ	Bi µg/ℓ	C-inorg mg/ℓ	C-org mg/ℓ	Ca mg/ℓ	Cd % µg/ℓ	Cl mg/ℓ	Co µg/ℓ	Cr µg/ℓ
73B-W82	12	<1	<10	---	---	34	<1	35	<2	19
74A-W82	84	<1	<10	---	---	119	<1	70	<2	<1
74B-W82	83	<1	<10	---	---	117	<1	68	<2	<1
75A-W82	233	<1	<10	72	.3	164	<1	74	<2	1
76A-W82	225	<1	<10	84	.4	160	<1	71	<2	1
77A-W82	120	<1	100	320	1.0	239	<1	470	3	<1
78A-W82	73	<1	<10	15	.5	48	<1	23	<2	2
78B-W82	79	<1	<10	16	.4	47	<1	24	<2	2
79A-W84	76	<1	---	---	5.5	45	<1	22	<3	<1

Table 3. continued

Sample #	Cu µg/ℓ	F mg/ℓ	Fe µg/ℓ	Ga µg/ℓ	hardness mg/ℓ	HCO_3 mg/ℓ	He ppb	Hg µg/ℓ	K mg/ℓ	Li µg/ℓ
1A-W82	<2	.61	5	<5	240	179	5223	<.2	4	27
2A-W82	<2	.16	7	<5	290	190	5197	<.2	2	10
3A-W82	<2	.20	6	<5	290	223	5206	<.2	2	11
4A-W82	<2	1.1	6	<5	250	300	---	<.2	6	109
5A-W82	<2	3.8	18	11	390	806	5155	<.2	26	468
6A-W82	<2	.62	18	8	420	322	5197	<.2	8	78
7A-W82	<2	.18	6	<5	340	257	5163	<.2	4	14
8A-W82	4	.10	11	<5	290	252	5260	<.2	4	4
10A-W82	<2	.30	10	<5	320	301	5160	<.2	3	5
11A-W82	<2	.22	12	<5	390	302	5140	<.2	4	12
12A-W82	3	.21	5	10	250	153	5220	<.2	2	2
13A-W82	<2	.20	8	<5	250	73	5160	<.2	2	3
14A-W82	4	.20	13	<5	190	168	5230	<.2	1	5
15A-W82	<2	.20	8	<5	210	184	5193	<.2	<1	3
16A-W82	<2	.18	6	<5	220	143	5370	<.2	<1	6
17A-W82	<2	.71	16	9	280	234	5262	<.2	4	62
18A-W82	<2	.20	7	<5	190	491	5327	<.2	14	322
19A-W82	<2	.48	23	<5	380	277	5360	<.2	4	44
20A-W82	<2	.29	7	<5	300	244	---	<.2	3	21
21A-W82	<2	.48	4	16	670	393	---	<.2	10	87
22A-W82	<2	.49	27	14	710	397	5229	<.2	11	97
23A-W82	<2	.20	8	<5	320	282	---	<.2	3	15
24A-W82	3	.14	10	8	410	363	5273	<.2	3	3
25A-W82	<2	.14	5	<5	410	359	5273	<.2	2	4
26A-W82	<2	.26	4	<5	280	196	5262	<.2	3	11
27A-W82	<2	.19	<2	<5	270	230	5284	<.2	2	7
28A-W82	<2	.12	16	<5	180	152	---	<.2	3	28
29A-W82	4	.49	26	8	270	36	---	<.2	9	16
30A-W82	<2	.32	18	6	420	178	---	<.2	3	13
30B-W82	<2	.32	12	<5	410	179	---	<.2	2	19
31A-W82	2	.21	7	7	370	329	---	<.2	1	15
31B-W82	5	.20	8	<5	360	329	---	<.2	<1	14
32A-W82	<2	.22	14	5	380	323	---	<.2	3	14
33A-W82	<2	.16	14	10	380	323	---	<.2	<1	3
33B-W82	<2	.16	15	9	370	324	---	<.2	<1	<2
34A-W82	<2	.16	5	<5	250	213	---	<.2	<1	<2
34B-W82	<2	.16	5	<5	260	213	---	<.2	<1	3
35A-W82	<2	.34	8	9	280	121	---	<.2	<1	12
36A-W82	<2	.31	16	<5	220	138	---	<.2	<1	3
37A-W82	<2	.17	5	<5	250	229	---	<.2	<1	<2

Table 3. continued

Sample #	Cu µg/ℓ	F mg/ℓ	Fe µg/ℓ	Ga µg/ℓ	hardness mg/ℓ	HCO_3 mg/ℓ	He ppb	Hg µg/ℓ	K mg/ℓ	Li µg/ℓ
38A-W82	<2	.44	16	6	421	188	5278	<.2	2	16
39A-W82	<2	.38	<2	<5	359	258	5300	<.2	<1	4
39B-W82	<2	.37	9	7	358	256	5280	<.2	<1	7
41A-W82	<2	.54	11	<5	302	248	5254	<.2	2	<2
41B-W82	<2	.52	9	<5	301	242	5260	<.2	1	<2
42A-W82	<2	.47	11	14	334	278	5240	<.2	3	12
43A-W82	<2	1.1	54	<5	315	268	5190	<.2	3	5
44A-W82	<2	.24	34	<5	329	291	5200	<.2	2	7
45A-W82	<2	.77	54	<5	195	145	5260	<.2	2	19
45B-W82	<2	.50	29	<5	192	141	5300	<.2	3	21
47A-W82	<2	.21	13	5	539	523	5276	<.2	<1	6
47B-W82	<2	.25	13	6	533	498	---	<.2	<1	7
48A-W82	<2	.15	15	<5	358	220	5270	<.2	1	5
49A-W82	<2	.85	<2	<5	1810	99	5280	<.2	28	82
50A-W82	<2	.97	35	15	1310	145	5273	<.2	7	44
51A-W82	<2	.65	13	14	1110	180	5220	<.2	5	20
53A-W82	<2	.73	6	7	219	183	5259	<.2	1	7
54A-W82	<2	1.1	<2	<5	362	269	5320	<.2	2	<2
55A-W82	<2	1.0	7	<5	365	333	5280	<.2	<1	3
56A-W82	<2	.15	15	<5	365	225	---	<.2	1	6
56B-W82	<2	.20	13	7	365	227	5230	<.2	1	7
57A-W82	<2	.23	129	<5	538	227	5230	<.2	<1	8
57B-W82	<2	.24	124	<5	527	232	5230	<.2	<1	9
58A-W82	<2	.24	4	<5	224	189	5210	<.2	<1	7
59A-W82	<2	.26	4	9	358	305	5270	<.2	4	24
60A-W82	<2	.17	3	<5	367	336	5230	<.2	1	3
61A-W82	<2	.54	10	<5	437	367	5200	<.2	<1	3
62A-W82	<2	.36	24	<5	234	185	---	<.2	2	15
63A-W82	<2	.22	6	<5	364	306	5290	<.2	2	10
64A-W82	<2	.35	10	<5	338	283	5300	<.2	1	9
65A-W82	<2	1.1	12	<5	307	307	5220	<.2	<1	11
66A-W82	<2	.35	6	6	471	---	5240	<.2	4	19
67A-W82	<2	1.1	7	<5	376	416	5280	<.2	9	154
68A-W82	<2	.96	4	<5	310	221	5240	<.2	1	9
69A-W82	<2	.22	56	8	315	263	---	<.2	<1	6
70A-W82	<2	.22	31	8	571	428	5260	<.2	<1	7
71A-W82	<2	.28	5	<5	364	300	5280	<.2	2	10
72A-W82	<2	.68	7	<5	220	168	---	<.2	1	7
73A-W82	<2	1.0	15	<5	215	153	5285	<.2	2	8
73B-W82	<2	.90	71	<5	213	159	5286	<.2	2	11

Table 3. continued

Sample #	Cu µg/l	F mg/l	Fe µg/l	Ga µg/l	hardness mg/l	HCO_3 mg/l	He ppb	Hg µg/l	K mg/l	Li µg/l
74A-W82	<2	.74	49	<5	417	386	5210	<.2	1	23
74B-W82	<2	1.0	58	<5	408	354	5171	<.2	1	25
75A-W82	<2	.21	6	<5	660	635	5660	2.4	6	214
76A-W82	<2	.21	<2	6	640	490	9560	2.4	6	178
77A-W82	<2	2.5	45	10	880	1511	6440	1.8	103	3200
78A-W82	<2	.22	14	<5	250	160	5240	.4	1	14
78B-W82	<2	.22	9	<5	250	170	5260	.3	<1	10
79A-W84	<10	.30	<3	---	---	---	---	---	2	13

Table 3. continued

Sample #	Mg mg/ℓ	Mn µg/ℓ	Mo µg/ℓ	Total N µg/ℓ	Na mg/ℓ	Ni µg/ℓ	P mg/ℓ	Pb µg/ℓ	pH	Rn total counts
1A-W82	34	<2	2	2	23	<5	<1	<6	7.6	0
2A-W82	35	<2	<2	8.6	19	<5	<1	<6	7.2	100
3A-W82	41	4	<2	.27	19	<5	<1	<6	7.6	33
4A-W82	40	<2	2	.29	92	<5	<1	<6	8.4	---
5A-W82	71	3	8	<.04	482	<5	<1	8	7.6	0
6A-W82	64	6	3	.41	62	<5	<1	<6	7.6	48
7A-W82	45	5	<2	2.9	25	<5	<1	<6	7.8	15
8A-W82	20	35	<2	<.04	6	<5	<1	<6	7.6	0
10A-W82	28	7	<2	<.04	8	<5	<1	<6	8.3	4
11A-W82	20	56	3	2.2	6	<5	<1	<6	7.0	31
12A-W82	12	2	<2	<.04	4	<5	<1	<6	6.6	18
13A-W82	12	8	2	<.04	4	<5	<1	<6	6.0	20
14A-W82	9	3	<2	2.9	11	<5	<1	<6	8.2	0
15A-W82	17	6	<2	.5	12	<5	<1	<6	8.0	1
16A-W82	9	<2	<2	4.5	11	<5	<1	17	6.8	10
17A-W82	43	5	3	2.9	64	<5	<1	<6	8.2	---
18A-W82	31	5	3	.29	301	<5	<1	<6	8.5	0
19A-W82	62	<2	3	.38	45	<5	<1	<6	8.4	1
20A-W82	36	<2	2	2.1	25	<5	<1	<6	8.2	4
21A-W82	122	4	<2	1.6	89	<5	<1	<6	8.0	---
22A-W82	131	2	5	1.4	99	<5	<1	7	8.3	5
23A-W82	57	7	3	1.2	21	<5	<1	<6	8.2	---
24A-W82	51	6	<2	.41	16	<5	<1	<6	7.6	1
25A-W82	50	<2	<2	2	14	<5	<1	<6	7.6	0
26A-W82	39	4	2	4.7	20	<5	<1	<6	8.8	1
27A-W82	39	<2	<2	2	17	<5	<1	<6	8.4	0
28A-W82	11	43	12	.07	2	<5	<1	<6	7.5	2
29A-W82	42	<2	6	.52	40	<5	<1	<6	---	6
30A-W82	61	<2	5	.59	27	<5	<1	<6	7.0	32
30B-W82	59	<2	6	.56	27	<5	<1	<6	7.0	32
31A-W82	60	5	<2	2.9	22	<5	<1	<6	8.2	3
31B-W82	59	4	<2	2.9	22	<5	<1	<6	8.2	4
32A-W82	55	<2	<2	1.2	24	<5	<1	<6	7.6	15
33A-W82	51	3	<2	2.7	14	<5	<1	<6	7.5	3
33B-W82	49	<2	<2	2.5	13	<5	<1	<6	7.5	3
34A-W82	20	4	<2	.52	10	<5	<1	<6	7.3	0
34B-W82	21	2	2	.52	10	<5	<1	<6	7.3	0
35A-W82	29	<2	7	.97	7	<5	<1	<6	7.6	41
36A-W82	21	4	2	.79	6	<5	<1	<6	8.4	
37A-W82	26	<2	<2	.5	8	<5	<1	32	8.4	3

Table 3. continued

Sample #	Mg mg/ℓ	Mn µg/ℓ	Mo µg/ℓ	Total N µg/ℓ	Na mg/ℓ	Ni µg/ℓ	P mg/ℓ	Pb µg/ℓ	pH	Rn total counts
38A-W82	60	18	2	<.04	22	<5	<1	<6	6.3	16
39A-W82	41	<2	<2	.9	12	<5	<1	<6	7.2	0
39B-W82	41	<2	<2	.93	12	<5	<1	<6	7.2	17
41A-W82	23	11	<2	.61	10	<5	<1	<6	7.4	4
41B-W82	23	8	<2	.68	9	<5	<1	<6	7.4	40
42A-W82	49	4	4	1.5	17	<5	<1	10	8.2	0
43A-W82	39	50	<2	<.04	19	<5	<1	<6	7.8	59
44A-W82	41	21	<2	.09	18	<5	<1	<6	7.4	4
45A-W82	31	3	<2	3.3	16	<5	<1	<6	7.5	32
45B-W82	31	7	<2	3.6	16	<5	<1	<6	7.5	4
47A-W82	105	4	<2	<.04	18	<5	<1	<6	8.1	4
47B-W82	103	2	<2	<.04	18	<5	<1	<6	8.1	3
48A-W82	42	6	<2	16	20	<5	<1	<6	8.4	3
49A-W82	243	19	<2	<.04	84	<5	<1	<6	7.2	0
50A-W82	131	5	7	<.04	27	<5	<1	6	7.6	160
51A-W82	98	4	4	<.04	18	<5	<1	<6	7.7	55
53A-W82	27	<2	<2	5	13	<5	<1	<6	8.4	5
54A-W82	35	<2	<2	2	13	<5	<1	<6	7.0	18
55A-W82	54	<2	<2	1.1	16	<5	<1	<6	7.8	0
56A-W82	41	7	<2	18	20	<5	<1	<6	7.6	10
56B-W82	42	5	2	17	19	<5	<1	<6	7.6	24
57A-W82	23	62	<2	41	16	<5	<1	<6	7.2	24
57B-W82	22	60	<2	40	16	<5	<1	<6	7.2	24
58A-W82	26	<2	2	4.1	13	<5	<1	<6	8.2	10
59A-W82	56	3	<2	1.5	21	<5	<1	<6	8.6	0
60A-W82	55	<2	2	2.6	14	<5	<1	<6	8.4	4
61A-W82	58	<2	<2	1.8	18	<5	<1	<6	8.1	0
62A-W82	31	<2	3	2.2	18	<5	<1	<6	8.6	0
63A-W82	47	<2	<2	3.2	15	<5	<1	<6	8.0	64
64A-W82	34	3	2	.63	15	<5	<1	<6	7.8	0
65A-W82	37	12	<2	.25	27	<5	<1	<6	8.2	75
66A-W82	91	116	8	<.04	39	<5	<1	<6	8.6	4
67A-W82	39	5	5	.32	145	<5	<1	<6	6.9	64
68A-W82	30	<2	<2	1.1	14	<5	<1	<6	6.9	31
69A-W82	43	6	<2	2.5	15	<5	<1	<6	8.3	3
70A-W82	85	353	<2	<.04	28	<5	<1	<6	7.0	9
71A-W82	56	2	<2	1.2	19	<5	<1	<6	8.6	0
72A-W82	31	4	<2	4.1	14	<5	<1	<6	8.0	0
73A-W82	32	6	<2	4.1	20	<5	<1	<6	7.4	115

Table 3. continued

Sample #	Mg mg/ℓ	Mn µg/ℓ	Mo µg/ℓ	Total N µg/ℓ	Na mg/ℓ	Ni µg/ℓ	P mg/ℓ	Pb µg/ℓ	pH	Rn total counts
73B-W82	31	7	3	3.6	21	<5	<1	<6	7.4	115
74A-W82	29	88	3	.07	63	<5	<1	<6	7.6	105
74B-W82	28	89	<2	<.04	63	5	<1	<6	7.6	139
75A-W82	61	<2	<2	.79	77	<5	14	<6	7.6	11
76A-W82	59	<2	<2	.79	75	<5	<1	<6	6.8	15
77A-W82	69	210	<2	<.04	>1000	<5	<1	<6	7.0	12
78A-W82	32	<2	3	2.3	12	<5	3	<6	7.8	15
78B-W82	32	4	2	2.2	13	<5	<1	<6	7.8	14
79A-W84	24	<1	<10	.1	11	---	<.01	<10	8.4	---

Table 3. continued

Sample #	Se µg/ℓ	Si mg/ℓ	Sn mg/ℓ	SO_4 mg/ℓ	Sr µg/ℓ	temp °C	Ti µg/ℓ	V µg/ℓ	Zn µg/ℓ	Zr µg/ℓ
1A-W82	<2	13	<6	29	.50	17	<1	19	8	<1
2A-W82	2	8	<6	26	.11	18	<1	6	16	<1
3A-W82	<2	9	<6	30	.16	18	<1	<5	65	<1
4A-W82	<2	12	<6	38	.30	28	<1	5	1	<1
5A-W82	<2	21	<6	170	.52	29	69	<5	3	2
6A-W82	<2	14	<6	100	.49	19	<1	<5	19	<1
7A-W82	<2	10	<6	40	.24	20	<1	<5	20	<1
8A-W82	<2	14	<6	1.7	.10	17	<1	<5	9	<1
10A-W82	<2	4	<6	7	<.05	17	<1	<5	5	<1
11A-W82	<2	8	<6	6.8	.12	19	<1	<5	8	<1
12A-W82	<2	5	<6	5.3	<.05	14	<1	<5	13	<1
13A-W82	<2	5	<6	5.4	.06	21	1	<5	54	<1
14A-W82	<2	8	<6	16	.21	25	<1	<5	175	<1
15A-W82	5	4	<6	17	<.05	9	<1	<5	10	<1
16A-W82	<2	9	<6	14	.16	18	<1	<5	2880	<1
17A-W82	<2	13	<6	44	.20	24.5	3	8	33	<1
18A-W82	<2	26	<6	60	.37	18	3	8	9	2
19A-W82	<2	14	<6	75	.34	25.5	<1	6	5	<1
20A-W82	<2	9	<6	30	.23	22	<1	<5	5	<1
21A-W82	4	20	6	180	.71	19	<1	12	3	1
22A-W82	4	21	<6	200	.76	19	<1	10	23	<1
23A-W82	4	10	<6	25	.14	25	<1	6	4	<1
24A-W82	4	8	<6	17	.15	24.5	<1	5	15	<1
25A-W82	4	8	<6	16	.11	24	<1	<5	4	<1
26A-W82	4	8	<6	25	.15	27	<1	8	3	<1
27A-W82	4	7	7	28	.12	27	<1	6	<1	<1
28A-W82	<2	2	6	5	.15	17	<1	<5	12	<1
29A-W82	<2	9	<6	82	.33	32	<1	19	9	<1
30A-W82	16	6	<6	130	.52	17	<1	7	20	<1
30B-W82	16	6	<6	140	.50	17	<1	9	20	<1
31A-W82	<2	7	<6	28	.14	14	<1	7	37	<1
31B-W82	<2	7	<6	42	.20	14	<1	6	37	<1
32A-W82	<2	11	<6	33	.34	24	<1	<5	3	<1
33A-W82	<2	9	<6	16	.19	23	<1	6	1	<1
33B-W82	<2	8	<6	16	.18	23	<1	6	9	<1
34A-W82	2	4	<6	12	.13	11	<1	<5	11	<1
34B-W82	2	4	<6	12	.12	11	<1	<5	5	<1
35A-W82	16	5	<6	130	.73	15	<1	<5	29	1
36A-W82	12	4	<6	77	.49	17	<1	<5	23	<1
37A-W82	2	4	<6	13	.11	10	<1	<5	6	<1

Table 3. continued

Sample #	Se µg/ℓ	Si mg/ℓ	Sn mg/ℓ	SO_4 mg/ℓ	Sr µg/ℓ	temp °C	Ti µg/ℓ	V µg/ℓ	Zn µg/ℓ	Zr µg/ℓ
38A-W82	<2	20	<6	19	.49	17	<1	<5	10	<1
39A-W82	<2	16	<6	24	.34	17	<1	8	4	<1
39B-W82	<2	17	<6	24	.39	17	<1	10	3	<1
41A-W82	<2	16	<6	20	.43	14.5	<1	6	19	<1
41B-W82	<2	15	<6	20	.39	14.5	<1	<5	2	<1
42A-W82	<2	25	<6	24	.49	17	<1	8	8	2
43A-W82	<2	15	<6	19	.49	16	<1	<5	29	<1
44A-W82	<2	17	<6	13	.47	15	2	<5	22	<1
45A-W82	<2	16	<6	16	.60	17	2	14	25	<1
45B-W82	<2	16	<6	16	.59	17	1	13	22	2
47A-W82	<2	10	<6	34	.13	21	<1	<5	18	<1
47B-W82	<2	10	7	32	.10	21	<1	<5	20	<1
48A-W82	6	6	<6	37	.06	18	<1	<5	1310	<1
49A-W82	18	11	<6	1700	4.77	24	<1	<5	99	4
50A-W82	9	7	16	1100	3.31	22	2	<5	21	<1
51A-W82	7	6	<6	890	2.77	17	1	<5	45	1
53A-W82	<2	9	<6	17	.20	24	<1	5	7	<1
54A-W82	<2	19	<6	24	.38	15	<1	<5	<1	1
55A-W82	<2	6	<6	27	.07	15	<1	<5	4	<1
56A-W82	2	7	<6	39	.16	24	<1	<5	217	<1
56B-W82	2	6	<6	37	.14	24	<1	<5	220	<1
57A-W82	2	12	<6	42	.42	15.5	<1	<5	7320	<1
57B-W82	2	11	<6	46	.41	15.5	<1	<5	6580	<1
58A-W82	<2	9	<6	17	.21	22	<1	8	2	<1
59A-W82	<2	10	<6	36	.18	27	<1	<5	13	<1
60A-W82	<2	9	<6	20	.15	20	<1	6	4	<1
61A-W82	2	10	<6	32	.15	21	<1	<5	3	<1
62A-W82	<2	7	<6	43	.21	27	<1	<5	1	<1
63A-W82	<2	9	<6	21	.15	20	<1	<5	3	<1
64A-W82	<2	15	<6	21	.36	19	<1	<5	5	<1
65A-W82	<2	12	<6	37	.31	17	<1	5	11	<1
66A-W82	<2	18	<6	57	.23	29	<1	<5	2	<1
67A-W82	<2	10	<6	56	.52	23	<1	<5	3	<1
68A-W82	<2	13	<6	15	.32	20	<1	6	4	<1
69A-W82	<2	9	<6	17	.18	21	<1	5	3	<1
70A-W82	<2	13	<6	30	.26	19.5	<1	<5	8	<1
71A-W82	<2	11	<6	24	.17	23	<1	<5	2	<1
72A-W82	<2	6	<6	20	.11	20	<1	7	4	<1
73A-W82	2	13	<6	20	.54	24	<1	13	53	<1

Table 3. continued

Sample #	Se µg/ℓ	Si mg/ℓ	Sn mg/ℓ	SO_4 mg/ℓ	Sr µg/ℓ	temp °C	Ti µg/ℓ	V µg/ℓ	Zn µg/ℓ	Zr µg/ℓ
73B-W82	2	12	<6	19	.48	24	<1	13	44	<1
74A-W82	<2	17	<6	48	.39	22	<1	<5	149	<1
74B-W82	<2	17	<6	46	.38	22	<1	<5	94	<1
75A-W82	1	9	<6	33	2.47	26	<1	6	22	<1
76A-W82	<1	9	<6	32	.43	26	<1	6	21	1
77A-W82	<1	72	8	350	8.06	32	<1	<5	32	<1
78A-W82	2	6	<6	68	.17	24	<1	<5	9	<1
78B-W82	2	6	<6	69	.19	24	<1	<5	4	<1
79A-W84	1	14	---	12	180	---	--	6	4	--

Table 4. Hualapai water statistical analyses

Variable	Transformation	Minimum	Maximum	Mean	Standard Deviation	Number Valid Values	Number Not Determined	Number < detection limit	Number > upper detection limit
U	Log	0.16	28	4.3	5.9	75	0	0	0
sp cond	Log	300	6000	956	851	75	0	0	0
U/cond	Log	0.05	1.6	0.40	0.34	75	0	0	0
Ag	None	* <2	5	--	--	3	2	70	0
Al	Log	58	1080	251	163	74	0	1	0
alklin	Log	114	1867	322	225	74	1	0	0
As	None	* <1	350	20	46	68	0	7	0
B	Log	28	11900	374	1747	75	0	0	0
Ba	Log	3	327	78	63	75	0	0	0
Bi	None	* <10	100	--	--	5	1	69	0
C-inorg	Log	15	320	53	43	53	22	0	0
C-org	Log	0.30	17	2.4	2.8	54	21	0	0
Ca	Log	27	324	77	58	75	0	0	0
Cd-pc	None	* <1	5	--	--	4	0	71	0
Cl	Log	3.0	470	45	64	75	0	0	0
**Co	None	* <2	4	--	--	7	1	67	0
Cr	Log	* <1	30	3.3	5.3	39	1	35	0
**Cu	None	* <2	4	--	--	6	1	68	0
F	Log	0.10	3.8	0.49	0.54	75	0	0	0
**Fe	Log	* <2	129	16	19	68	1	6	0
Ga	Log	* <5	16	9	3	24	2	49	0
hard	Log	180	1810	393	254	74	1	0	0
HCO_3	Log	36	1511	286	191	73	2	0	0
He	None	5140	9560	5352	599	56	19	0	0
Hg	None	* <0.20	2.4	--	--	4	1	70	0
K	Log	* <1	103	6	14	59	0	16	0
Li	Log	* <2	3200	81	383	71	0	4	0
Mg	Log	9	243	48	34	75	0	0	0
**Mn	Log	* <2	353	26	61	48	0	27	0
**Mo	Log	* <2	12	3.9	2.4	30	1	44	0
total N	Log	* <0.04	41	2.9	5.9	61	0	14	0
Na	Log	2	* >1000	36	67	74	0	0	1
**P	None	* <0.01	14	--	--	2	0	73	0
**Pb	Log	* <6	32	--	--	6	1	68	0
pH	None	6.0	8.8	7.8	0.60	74	1	0	0

Table 4. continued

Variable	Transformation	Minimum	Maximum	Mean	Standard Deviation	Number Valid Values	Number Not Determined	Number < detection limit	Number > upper detection limit
Rn	None	0.00	160	19	31	70	4	0	0
**Se	Log	* <1	18	5.4	5	25	0	50	0
Si	Log	2	72	12	8.7	75	0	0	0
Sn	None	* <6	16	--	--	4	2	69	0
SO_4	Log	1.7	1700	90	250	75	0	0	0
Sr	Log	* <0.05	180	3.1	21	72	0	3	0
temp	None	9.0	32	20	4.8	74	1	0	0
Ti	Log	* <1	69	--	--	8	2	65	0
V	Log	* <5	19	8	3.7	31	1	43	0
Zn	Log	* <1	7320	181	930	72	1	2	0
Zr	None	* <1	4	--	--	9	2	64	0

* - Lower or Upper Detection Limit
** - Variable Detection Limit

Table 5. Hualapai Water Correlation Coefficients (number of samples = 75)

	Log U	Log sp cond	Log U/cond	Log Al	Log alkalin	As	Log B	Log Ba
Log U		.71	.82	.36	.35	.44	.70	.14
Log sp cond			.17	.41	.51	.54	.74	.14
Log U/cond				.16	.07	.18	.37	.08
Log Al					.20	-.02	.31	-.17
Log alklin						.57	.66	.25
As							.77	.19
Log B								.20
Log Ba								
Log C-inorg								
Log C-org								
Log Ca								
Log Cl								
Log Cr								
Log F								
Log Fe								
Log hard								
Log HCO_3								
Log K								
Log Li								
Log Mg								
Log Mn								
Log Total N								
Log Na								
Log pH								
Rn								
Log Si								
Log SO_4								
Log Sr								
Temperature								
Log Zn								

Table 5. continued

	Log C inorg	Log C org	Log Ca	Log Cl	Log Cr	Log F	Log Fe	Log hard
Log U	.42	-.14	.32	.63	-.02	.51	.01	.53
Log sp cond	.51	.06	.54	.61	-.10	.38	.08	.73
Log U/cond	.18	-.25	.00	.38	.04	.41	-.04	.15
Log Al	.07	-.08	.18	.42	-.05	.18	.15	.55
Log alklin	.77	-.03	.17	.50	-.16	.21	.03	.33
As	.67	-.06	.13	.51	.08	.39	.02	.22
Log B	.68	-.09	.15	.72	-.03	.45	.01	.43
Log Ba	.13	.01	.15	.03	-.31	-.25	.07	.02
Log C-inorg		-.03	.14	.46	.06	.26	-.04	.28
Log C-org			-.13	-.08	-.09	-.03	.13	.00
Log Ca				.11	-.18	.09	.03	.77
Log Cl					.00	.51	.15	.47
Log Cr						.29	.07	-.21
Log F							.12	.25
Log Fe								.01
Log hard								
Log HCO_3								
Log K								
Log Li								
Log Mg								
Log Mn								
Log Total N								
Log Na								
Log pH								
Rn								
Log Si								
Log SO_4								
Log Sr								
Temperature								
Log Zn								

Table 5. continued

	Log HCO_3	Log K	Log Li	Log Mg	Log Mn	Log Total N	Log Na	Log pH
Log U	.38	.66	.69	.50	-.04	-.25	.69	-.05
Log sp cond	.46	.72	.68	.59	.34	-.25	.73	-.20
Log U/cond	.16	.33	.41	.23	-.33	-.15	.37	.09
Log Al	.18	.26	.25	.81	.03	.01	.29	.09
Log alklin	.76	.45	.48	.33	.23	-.25	.67	-.17
As	.52	.66	.68	.19	.30	-.20	.81	-.05
Log B	.60	.83	.93	.51	.16	-.25	.93	.04
Log Ba	.13	.07	.24	-.19	.08	.02	.12	-.02
Log C-inorg	.77	.51	.52	.25	.25	-.16	.65	-.16
Log C-org	-.20	.13	-.09	.01	.33	-.32	-.11	.05
Log Ca	.14	.27	.16	.26	.32	-.19	.18	-.46
Log Cl	.42	.53	.67	.63	.10	.05	.84	.04
Log Cr	-.11	-.01	.01	-.13	-.15	.15	.01	-.11
Log F	.16	.43	.45	.31	.07	-.23	.54	-.07
Log Fe	-.04	-.05	.05	-.01	.42	-.04	.05	-.02
Log hard	.32	.48	.40	.79	.26	-.24	.44	-.18
Log HCO_3		.30	.43	.36	.20	-.13	.59	.12
Log K			.82	.45	.19	-.36	.74	-.09
Log Li				.43	.14	-.23	.84	.00
Log Mg					.05	-.13	.52	.16
Log Mn						-.37	.20	-.23
Log Total N							-.16	.20
Log Na								.01
Log pH								
Rn								
Log Si								
Log SO_4								
Log Sr								
Temperature								
Log Zn								

Table 5. continued

	Rn	Log Si	Log SO_4	Log Sr	Temperature	Log Zn
Log U	.28	.44	.67	.44	.20	-.01
Log sp cond	.18	.49	.60	.39	.29	.16
Log U/cond	.25	.21	.44	.29	.05	-.15
Log Al	.09	.15	.55	-.15	.19	-.10
Log alklin	-.12	.54	.07	.07	.32	-.19
As	-.05	.57	.33	.33	.32	-.08
Log B	.04	.55	.54	.39	.53	-.12
Log Ba	-.15	-.16	-.10	-.05	.18	.13
Log C-inorg	-.04	.56	.09	.18	.22	-.09
Log C-org	-.23	.03	-.05	.06	-.02	.02
Log Ca	.27	.03	.39	.37	-.04	.34
Log Cl	.09	.63	.65	.40	.42	.04
Log Cr	.20	.27	.00	.14	-.05	.04
Log F	.32	.49	.49	.42	.21	-.15
Log Fe	.27	.08	.10	-.02	-.05	.36
Log hard	.21	.30	.68	.49	.19	.12
Log HCO_3	-.10	.50	.07	.13	.15	-.22
Log K	.06	.47	.53	47	.45	-.10
Log Li	.13	.49	.57	.49	.50	-.02
Log Mg	.10	.38	.70	.31	.32	-.20
Log Mn	.13	.27	.01	.09	-.02	.28
Log Total N	-.11	-.11	-.10	-.35	.04	.19
Log Na	.07	.68	.59	.42	.50	-.04
Log pH	-.23	-.05	.09	-.07	.19	-.28
Rn		.04	.28	.24	-.04	.19
Log Si			.25	.42	.29	-.08
Log SO_4				.51	.29	.12
Log Sr					.14	.04
Temperature						-.21
Log Zn						

Table 6. Factor groups resulting from R-mode factor analysis of the water data matrix (parentheses denote secondary relationships). Values are factor loadings which indicate the strength of the element relative to the grouping. A minus sign in front of the element indicates a negative relation to the group.

Group 1		Group 2		Group 3		Group 4	
HCO_3	0.87	Mg	0.89	Ca	0.84	Cr	0.76
Alkin	0.85	Al	0.89	pH	-0.74	F	0.53
C-inorg	0.84	Hardness	0.73			Ba	-0.75
Si	0.55	SO_4	0.62	(Hard)	0.51		
				(Zn)	0.48	(Si)	0.46
(As)	0.56	(Cond.)	0.45				
(Na)	0.53	(Cl)	0.41				
(B)	0.52						

Group 5		Group 6		Group 7		Group 8	
U/cond	0.90	C-org	0.70	Fe	0.86	Li	0.81
U	0.72	N	-0.81	Zn	0.61	B	0.76
Rn	0.48			Mn	0.57	Na	0.74
		(Mn)	0.45			K	0.74
(F)	0.40					Temp	0.69
						Cl	0.64
						As	0.63
						Sp cond	0.54
						Sr	0.54