IDENTIFIYING PREFERENTIAL FLOWPATHS IN FRACTURE FLOW DOMINATED AQUIFERS: THE EASTER SNAKE RIVER PLAIN AQUIFER CASE STUDY

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NOVEMBER 2006

Location:

Eastern Snake River Plain Aquifer (ESRiPA) in Idaho, United States of America (44°N, 113W) *(Figure 1)*

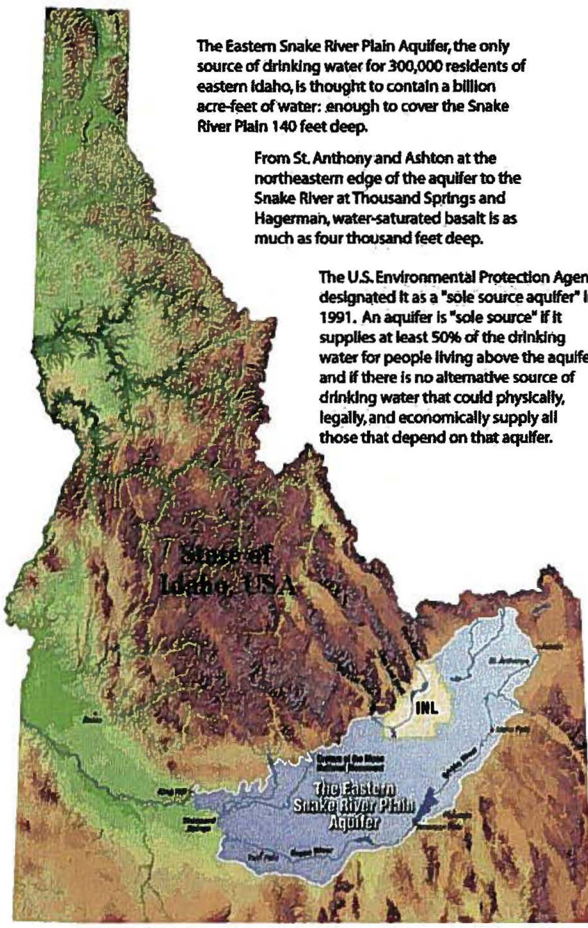

Figure 1. Location of the Eastern Snake River Plain Aquifer in Idaho, USA.

Main problem illustrated:

How to use radiogenic, radioactive and stable isotope tracers together with major element concentrations to identify preferential flow pathways in aquifers?

Summary:

In highly fractured and heterogeneous aquifers (eg: basalt and karst aquifers) preferential flow is one of the primary groundwater flow mechanisms because they act as a major conduit for water, dissolved matter and contaminants.

Radiogenic isotope tracers can provide a unique "x-ray" photograph of the physical and chemical processes occurring in the aquifer that is not provided by the elemental solute concentration data alone. Isotopic studies can provide information about mixing of groundwater, flow patterns, recharge rates and locations, together with rates and types of rock-water interaction. In general, the addition of isotopic measurements will give you a clearer idea of the chemical and physical processes than do other chemical parameters alone.

Tracers Used:

$^{87}Sr/^{86}Sr$, $^{234}U/^{238}U$, Tritium (^{3}H), ^{14}C, Stable Isotopes of Oxygen, Hydrogen, Carbon and Sulfur (Sulfate).

People affected environmental, ecological impacts:

Basalt and Karst dominated aquifers cover large parts of the world and often those aquifers are the primary or sole provider of potable water for the cities and countries that overlie them. Having an understanding of the location and extent of preferential flow pathways is of critical importance to the assessment of groundwater resources, underground disposal sites and prediction of the movement of pollutants in these fractured dominated aquifers.

This specific case study is focused on the Eastern Snake River Plain Aquifer in the State of Idaho, USA and more specifically on the Idaho National Engineering and Environmental Laboratory (INEEL) region *(Figure 1 and Figure 2).* Where in the 1950 low level radioactive and non-radioactive waste was disposed by means of injections wells to the aquifer. These contaminants are moving down gradient from the INEEL site taking advantage of preferential flow. This aquifer is one of the largest basalt aquifers in the USA and it is the primary source for drinking and agricultural water in southern Idaho.

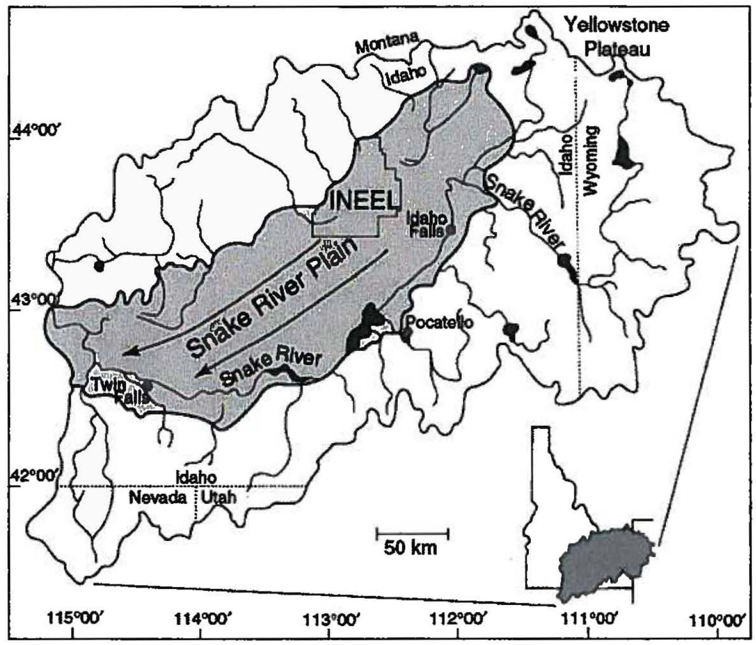

Figure 2. Snake River Plain Aquifer (ESRiPA) and watersheds that recharge it. Approximate regional groundwater flow direction is given by arrows. Also the boundaries of the Idaho National Engineering and Enviromental Laboratory (INEEL) are shown.

Hydrogeological setting:

The ESRiPA covers an area of approximately 25,000 km^2 and stores 1.2 to 2.5 x 10^{12} m^3 (1 to 2 billion acre-feet) of water. Recharge occurs along the Snake River and its tributaries on the northeastern and eastern edges of the aquifer. Precipitation accounts for 10 percent, while surface water from streams, diversion and irrigation of land comprises about 67 percent of the total recharge. Regional ground water flow is from the northeast to the southwest. Finally groundwater discharges in a series of large springs between Twin Falls and King Hill *(Figure 3).*

Figure 3. Large springs that issue from the north wall of the Snake River Canyon near Twin Falls, Idaho, discharge thousands of gallons of water per minute.

The ESRiPA consists of multiple thin flows of Pliocene and younger basaltic rock interbedded with unconsolidated alluvial deposits underlain by Miocene basaltic-rock aquifers and in some places underlain by silicic volcanic rocks. In general the aquifer is an unconfined system but in some places unfractured basalt and interbedded clay layers cause confining conditions. Permeability on the younger upper layers of the aquifer is highly variable due to the different kinds of fractures and features (lava tubes, pillow lava, columnar basalt and individual lava flows) that compose it *(Figure 4).* Therefore, in the highland mountainous region and at depth rainfall and snowmelt can infiltrate quickly.

Water sampling and analysis summary:

Sixty-four water samples were taken from several purged groundwater wells near the INEEL screened in the upper part of the ESRiPA aquifer. All samples were filtered to 0.45 μm on site, preserved with Nitric Acid (HNO_3) and stored in acid washed HDPE bottles. The samples were analyzed for uranium and strontium isotopic composition as well as major elemental chemistry, using different analytical methods such as Thermal Ionization Mass Spectrometry (Uranium, Strontium isotopes), ICPMS (cations), Ion chromatography (anions).

Results of tracer studies:

Figure 5 shows the result of the sample analysis as a contour plot interpolated using the KRIGIN interpolation method. The contour plots of the Uranium and Strontium isotopic ratios show water masses with high isotopic ratios emanating from Little Lost River and Birch Creek that penetrate water masses of low isotopic ratios originating elsewhere in the aquifer. These distinct water masses continue for tens of kilometers away from their apparent sources. Also it is important to note the low isotope ratio zones in the Southwest and Central regions, near the INEEL site *(Figure 5 A and E)*. The elemental concentrations data also reflect some spatial similarities to the isotopic ratio data. For example high Mg concentration and low Na and Si concentration slightly resembles the high isotopic ratio zone. The inverse is also true for the low isotopic ratio zones *(Figure 5 B-D)*.

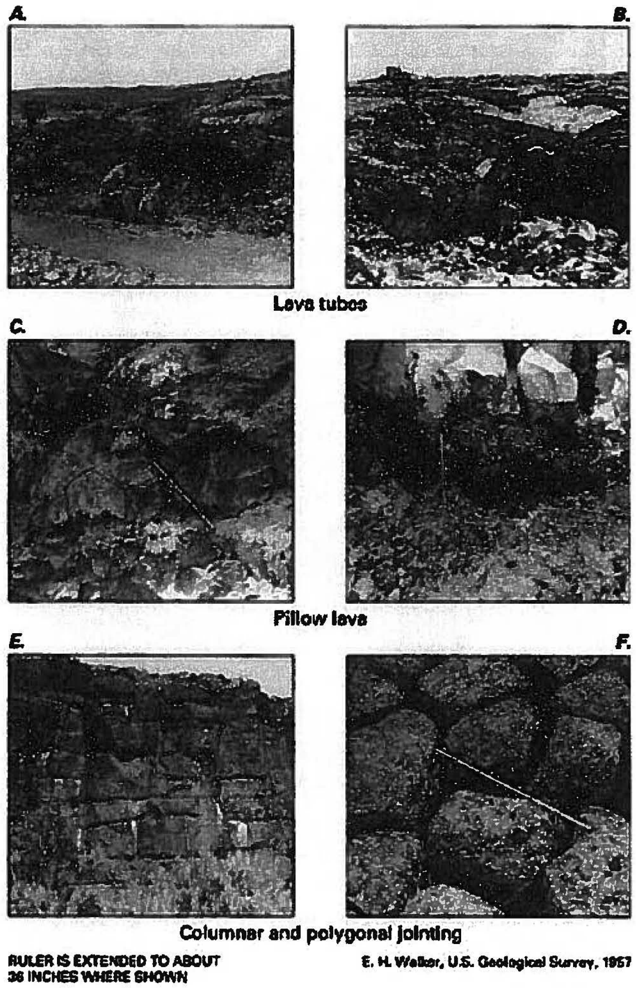

Figure 4. Surficial features show the characteristic type of openings in the Pliocene and younger basaltic-rock aquifers. A and B show, undulating surface of a basalt flow with collapsed and partly collapsed lava tubes. C and D shows pillow basalt raging from large boulders to tand grain sand that formed when lava entered water and cooled quickly. E shows side view of columnar basalt showing typical cooling joints. These openings provide easy access for water from recharge sources to enter the underlying aquifer.

Water-rock interactions affect groundwater elemental concentrations through different processes, including mineral dissolution, ion exchange, desorption and adsorption. Unlike elemental concentrations, isotopic ratios are unaffected by those processes, because the Uranium and Strontium transferred to the water is isotopically identical to the host rock. With this important fact in mind both isotopic ratios (Uranium and Strontium) suggest a channeling of radiogenic groundwater from the north, through zones of relatively unradiogenic materials and around the western and central zones that have low isotopic ratios. These same preferential flow paths appear to cause some sort of stagnation of waters with low isotopes ratios (CLZ, WLZ) *(Figure 5D)*.

One key fact about these aquifer systems is that the host basalt rock and sediments in the aquifer are characterized by low isotopic ratios while mountain ranges and their sediments (Paleozoic and Precambrian Clastic Rocks) are characterized by high isotopic ratios. Therefore we can use the isotopic ratios as an indicator of water-rock contact time when compared to elemental chemistry.

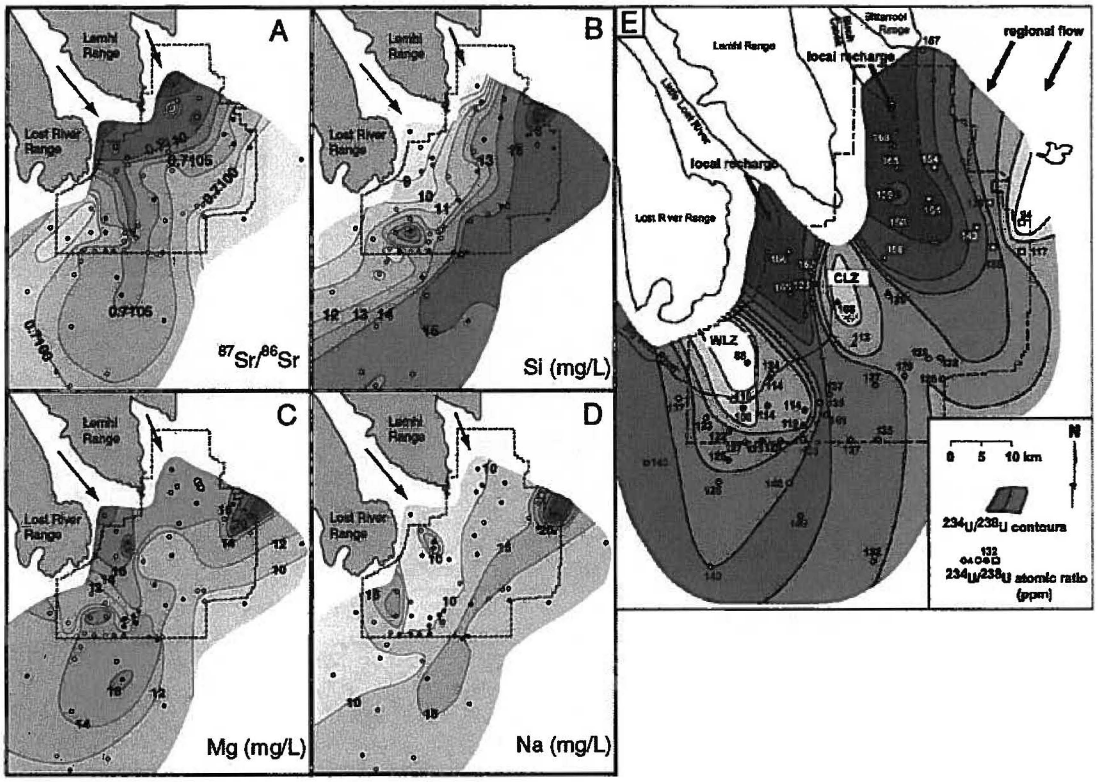

Figure 5. Contour plots of (A) Strontium Isotopic Ratios, (B) concentration of (B) Si, (C) Mg, (D) Na and (E) Uranium Isotopic Ratios. (E) also shows location of river channels. Arrows indicate direction of groundwater influxes.

The results then suggest that the higher the isotopic value the shorter the residence time of ground waters. Nevertheless, the data suggest that preferential flow is not the only mechanisms acting in the aquifer. As the elemental chemistry suggests, mixing of ground waters also plays an important role. Other alternate interpretations of the data were explored but failed to adequately explain the observed phenomena.

Findings and conclusions:

Sr and U isotope ratios were used to distinguish preferential flowpaths in aquifer systems because of their relatively predictable reactions. Therefore in the ESRiPA, in the vicinity of the INEEL it was determined that the mixing of groundwaters from the mounts of Birch Creek and Little Lost River with waters from the east and south seems to be an important process. More important was the fact that two preferential flow pathways extending southeast from these two rivers dominate the entire flow system in this area. The findings of these studies illustrate the importance of understanding fractured flow to the management of groundwater resources and contaminant transport.

Take home message:

Using radiogenic isotope ratios together with elemental chemistry in the ESRiPA made possible the identification of ground water sources, preferential flow paths, together with a better understanding of the chemical and physical processes in a highly heterogeneous aquifer system. This case study shows that a similar approach could potentially be used in other heterogeneous aquifer systems.

Credits:

Case study was written by Carlos D. Soto, Department of Hydrology and Water Resources, University of Arizona, Tucson. Original work by Johnson et al. (2000) and Roback et al. (2001)

Further reading:

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