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Vertical Variability in Saturated Zone Hydrochemistry near Yucca Mountain, Nevada

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Abstract – The differences in the saturated zone hydrochemistry with depth at borehole NC-EWDP-22PC reflect the addition of recharge along Fortymile Wash. The differences in water chemistry with depth at borehole NC-EWDP-19PB appear to indicate that other processes are involved. Water from the lower part of NC-EWDP-19PB possesses chemical characteristics that clearly indicate that it has undergone cation exchange that resulted in the removal of calcium and magnesium and the addition of sodium. This water is very similar to water from the Western Yucca Mountain facies that has previously been thought to flow west of NC-EWDP-19PB. Water from the lower zone in NC-EWDP-19PB also could represent water from the Eastern Yucca Mountain facies that has moved through clay-bearing or zeolitized aquifer material resulting in the altered chemistry. Water chemistry from the upper part of the saturated zone at NC-EWDP-19PB, both zones at NC-EWDP-22PC, and wells in the Fortymile Wash facies appears to be the result of recharge through the alluvium south of Yucca Mountain and within the Fortymile Wash channel.

I. INTRODUCTION

Yucca Mountain, Nevada, is being proposed as a permanent disposal facility for high-level radioactive waste. Assessment of the overall performance of the proposed repository requires a thorough understanding of the factors influencing flow and transport in the saturated zone. Some of the critical factors are the length and direction of the flow paths, flow velocity, and mixing as ground water moves from volcanic aquifers immediately below Yucca Mountain into aquifers influenced by the presence of alluvium east and south of Yucca Mountain. Because these factors cannot be readily measured, the chemical and isotopic composition of ground water throughout the flow system must be used to assess the general character of saturated zone flow.

Since 1997, approximately 250 ground-water samples have been collected from wells throughout the Fortymile Wash, Amargosa Valley, and Yucca Mountain area (Fig.1). Wells sampled include domestic wells, Yucca Mountain Project wells, and new wells drilled by Nye County as part of their Early Warning Drilling Program (EWDP).¹ These samples are analyzed for cations, anions, trace elements, and a variety of isotopic constituents. The results of these analyses are entered into the U.S. Geological Survey (USGS) hydrochemical and isotopic database (USGS, unpub. data) which also

Fig. 1. Hydrochemical facies from samples of ground water near Yucca Mountain, Nevada.

includes more than 600 historical analyses of ground-water samples from the Yucca Mountain region. These chemical and isotope analyses have been interpreted using a variety of methods to help determine source areas, flow direction, mixing relations, ages, and travel time. All chemical data discussed in this paper are from the USGS hydrochemical and isotopic database.

II. BACKGROUND

The chemical and isotopic content of ground water in the vicinity of Yucca Mountain has been used to identify relatively distinct hydrochemical facies (Fig. 1).² This discussion will focus on three facies: Western Yucca Mountain, Eastern Yucca Mountain, and Fortymile Wash. Water from the Western Yucca Mountain facies contains elevated sodium (Na^+), bicarbonate (HCO_3^-), fluoride (F^-), uranium (U), and boron (B) as compared to water from the Eastern Yucca Mountain facies and the Fortymile Wash facies. The average calcium (Ca^{2+}) concentration of water from the Western Yucca Mountain facies is 2.1 milligrams per liter (mg/L) and the average Na^+ concentration is 101.0 mg/L. Water from the Eastern Yucca Mountain and Fortymile Wash facies are similar except that water from the Eastern Yucca Mountain facies contains slightly higher Na^+ and HCO_3^- and water from the Fortymile Wash facies contains higher magnesium (Mg^{2+}) and potassium (K^+). The average Ca^{2+} concentration is 11.3 mg/L and the average Na^+ concentration is 58.3 mg/L in the Eastern Yucca Mountain facies. Within the Fortymile Wash facies Ca^{2+} concentrations average 15.4 mg/L and Na^+ concentrations average 40.9 mg/L. The general relation between the major ion chemistries of these three facies is shown in Figure 2.

Fig. 2. Modified piper diagram showing water chemistry in ground-water samples representing three hydrochemical facies near Yucca Mountain, Nevada.

The distinct nature of these hydrochemical facies indicates the presence of long flow paths from eastern Yucca Mountain toward Fortymile Wash to the southeast and from western Yucca Mountain south toward Amargosa Valley.²

III. WORK DESCRIPTION

The interpretation described above was determined without regard to vertical variability in saturated zone chemical characteristics because few wells were completed to isolate water from different depths. The availability of saturated zone core samples collected while drilling the alluvial wells NC-EWDP-19PB (19PB) in December, 2003 and NC-EWDP-22PC (22PC) in November, 2004 allowed a detailed look at discrete hydrochemical characteristics through about one hundred meters of saturated zone. The core samples were preserved in heat sealed plastic tubing inserted into a Lexan® liner with securely taped end caps. The samples are then placed in refrigerated storage until processing in the lab. The water samples were extracted from the unconsolidated material by centrifuge and analyzed for cations, anions, trace elements, and a variety of isotopic constituents.

Twenty-six samples were analyzed from borehole 19PB, which is located south of Yucca Mountain and falls within the Eastern Yucca Mountain facies. These samples range from a depth of 108 meters (m) (just below the water table) to 192 m below land surface. Twelve samples were analyzed from borehole 22PC, which is located southeast of Yucca Mountain within the Fortymile Wash facies. These samples range from a depth of 145 to 232 m below land surface.

Ground-water samples from four zones in borehole NC-EWDP-19D (19D) were collected from August through November, 2000. The samples were collected using a submersible pump suspended between two packers. Zone 1 samples were collected at a depth interval of 125.9 to 131.4 m below land surface; Zone 2 samples from 151.8 to 157.3 m; Zone 3 samples from 176.2 to 206 m; and Zone 4 samples from 220.4 to 242.3 m.

IV. RESULTS

The major ion chemistry of 16 core samples from the upper 61 m of the saturated zone in borehole 19PB is relatively homogeneous with Ca^{2+} concentrations varying from 17 to 56.1 mg/L (average 33.1 mg/L), Mg^{2+} concentrations from 1.9 to 4.9 mg/L (average 3.4 mg/L), and Na^+ concentrations from 44.2 to 127 mg/L (average 71.4 mg/L). The average Na/Ca ratio is 1.9. Below 61 m within the saturated zone in borehole 19PB the major ion

chemistry of 10 core samples is distinctly different. Ca^{2+} concentrations range from 4.8 to 19 mg/L (average 9.2 mg/L), Mg^{2+} concentrations from less than 0.25 to 0.94 mg/L (average 0.55 mg/L), and Na^+ concentrations from 126 to 219 mg/L (average 160 mg/L). The average Na/Ca ratio is 19.7.

The water chemistry of core samples from borehole 22PC shows very slight differences between an upper and lower zone. Water from 5 core samples in the upper 38 m of the saturated zone has Ca^{2+} concentrations that range from 13.1 to 19.9 mg/L (average 16.4 mg/L), Mg^{2+} concentrations from 2.3 to 3.3 mg/L (average 2.8 mg/L), and Na^+ concentrations from 31 to 38.1 mg/L (average 34.9 mg/L). The average Na/Ca ratio is 1.9. Water from 7 core samples below 38 m in the saturated zone has Ca^{2+} concentrations from 17.4 to 34 mg/L (average 24.7 mg/L), Mg^{2+} concentrations from 2.9 to 4.5 mg/L (average 3.9 mg/L), and Na^+ concentrations from 33.3 to 104 mg/L (average 59.5 mg/L). The average Na/Ca ratio is 2.1.

The slight increase in major ion concentration with depth at borehole 22PC reflects the addition of recharge along Fortymile Wash. Many chemical constituents indicate that there is a plume of relatively dilute water along the trace of Fortymile Wash.² Water from the Fortymile Wash facies also possesses relatively light delta carbon-13 ($\delta^{13}\text{C}$) values that also indicate the presence of relatively young recharge (Fig. 3). The chemical content

Fig. 3. Delta carbon-13 ($\delta^{13}\text{C}$) in ground-water samples near Yucca Mountain, Nevada.

of water from both zones in 22PC fall within the variability of that representative of wells within the Fortymile Wash facies. Because borehole 22PC is located on the eastern edge of the Fortymile Wash channel it is unlikely that water from the Western or Eastern Yucca Mountain facies (to the west of the Fortymile Wash channel) would reach this location until after it had mixed with water from upper Fortymile Wash.

Borehole 19PB is west of Fortymile Wash and has been included in the group of wells representing the Eastern Yucca Mountain facies. The major ion chemistry of water samples from the upper 61 m of the saturated zone is similar to that of samples from other wells within the Eastern Yucca Mountain facies. However, water from below 61 m within the saturated zone at 19PB possesses chemical characteristics that clearly indicate that it has undergone cation exchange that resulted in the removal of Ca^{2+} and Mg^{2+} and the addition of Na^+ . These vertical changes in chemistry occur somewhat gradationally over a 20- to 30-m interval, which supports the conclusion that the chemical differences are a reflection of vertical mixing. Also, there is no indication of the presence of any lithologic zones with unusually high percentages of clay material in the borehole at or immediately above the transition depth (R.W. Spengler, USGS, written commun., 2005). The water from the lower zone is very similar to water from the Western Yucca Mountain facies that has been thought previously to occur west of 19PB. Therefore, water from the lower zone in 19PB either represents water from the Eastern Yucca Mountain facies that has moved through clay bearing or zeolitized aquifer material (upgradient from 19PB) resulting in the altered chemistry, or it represents water from the Western Yucca Mountain facies, which flows substantially further east than was thought previously.

The major ion chemistry of pumped water samples from borehole 19D, water samples extracted from core from boreholes 19PB and 22PC, average concentrations from all wells representing the Western and Eastern Yucca Mountain facies and the Fortymile Wash facies, and one analysis of precipitation near Yucca Mountain is presented on the diagram shown in Figure 4. The major ion chemistry of precipitation, water from the upper zone from 19PB, and both zones from 22PC form a cluster with the average of all wells within the Fortymile Wash facies. These zones and all of the Fortymile Wash facies are all affected by the presence of local recharge. Pumped water samples from Zones 1 and 2 of borehole 19D represent the same interval as the upper zone of core samples from 19PB. The major ion chemistry of these samples is similar to the average of all wells within the Eastern Yucca Mountain facies. These chemistries fall intermediate between those of the lower zones and the upper zone of samples extracted from core at 19PB. This

Fig. 4. Piper diagram showing chemistry of water samples from different depths at boreholes NC-EWDP-19PB, NC-EWDP-19D, and NC-EWDP-22PC, and average concentrations in ground-water samples representing three hydrochemical facies near Yucca Mountain, Nevada.

is likely due to mixing of the zones during pumping, which results in slightly altered major ion chemistry. The pumped samples from Zones 3 and 4 of 19D are from a similar depth interval as the lower zone of core samples from 19PB. The chemistries of these pumped samples cluster with the average value of wells from the Western Yucca Mountain facies and, with respect to the cation chemistry, the lower zone of core samples from 19PB. Some of the water samples from core collected at 19PB, however, contain substantially elevated sulfate concentrations. These few samples greatly alter the average sulfate concentration causing this water to plot outside of the cluster. The source of these elevated sulfate concentrations is not known, but they are possibly due to the presence of pyrite in tuff clasts that has been oxidized to sulfate.

V. DISCUSSION AND CONCLUSIONS

Ground water chemistry in the upper part of the saturated zone at borehole 19PB, borehole 22PC (both zones), and boreholes within the Fortymile Wash facies

appears to be the result of recharge through the alluvium south of Yucca Mountain and within the Fortymile Wash channel. Ground water chemistry in the deeper zones at boreholes 19PB and 19D appears to be derived from either the Western or Eastern Yucca Mountain facies and probably represents water that would carry any potential contaminant from the vicinity of the proposed repository. The concept of a layered saturated zone is important to the prediction of the fate of any potential contaminant plume moving from Yucca Mountain. If the water from the lower zones in boreholes 19PB and 19D is water from the Eastern Yucca Mountain facies that has moved through clay-bearing aquifer material, many radionuclides would be sorbed by the same materials that remove the Ca and Mg. On the other hand, if the water from the lower zones represents water from the Western Yucca Mountain facies, it means that water can move from the volcanic aquifers into the alluvium relatively unaltered and that water from the Western Yucca Mountain facies flows southeast toward Fortymile Wash rather than south-southwest toward the Amargosa Valley.

The concept of a widespread, layered, saturated zone system with recharge through the alluvium essentially sitting on top of older water flowing from the vicinity of Yucca Mountain is important for obtaining reliable radiocarbon ground-water ages to calculate time of travel. Ground water from zones mixed with substantial amounts of local recharge would possess younger apparent ages than ground water from zones not mixed with local recharge.

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of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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