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Evidence for Ground-Water Stratification near Yucca Mountain, Nevada

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Abstract – *Major- and trace-element concentrations and strontium isotope ratios (strontium-87/strontium-86) in samples of ground water potentially can be useful in delineating flow paths in the complex ground-water system in the vicinity of Yucca Mountain, Nevada. Water samples were collected from boreholes to characterize the lateral and vertical variability in the composition of water in the saturated zone. Discrete sampling of water-producing intervals in the saturated zone includes isolating borehole sections with packers and extracting pore water from core obtained by sonic drilling. Chemical and isotopic stratification was identified in the saturated zone beneath southern Fortymile Wash.*

I. INTRODUCTION

The U.S. Department of Energy (DOE) and Nye County Nuclear Waste Repository Project Office (NWRPO) have drilled numerous boreholes in the vicinity of Yucca Mountain, Nevada, site of the proposed repository for high-level radioactive waste. The U.S. Geological Survey (USGS) analyzed ground-water samples from many of these boreholes for major- and trace-element concentrations and strontium (Sr) isotope ratios ($^{87}Sr/^{86}Sr$). The NWRPO, through the Early Warning Drilling Program (EWDP)[1], drilled boreholes downgradient and across the generally accepted north-to-south ground-water flow paths from Yucca Mountain (Fig. 1)[2]. Establishment of baseline geochemistry of the saturated zone (SZ) at and around Yucca Mountain augments the understanding of ground-water-flow pathways and SZ transport processes.

II. SAMPLE DESCRIPTION AND ANALYTICAL METHODS

A better understanding of ground-water flow and transport results from improved methods of isolating and collecting water samples. Open-hole ground-water samples represent a column of water that is mixed in proportion to the amount of ground-water flow in each of the units penetrated by the borehole[3]. Ground-water samples from packed-off intervals in boreholes represent water from discrete aquifer layers. Despite preliminary pumping before collecting water samples from each isolated interval, the geochemical data on periodically sampled intervals indicate some inhomogeneous mixing in the borehole[3]. In addition to conventional drilling, core samples were collected for the EWDP using sonic drilling to avoid contamination of pore water in the core by drilling fluids.

Multiple-borehole complexes, Site NCEWDP19 and Site NCEWDP22, located adjacent to southern Fortymile Wash (Fig. 1), have boreholes (19D, 19PB, 22S, 22PC, and others) equipped for collecting water samples at discrete depths. The water table in this area is located in the alluvium, and most of the samples discussed in this paper were collected from the alluvial aquifer. One borehole at each site (19D and 22S) is equipped with multiple packers, which allows samples to be collected from the isolated, screened intervals in the borehole (Fig. 2). Borehole 19D is equipped with seven screened intervals, of which Sr data are available only for intervals 1 through 5. Land-surface altitude of borehole 19D is 818.9 meters (m) above the National Geodetic Vertical Datum of 1929, and the water table altitude is 711.8 m[1]. Despite the 77.7 m distance between borehole 19D and 19PB, borehole 19PB has similar values for land-surface and water table altitudes. Borehole 22S is equipped with four screened intervals and has a land-surface altitude of 869.1 m and a water table altitude of 724.4 m[1]. At site 22 borehole 22PC is separated from 22S by 25.5 m and has similar land-surface and water table altitudes.

After using conventional techniques to drill from the surface to near the water table in boreholes 19PB and 22PC (Fig. 2), core from the SZ was obtained by sonic drilling. About 80 m of sonic core from borehole 19PB and about 90 m of sonic core from borehole 22PC were collected, and selected portions of each core were sealed in polycarbonate tubes for geochemical analysis. In the laboratory, pore-water samples were extracted by ultracentrifugation of selected portions of about 1-m intervals

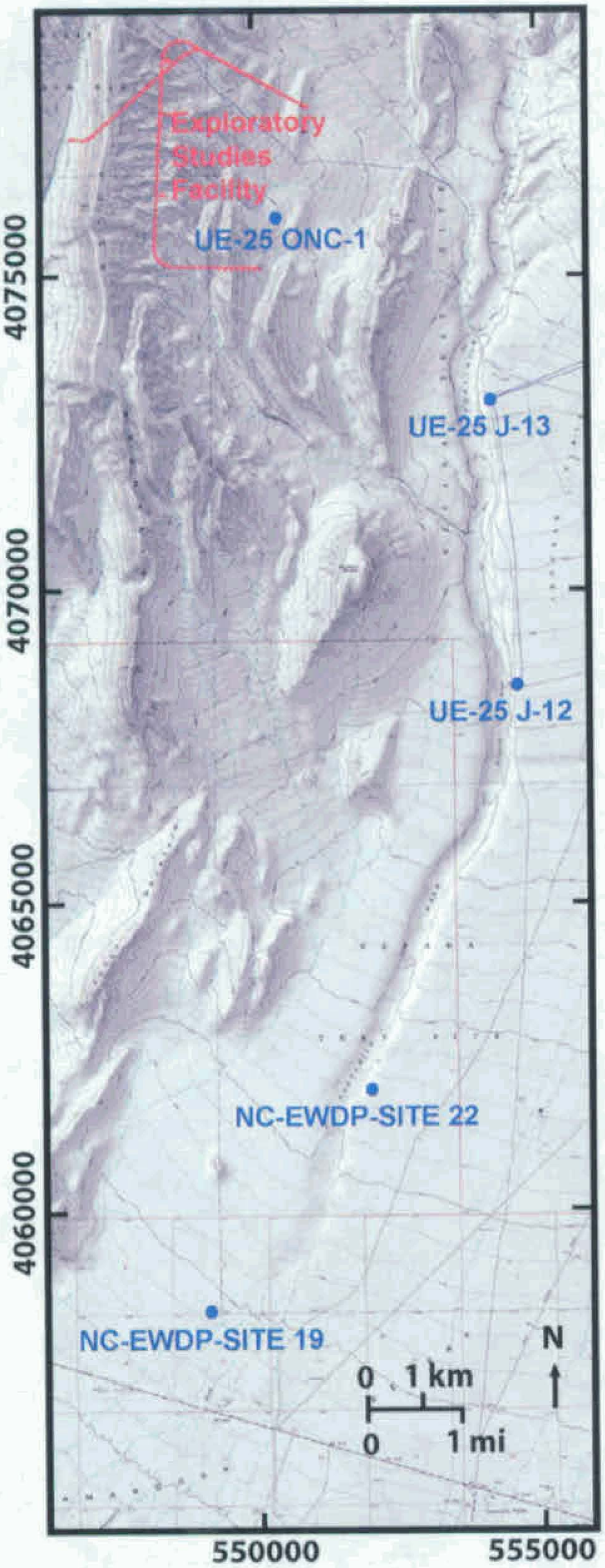

Figure 1. Locations of boreholes relative to the Exploratory Studies Facility, Yucca Mountain, Nevada. Multiple-borehole complexes, Sites NCEWDP19 and NCEWDP22, are located near the southern end of Fortymile Wash[1]. Base map is derived from Busted Butte and Amargosa Valley shaded relief quadrangle maps (U.S. Geological Survey 7.5minute series).

of core. This sampling resolution allows more detailed characterization of the chemical and isotopic compositions of water in the upper part of the SZ than screened interval sampling.

Concentrations of Na, Ca, and Sr in the water samples were determined by ion chromatography and inductively coupled plasma mass spectrometry at the U.S.G.S. lab in Denver, Colorado. Reproducibility of the elemental concentrations in the routinely analyzed National Institute of Standards and Technology (NIST) standard is approximately 5 percent. The $^{87}Sr/^{86}Sr$ ratios were measured on a thermal ionization mass spectrometer, with precision averaging 0.00005 (at the 95-percent confidence level), based on repeat analyses of the USGS seawater standard (EN1) and replicate analyses of samples. All the $^{87}Sr/^{86}Sr$ ratios were normalized to the present-day value of 0.70920 assumed for the standard EN1.

III. WATER CHEMISTRY AND STRONTIUM ISOTOPES

Ultracentrifuged pore-water samples from boreholes 19PB and 22PC have $^{87}Sr/^{86}Sr$ ratios that generally decrease from the water table to about 80 m below the water table (Fig. 3). Similar changes with depth also are observed in the average $^{87}Sr/^{86}Sr$ values for samples collected from each screened interval of boreholes 19D and 22S (Fig. 3). Although 19PB and 22PC have a similar change with depth in the Sr isotopic ratios, pore-water samples from borehole 19PB have sodium/calcium (Na/Ca) ratios that substantially increase and Sr concentrations that decrease below 60 m from the water table, but the Na/Ca ratios and Sr concentrations of the pore-water samples from 22S are little changed below this depth[4]. The geochemistry of the pore-water samples collected from the water table to 73.2 m and 88.3 m from 19PB and 22PC, respectively, is influenced by the volume of water and by the ground-water flow rate in these intervals. This influence may be demonstrated by considering the results of the pump-spinner tests[5,6] recorded for the screened intervals of the companion boreholes 19D and 22S, respectively (Fig. 4). Pump-spinner tests performed on borehole 19D indicate a small percentage (8 percent) of total flow (upper, low-flow) to the well in the intervals between 18.4 and 52.1 m below the water table (intervals #1 and #2), a large percentage (92 percent) of total flow (high-flow) in the intervals between 67 and 217.3 m below the water table (intervals #3, #4, and #5), and a very

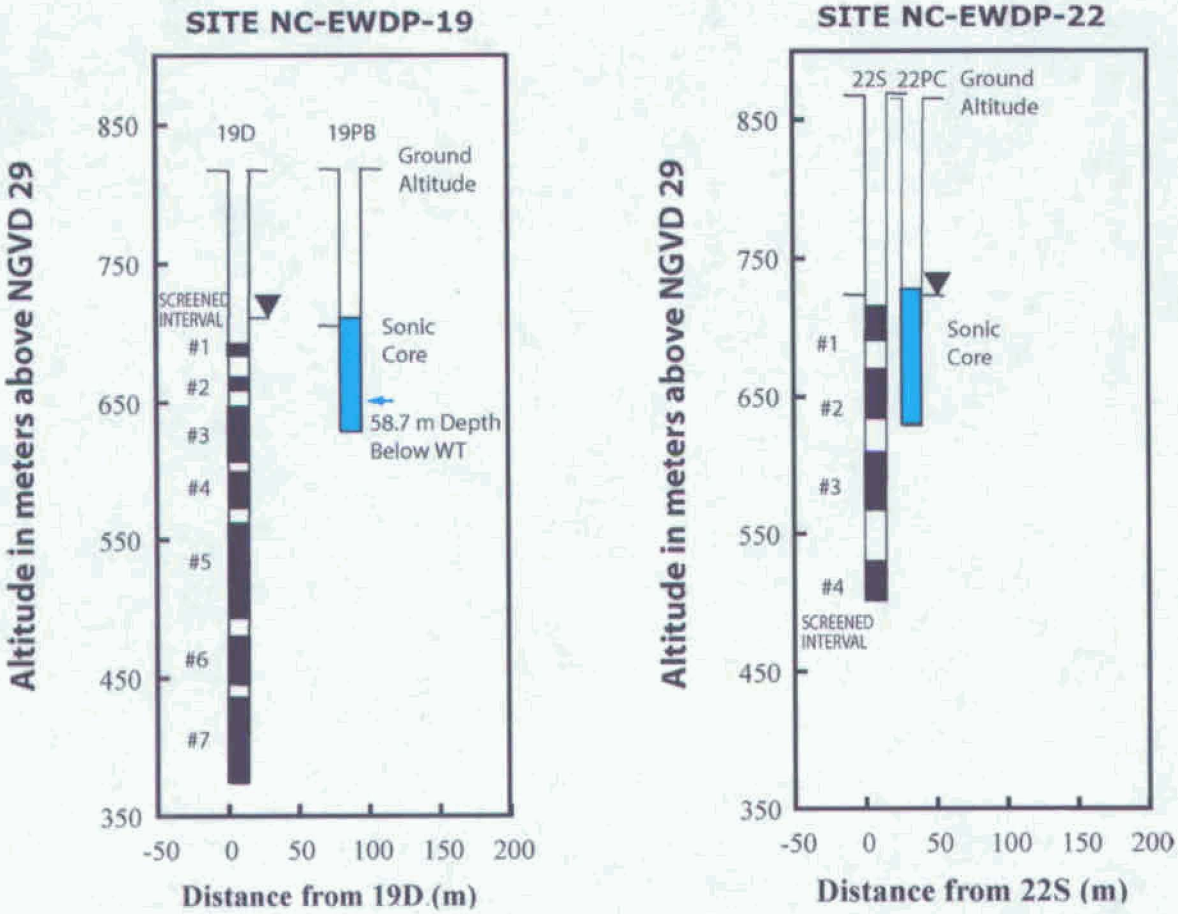

Figure 2. Completion information for boreholes NC-EWDP-19D, -19PB, -22S, and -22PC (borehole diameters are not to scale) south of Yucca Mountain, Nevada. The inverted triangle indicates the approximate location of the water table (WT) at each site.

small percentage of total flow (lower, low-flow) in the intervals between 232 and 338 m below the water table (intervals #6 and #7)[5]. Results from the pump-spinner tests in borehole 22S show that 73 percent of the ground-water flow (high-flow) occurs in upper intervals #1 and #2 (0 to 88.9 m below water table) in this borehole (Fig. 4)[6].

The Sr concentrations and the $^{87}Sr/^{86}Sr$ ratios of the ultracentrifuged water extracted from -5.4 to 51.9 m below the water table of borehole 19PB, which approximately corresponds to the upper, low-flow portion of 19D (Fig. 2) and from -3 to 88.3 m below the water table of borehole 22PC, which approximately corresponds to the upper intervals #1 and #2 (high-flow) of 22S (Fig. 2), show a range of $^{87}Sr/^{86}Sr$ ratios, with a small range in Sr concentrations (with one exception), as seen on a mixing diagram of $^{87}Sr/^{86}Sr$ plotted in relation to 1/Sr (Fig. 5). A theoretical mixing line for the upper, low-flow portion of borehole 19PB is shown with one end member assumed to be the value of local recharge for the alluvium in Fortymile Wash[7] and the other end member as water with the lowest $^{87}Sr/^{86}Sr$ ratio in 19PB. The Sr concentration for one sample in the upper, low-flow portion of borehole 19PB (at 40.2 m below the water table) is much smaller than the others and the sample has an intermediate $^{87}Sr/^{86}Sr$ ratio. This sample may indicate a third end member, because several of the upper, low-flow samples with $^{87}Sr/^{86}Sr$ values between 0.7110 and 0.7116 have Sr concentrations that are smaller than corresponding points on the mixing line. These Sr data also may reflect a zeolitic influence (discussed below) in this portion of the alluvium.

The Sr data for the ultracentrifuged water for the 58.7 to 72.7 m below the water table of borehole 19PB, which corresponds to the upper part of interval #3 of the high-flow portion of borehole 19D, form a second trend shown by the filled triangles on Fig. 5. Strontium concentrations in the high-flow portion of 19PB generally are lower than those of the upper, low-flow portion of 19PB, and the

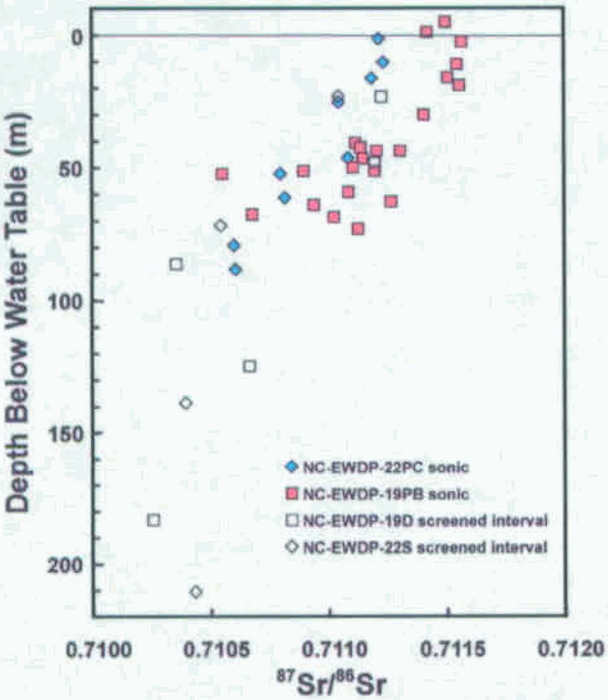

Figure 3. Strontium-87/strontium-86 ($^{87}Sr/^{86}Sr$) ratios for water samples extracted from sonic core by ultracentrifugation and from screened intervals (average ratios) plotted relative to the depth of the water table (mid-screen depth for screened intervals), boreholes NCEWDP19D and NCEWDP22S, south of Yucca Mountain, Nevada.

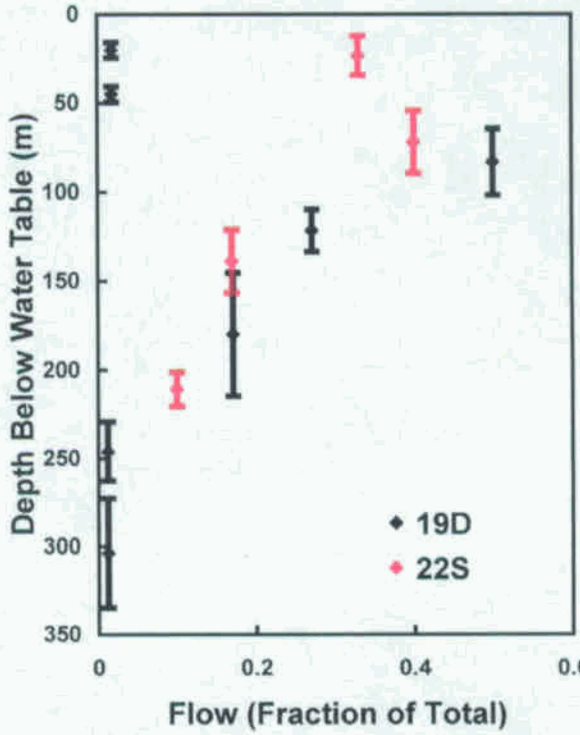

Figure 4. Flow surveys of boreholes NCEWDP19D and NCEWDP22S, south of Yucca Mountain, Nevada, show the fraction of total ground-water flow in each of the screened intervals (see fig. 2) as measured by pump-spinner tests[5,6].

water has a small range of $^{87}Sr/^{86}Sr$ ratios, except for one low value for the sample at 67.1m below the water table. The Sr concentration in ground water may be reduced substantially without a major change in the $^{87}Sr/^{86}Sr$ ratio by ion exchange. Widely distributed in tuffs, zeolites in contact with ground water can exchange Na for Ca and Sr, resulting in higher Na/Ca ratios and lower Sr concentrations in ground water. As indicated earlier in this paper, the Na/Ca ratios of the ultracentrifuged water samples from borehole 19PB increase substantially at a depth of 58.7 m below the water table. The Sr data from the high-flow portion of borehole 19PB (58.7 to 72.7 m below the water table) also may result from Sr depletion due to the presence of zeolites and (or) mixing with water having a very low Sr concentration with a calculated $^{87}Sr/^{86}Sr$ ratio around 0.7113.

The Sr data for the 12 ultracentrifuged water samples, representing the entire 88.3 m of borehole 22PC, plot on a similar mixing line (Fig. 5) as the samples from the upper, low-flow portion of borehole 19PB. In contrast to borehole 19PB, the high-flow portion of borehole 22PC occurs in the intervals closest to the water table, but the Sr data of borehole 22PC plot on the upper, low-flow mixing line of borehole 19PB (Fig. 5). The majority of the high-flow ground water in borehole 22PC apparently mixes according to the mixing line presented in Figure 5; but with larger quantities of ground water in the high-flow intervals near the water table, the Sr signature of the water derived from local recharge is less apparent than in the samples from the upper, low-flow intervals in borehole 19PB. As a result of local recharge mixing with greater ground-water flow at the water table near borehole 22PC, the $^{87}Sr/^{86}Sr$ ratios of the water in borehole 22PC are generally lower from 0 to about 70 m below the water table than that at borehole 19PB, assuming the amount of local recharge at both sites is about equal. Mixing of local recharge with ground water can be an important influence on the water in the aquifer under Fortymile Wash.

The Sr data for ground water from boreholes UE-25 J13 (J-13) and UE-25 J12 (J-12) as well as UE-25 ONC-1 (ONC-1) are plotted with Sr data of waters from 19PB and 22PC (Fig. 5) to show the relationship of the water from central Fortymile Wash and water under Yucca Mountain. The open-hole sampling and the long-term pumping of J-13 and J-12 may have influenced the Sr data of the water samples from these boreholes. Although the Sr mixing diagram (Figure 5) shows some similarities in the Sr data of J-13 and J-12 to those from sites 19 and 22, this and other geochemical differences distinguish them from the waters of the sites 19 and 22. The Sr data on the

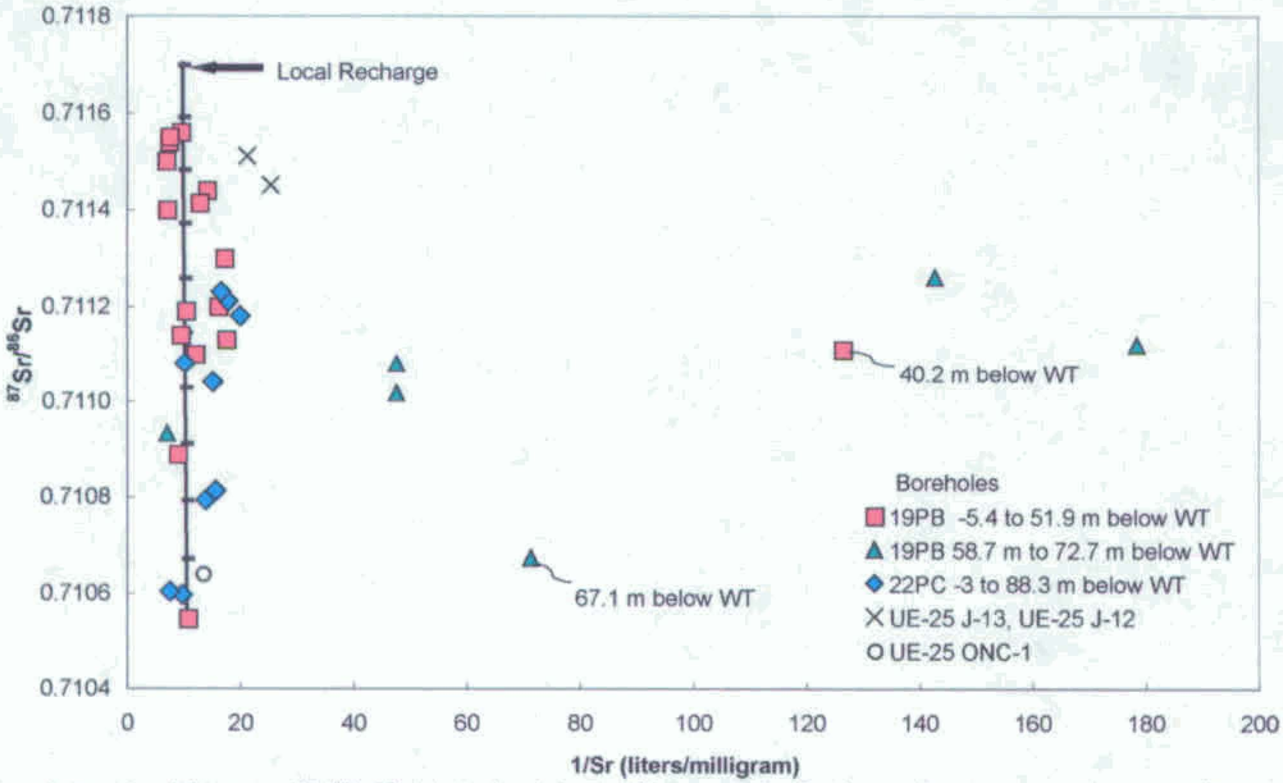

Figure 5. Strontium-87/strontium-86 ($^{87}Sr/^{86}Sr$) plotted in relation to 1/Sr concentration for ultracentrifuged water samples extracted from sonic core in boreholes NCEWDP19PB and NCEWDP22PC, south of Yucca Mountain, Nevada. A theoretical mixing line of the Sr data for water samples from the upper, low-flow portion (0 to 51.9 m depth below water table) of the sonic core from borehole 19PB (filled squares) is shown with tick marks indicating increments of 10 percent mixing between local recharge[7] and the composition corresponding to the lowest Sr ratio measured in the upper, low-flow portion of borehole 19PB. The Sr data for the water samples, associated with the section of high-flow contribution in borehole 19D, the portion between 58.7 to 72.7 m depth below the water table of borehole 19PB, show a trend toward lower Sr concentrations. Samples from borehole 22PC (filled diamonds) plot along a similar mixing line as the upper, low-flow portion of borehole 19PB.

ground-water sample from ONC-1 shows similarities to the $^{87}Sr/^{86}Sr$ ratios of the deep samples from 22PC and the lowest sample in the upper, low-flow interval of 19PB (Figure 5). The $^{87}Sr/^{86}Sr$ ratios of the water from ONC-1 is also close to the average Sr ratios of the deep screened intervals (#3, #4, and #5) of 19D and deep screened intervals (#2, #3, and #4) of 22S (Figure 3).

IV. CONCLUSIONS

Water samples obtained by ultracentrifugation of sonic core provided more detailed geochemical information on the SZ than open-hole sampling or packed-off interval sampling. Strontium concentrations and $^{87}Sr/^{86}Sr$ ratios for ground water extracted by ultracentrifugation and for samples pumped from packed-off intervals show evidence of stratification in the SZ ground water beneath southern Fortymile Wash. The Sr data for the samples from the upper, low-flow portion of borehole 19PB and for the sonic-core samples from borehole 22PC indicate an influx of local recharge mixing with ground water similar in composition to that under Yucca Mountain. Concentrations of Na, Ca, and Sr in the water samples from the middle, high-flow portion of borehole 19PB may reflect the presence of zeolites in the alluvium or in the upgradient regions of the aquifer. The geochemical and isotopic stratification of the ground water, sampled at borehole sites NCEWDP19 and NCEWDP22, indicates that water from beneath the proposed high-level radioactive waste repository at Yucca Mountain may flow beneath ground water derived from recharge in Fortymile Wash.

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