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ISOTOPIC DISCONTINUITIES IN GROUND WATER BENEATH YUCCA MOUNTAIN, NEVADA

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ABSTRACT

Analytical data for stable isotopes in ground water from beneath Yucca Mountain, when examined in map view, show areal patterns of heterogeneity that can be interpreted in terms of mixing of at least three end members. One end member must be isotopically heavy in terms of hydrogen and oxygen and have a young apparent ^{14}C age such as water found at the north end of Yucca Mountain beneath Fortymile Wash. A second end member must contain isotopically heavy carbon and have an old apparent ^{14}C age such as water from the Paleozoic aquifer. The third end member cannot be tightly defined. It must be isotopically lighter than the first with respect of hydrogen and oxygen and be intermediate to the first and second end members with respect to both apparent ^{14}C age and $\delta^{13}\text{C}$. The variable isotopic compositions of hydrogen and oxygen indicate that two of the end members are waters, but the variable carbon isotopic composition could represent either a third water end member or reaction of water with a carbon-bearing solids such as calcite.

INTRODUCTION

Yucca Mountain, which is composed of tuffaceous rocks, has been designated for study as a possible site for the nation's first geologic repository for high-level radioactive waste. Geohydrologic investigations at regional and site scale are being conducted as part of this study because water is thought to be the most likely medium for transport of radionuclides to the accessible environment. The repository is proposed to be constructed in welded tuff in the unsaturated zone, a minimum of about 200 meters above the current water table.¹ This paper provides a review and preliminary evaluation of stable isotopic data for ground water in the immediate vicinity of Yucca Mountain and adjacent Fortymile Wash.

Yucca Mountain and Fortymile Wash are within the Oasis Valley and Fortymile Wash ground-water basin.² The shallowest ground water in the basin is located in Tertiary volcanic units (largely ash-flow tuffs) and Quaternary alluvium.² Ground water beneath the proposed repository block (as outlined on figs. 2 & 3) is about 300 to 700 m below land surface. Two striking features of the potentiometric surface are: (1) to the south and east of Yucca Mountain, it is nearly flat ranging in elevation from about 728 to 730 m,³ and (2) to the north, and to a lesser extent, to the west, it rises sharply, such that only 3 km north of the proposed repository, the water-table rises to an elevation of about 1000 m.^{1,3} The hydrogeologic factors responsible for these features are presently unknown.

Blankennagel and Weir suggested that recharge for the Oasis Valley and Fortymile Wash ground-water basin occurred in the northern highlands (Pahute Mesa) with subsequent flow southwest-ward towards Oasis Valley and southward towards the Fortymile Canyon area.⁴ White and White and Chuma reported chemical and isotopic data that support the southwesterly flow path,^{5,6} but Claassen proposed that Fortymile Wash was itself an area of recharge for areas south of Yucca Mountain through infiltration of overland flow within and adjacent to the current surface drainage channel.⁷ Benson and Klieforth have supported this hypothesis and have noted that isotopic compositions and radiocarbon contents of waters beneath Yucca Mountain could represent two recharge sources.⁸

Bish and others noted that waters from the saturated tuffs in the vicinity of the proposed repository block are fairly similar to one another in chemical composition, but that there was a tendency in the data for the Na/Ca to decrease from west to east (from values greater than 25 to values less than 4).⁵ The authors did not elaborate on the possible cause of the observed trend.

MASTER

Table 1.-- Isotopic composition of water from wells in the Yucca Mountain Area, Nevada

Well No.	δD permil SMOW	$\delta^{18}O$ permil SMOW	$\delta^{13}C$ permil PDB	^{14}C percent modern	Apparent age (ka)
J-12	-97.5	-12.8	-7.9	32.2	9,100
J-13	-97.5	-13.0	-7.3	29.2	9,900
UE-25b#1	-99.5	-13.5	-8.6	18.9	13,400
UE-25c#1	-102	-13.5	-7.1	15.0	15,200
UE-25c#2	-100	-13.4	-7.0	16.6	14,400
UE-25c#3	-103	-13.5	-7.5	15.7	14,900
UE-25p#1	-106	-13.8	-2.3	2.3	30,300
UE-29a#2	-93.5	-12.8	-13.0	62.3	3,800
USW G-4	-103	-13.8	-9.1	22.0	12,160
USW H-1	-101	-13.5	-11.4	23.9	12,000
USW H-3	-101	-13.9	-4.9	10.5	18,100
USW H-4	-104	-14.0	-7.4	11.8	17,200
USW H-5	-102	-13.6	-10.3	21.4	12,400
USW H-6	-107	-14.0	-7.1	12.4	16,800
USW V-1	-108	-14.2	-8.5	12.4	17,000
UE-25 WT#12	-103	-13.8	-8.1	11.4	17,950
UE-25 WT#14	-97.5	-12.8	-12.7	24.1	11,760
UE-25 WT#15	-97.5	-13.2	-11.8	21.6	12,670

DATA

Most of the isotopic data used in this paper have been reported previously.^{7,10} The data in Table 1 include three unpublished analyses (UE-25 WT #12, #14, and #15) and published analyses of either the most recent or deepest sample for wells from which more than one analysis has been reported. The representativeness of individual analyses is questionable because in most cases, the extent of possible sample contamination by drilling fluid is unknown. Several samples contain organic carbon which could represent detergent used in drilling. Additionally, lithium contents of analyzed waters vary by three orders of magnitude which may suggest contamination by drilling fluids that contained LiBr as a tracer. Unfortunately, neither the normal levels and variability of Li contents of the regional aquifer nor any change in Li content as a function of volume of water removed by pumping are known. Finally, the data represent samples collected from saturated intervals ranging from 12 to 1142 m in length.

DISCUSSION

The $\delta^{18}O$ values for 18 samples of ground water from the Yucca Mountain area range from -12.8 to -14.2‰ and average -13.5‰ (Table 1). Three samples from Pahute Mesa range from -14.1 to -14.8‰ and average -14.4‰.⁶ The isotopic difference between

ground waters of the two areas is large enough to preclude recharge at Pahute Mesa for the waters beneath Yucca Mountain under climatic conditions similar to those existing when the current Pahute Mesa ground waters were recharged.

The δD values mirror the $\delta^{18}O$ values such that the lightest values are found for samples from Pahute Mesa and the heaviest values are for samples from the Yucca Mountain area. The close correlation between δD and $\delta^{18}O$ and the fact that data closely approximate the meteoric water line of Craig¹¹ have been used by previous workers as evidence that the ground waters of southern Nevada are of meteoric origin.^{6,7,8} These authors have variously interpreted the slight shift to the right of the meteoric water line (fig. 1) as reflecting paleoclimatic conditions that were different from modern conditions or possible minor modification of isotopic composition by evaporation prior to recharge.

The δD values in the Yucca Mountain area vary widely (-93.5 to -108.0‰) and form an areally distinct pattern such that the heaviest values tend to occur beneath the eastern side of the mountain (fig. 2). All of the values heavier than -99.5‰ are for water samples from wells drilled in or adjacent to Fortymile Wash. Claassen has suggested that episodic flow in Fortymile Wash and adjacent washes was a likely source of recharge to the valley fill.⁷ If the last of these recharge events was isotopically heavier than the earlier, and perhaps more extensive recharge events, the water

sampled beneath Fortymile Wash might represent that which has not yet mixed laterally (at least to the west where data are available) with the bulk of the Tertiary-Quaternary aquifer waters. The lack of lateral mixing would be consistent with hypotheses of fault control of Fortymile wash and consequent fracture flow.¹²

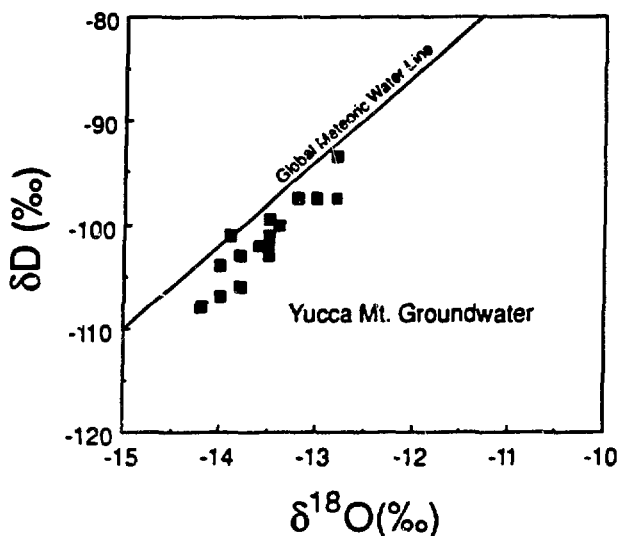


Figure 1.— Plot of δD versus $\delta^{18}O$ for ground water samples from the Yucca Mountain area. The global meteoric precipitation line of Craig¹¹ is shown for reference.

The carbon isotope data also suggest mixing of at least two end-member compositions in the vicinity of Yucca Mountain. Figure 3 shows a roughly east-west trending break between $\delta^{13}C$ values generally less than -9‰ to the north and values generally greater than -8‰ to the south. The two end-member compositions do not have to represent two waters, as they do in the case of hydrogen, because carbon is abundant in solid phases that can react with water at low temperatures, such as calcite, and as a gas, such as CO_2 in soil gas. Soil gas above a liquid can interact with water to alter the isotopic composition of carbon dissolved in water.⁶ However, because the discontinuity in isotopic compositions of carbon occurs along a trend that is roughly perpendicular to any topographic control and at a depth of 300 to 700 m below land surface, the effects of soil gas will not be considered here. By similar reasoning, infiltrating water analogous to that effecting hydrogen isotopic compositions in the vicinity of Fortymile Wash, seems to be an unlikely cause of the discontinuity.

One drill hole (UE-25p#1) located just south of the break in values and just west of Fortymile Wash, penetrates the Paleozoic carbonate aquifer that underlies

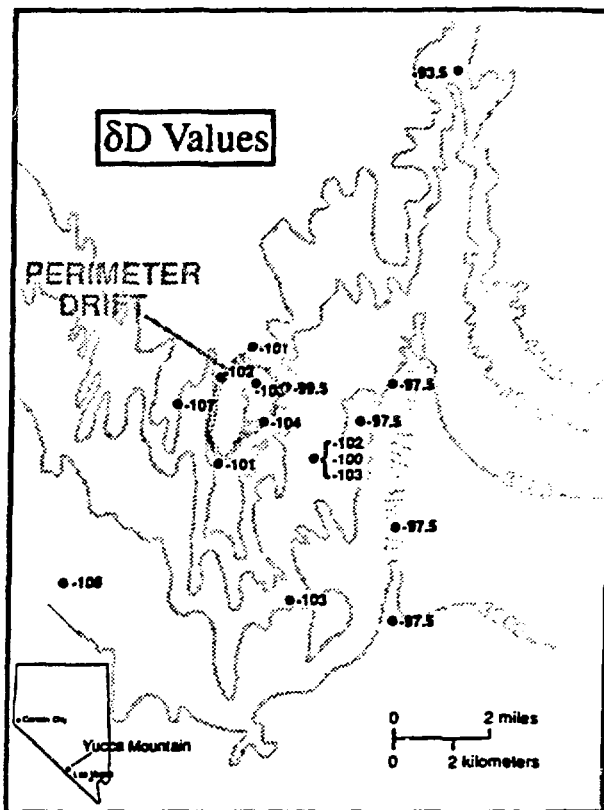


Figure 2.— Map of the Yucca Mountain area showing values for isotopic composition of hydrogen in ground water from the Tertiary/Quaternary aquifer.

the tuffs. This is the westernmost well in the vicinity of the NTS that is completed in the carbonates. At this location, the Tertiary and Paleozoic sections are separated by a fault¹³ that appears to restrict flow from the carbonates to the tuffs. Additionally, the basal part of the Tertiary rocks is significantly less permeable than overlying tuffs and the underlying carbonates, and appears to hydraulically confine the carbonates, as evidenced by the fact that the hydraulic head in the uppermost 560 m of the carbonates is about 20 m higher than that in the basal Tertiary rocks.¹⁴ The $\delta^{13}C$ value for water from the deep aquifer is -2.3‰ (UE25p#1, Table 1). If an east-west structure interrupts the confining unit beneath Yucca Mountain or if the confining section pinches out or has been removed by erosion to the south, upward leakage of the deeper water would be likely because of the head difference, and mixing of this water with that in the overlying Tertiary aquifer would result in higher $\delta^{13}C$ for the water down gradient from the zone of mixing.

If the discontinuity in carbon isotopic composition is caused by interaction of ground water and

a solid, two plausible scenarios can be developed. The Paleozoic carbonate should have $\delta^{13}\text{C}$ values close to 0‰ . If water could react with these rocks, for example in a horst block, the observed increase in $\delta^{13}\text{C}$ values down gradient could be produced. Alternatively, if a paleo ground-water flow system brought water up from the Paleozoic aquifer along a now sealed east-west trending zone and deposited calcite, reaction with that calcite by waters currently in the Tertiary aquifer could produce the observed discontinuity.

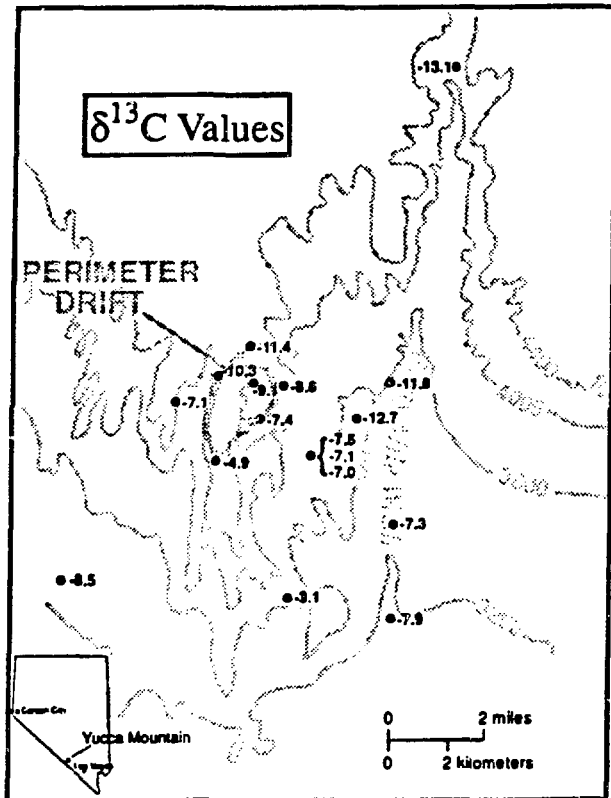


Figure 3.-- Map of the Yucca Mountain area showing values for isotopic composition of carbon in ground water from the Tertiary/Quaternary aquifer.

The ^{14}C data in conjunction with the $\delta^{13}\text{C}$ data suggest that the ground waters in the vicinity of Yucca Mountain may represent three distinct end members and at least two major recharge events.¹⁵ Figure 4 shows that water for 3 wells within Fortymile Wash forms an array that can be interpreted as mixing of waters like those sampled by well UE-29a#2 (north of Yucca Mountain in Fortymile Wash) and the water of the carbonate aquifer represented by the sample from UE-25p#1. (Similar patterns could be produced if only dead carbon from the Paleozoic limestone, or calcite derived from the Paleozoic aquifer, is used as one end member.) The

apparent ^{14}C ages of these end members are 4 and 30 ka respectively. Most of the data points plot along a less well defined trend for which water (or carbon) from the Paleozoic aquifer can still be an end member. The other end member must once again have fairly light carbon (about -13‰), but it must have a much older apparent age than the isotopically light end member needed for the Fortymile Wash trend. Such a trend using WT#14 as an end member is shown on figure 4. The greater scatter about the second trend can be explained by mixing water from the Paleozoic aquifer with water derived by a long period of recharge (from 12 to 17 ka). Alternatively, varying proportions of 15 ka water with both water from the Paleozoic aquifer and the younger water of Fortymile Wash could account for the scatter. A bounding curve computed using water analysis from UE20a#2 on Pahute Mesa is shown on figure 4. Finally, both mechanisms could be operating simultaneously.

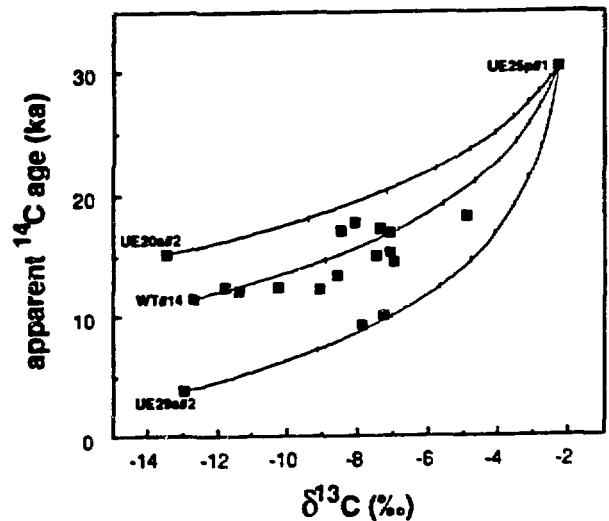


Figure 4.-- Plot of $\delta^{13}\text{C}$ versus apparent ^{14}C ages for ground water beneath Yucca Mountain. Curves are shown for mixtures of water from UE25-p#1 and UE20a#2, UE-25 WT#14 and UE-29a#2.

White and Chuma concluded that ^{14}C ages for waters in the Yucca Mountain Region may be too old by about 2,000 yrs owing to acquisition of dead carbon.⁶ Benson and Klieforth have argued that acquisition of dead carbon is unlikely; they note that present-day flood waters in Fortymile Wash are both saturated with respect to calcium carbonate and contain 100 percent modern carbon.⁸ If these waters represent recharge that infiltrated through Fortymile Wash as postulated by,⁷ the 4 ka age for one end member of the Fortymile Wash waters should be a reasonable age estimate.

The apparent ^{14}C age for water from the Paleozoic aquifer of 30 ka is most likely a maximum value. Flow within this aquifer and the area of recharge are not yet understood. None-the-less, the deepest water of the Yucca Mountain area is reasonably expected to be the oldest. However, the heavy $\delta^{13}\text{C}$ suggests that carbon in the water has at least partially equilibrated with the host rock. If so, an unknown quantity of dead carbon has been added to the water such that the apparent ^{14}C age is too old.

CONCLUSIONS

The isotopic compositions of oxygen, hydrogen, and carbon in ground water beneath Yucca Mountain are inhomogeneous, and when plotted on a map, the data form areally distinct patterns that can be interpreted as mixing of at least three end members. One end member is characterized by isotopically light carbon, an apparent young age, and isotopically heavy hydrogen. This end member can be represented by water from a well east of the north end of Yucca Mountain in Fortymile Wash (UE-29a#2). A second member is characterized by isotopically heavy carbon and an apparent old age. This end member can be represented by water from the Paleozoic aquifer or reaction with calcite precipitated from that water. The third end member is poorly constrained, but it must contain isotopically lighter hydrogen than the first end member and be intermediate to the first and second end members with respect to apparent age and $\delta^{13}\text{C}$. Water from UE-20a#2, located on Pahute Mesa, could represent such an end member in terms of both carbon isotopes and in isotopic composition of hydrogen.

The various possible explanations for the observed isotopic patterns can be tested through a combination of chemical and isotopic tracers. Classical chemical mixing models can be used to test mixing of waters, but much of the currently available data are suspect because they show high values of lithium and organic carbon which may have come from the drilling fluids. More complete pumping and resampling of these wells will be required before these data can be used confidently. If more accurate chemical data preclude mixing of known waters as an explanation, natural tracers, such as strontium isotopes, can be used to test the possible influence of interaction with a solid phase contaminant.

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