Strontium isotope characterization of flow systems in Southern Nevada, USA

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An international scientific consensus argues for the long-term isolation of nuclear waste in deep geologic repositories. Among the many geological criteria for selecting suitable sites, the hydrological setting is especially critical because release of radionuclides to the biosphere would most likely occur through the movement of ground water. Characterizing the hydrological setting entails understanding the present-day rates and paths of ground water flow, how these may have varied in the past, and how they are likely to vary in the future. Among the sites being evaluated worldwide, Yucca Mountain in southern Nevada is unique because the potential respository would be constructed several hundred metres above the water table within a thick, unsaturated zone.

Yucca Mountain is a broad ridge of Miocene ash-flow tuffs in the Basin-and-Range physiographic province of the western United States, where north-trending bedrock ranges alternate with alluvium-filled valleys. Mesozoic compression folded and faulted Upper Proterozoic and Palaeozoic clastic and carbonate rocks which had been deposited on the eastern Cordilleran miogeocline, and a thick sequence (*c* 1000–3000 m) of Miocene silicic ash-flow tuffs subsequently was deposited on this structurally complex terrane. Late Cenozoic extension faulted and tilted the volcanic rocks as well as the underlying Upper Proterozoic and Paleozoic rocks.

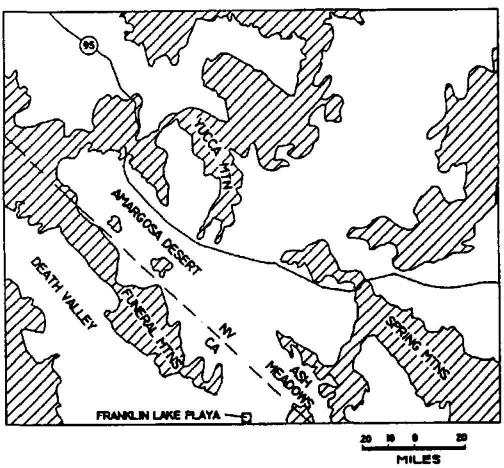

FIG. 1.

Within the Yucca Mountain area, the aquifers include Miocene tuffs, the older shelf carbonate and clastic rocks, and alluvial valley fill derived from the tuffs and from the sedimentary units. The Upper Proterozoic clastic units, a thick Mississippian-Devonian argillite, and altered parts of the volcanic sequence have been considered in earlier studies to be confining units. The Paleozoic limestones and dolomites, although structurally disrupted, are extensive over eastern Nevada and compose the 'regional carbonate aquifer' which is generally confined except in ranges where the carbonate rocks crop out. The tuffs and the alluvium commonly compose phreatic aquifers, but confined zones do occur at depth where these units are thick. In a drill hole near the potential repository site at Yucca Mountain, the hydraulic head in Paleozoic dolomite is 20 m higher than the head in overlying Miocene volcanic rocks. Thus, the potential for upward flow exists locally, and conceptually at least, downward flow from the volcanic aquifer into the carbonate aquifer could occur elsewhere.

In addition to conventional water quality and stable isotope analyses, strontium isotope ratios are being measured in ground waters of the Yucca Mountain region. The $^{87}Sr/^{86}Sr$ ratios are expressed as per mil deviation from the $^{87}Sr/^{86}Sr$ value for modern sea water:

$$\delta^{87}Sr = \{[(^{87}Sr/^{86}Sr)_{gw}/(^{87}Sr/^{86}Sr)_{sw}]-1\}\cdot 1000$$

where 'gw' is ground water and 'sw' is modern sea water.

In the Yucca Mountain region, ground-water flow is generally in a southerly direction. Two major flow systems, one in the carbonate sequence and one in the volcanic rocks, seemingly converge or overlap south of Yucca Mountain; it is uncertain what proportion of each discharges into Death Valley to the southwest. Flow in the Ash Meadows system, east and southeast of Yucca Mountain, is thought to be mainly within Paleozoic carbonate strata. The principal recharge occurs in structurally complex Paleozoic carbonate rocks of the high Spring Mountains (elevation up to 3,600 m). Springs in the carbonate terrane have $\delta^{87}Sr$ values between -1.1 and $+0.8$, which are consistent with those of the Paleozoic carbonates through which recharge is occurring (mean $\delta^{87}Sr$ of -1.06 ± 0.60). This large flow system discharges along a linear zone at Ash Meadows, southeast of Yucca Mountain, where springs accounting for 85 percent of the discharge have a mean $\delta^{87}Sr$ of $+4.65 \pm 0.19$. This increase in $\delta^{87}Sr$ over the values at recharge in the carbonates requires acquisition of radiogenic Sr along the flow path or additional recharge through radiogenic rocks. Springs at the southeastern end of the Ash Meadows discharge zone have even larger $\delta^{87}Sr$ values between $+11.0$ and $+13.9$. These ratios and extremely large $\delta^{87}Sr$ values of $+33.5$ to $+38.8$ for springs emerging from Upper Proterozoic clastic rocks upgradient in the northwestern Spring Mountains suggest substantially more flow through and interaction with the Upper Proterozoic section than conceptualized in earlier models.

The water table at Yucca Mountain is within silicic ash-flow tuffs at a depth of approximately 650 m at the potential repository site. Recharge occurs at higher elevations to the north where $\delta^{87}Sr$ values range from $+0.3$ to $+3.0$. $\delta^{87}Sr$ increases progressively southward with a local variability of about 3‰ at any particular latitude. Saline waters at Franklin Lake playa, a discharge site at the southern end of the system, show less variability with $\delta^{87}Sr$ values clustering between $+5.0$ and $+6.3$. Higher $\delta^{87}Sr$ values, up to $+10.7$, occur in ground water at the southwestern part of the system, in the Amargosa Desert along the northeastern side of the Funeral Mountains, where Upper Proterozoic clastic and carbonate rocks crop out. In Death Valley, along the southwestern side of the Funeral Mountains, springs that are presumed to represent discharge from the regional carbonate aquifer have $\delta^{87}Sr$ as large as $+13.8$. These similar $\delta^{87}Sr$ values on either side of the Funeral Mountains suggest the possibility that cross flow into the carbonate aquifer occurs from the upgradient volcanic and alluvial aquifer. Alternatively, the large $\delta^{87}Sr$ values of the Death Valley springs reflect flow through and interaction with the Upper Proterozoic clastic rocks in the Funeral Mountains.

Continued radiogenic isotopic studies integrated with other hydrochemical and hydrologic studies in the Yucca Mountain site characterization project will address (1) possible leakage between the two major aquifers, (2) the extent and path of ground-water flow through Upper Proterozoic rocks, (3) the source of ground water discharging into Death Valley, and (4) the identification of ground-water sources of paleospring deposits which now occur tens of metres above the water table.