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FINGERPRINTING OF GROUND WATER
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We have expanded our groundwater fingerprinting study of the south-central Nevada region by including more water samples from wells on the Nevada Test Site (NTS) and the region east and north of Yucca Mountain as well as from springs from the Spring Mountains, Pahrnagat Valley, and the base of the Shoshone Mountains on the NTS. These new samples include wells J-13, J-12, and ER-30 and Cane Spring from the NTS and Yucca Mountain region, Deer Creek Spring, Grapevine Spring, Willow Creek Spring, and Willow Spring from the Spring Mountains, Hiko, Crystal and Ash Springs from the Pahrnagat Valley, and Tippipah and Topopah Springs from the base of the Shoshone Mountains on the NTS. The geochemical analyses for these new samples were added to the analyses for the Ash Meadows springs, presented in earlier reports, in order to more thoroughly evaluate the regional groundwater chemistry and flow regime.

As before, these new samples were analyzed for the major solutes, field parameters, and the trace elements (see earlier reports). The new data were examined along with the previous Ash Meadows and Death Valley data by the multivariate statistical technique, principal component analysis (PCA). Moreover, a detailed analysis of the rare earth elements (REE) was also performed.

Figures 1 and 2 show the results of the PCA for the major solutes and trace elements, respectively, for the many different springs and wells included in the study. One of the most interesting and previously unrecognized observations that is clearly shown on Figure 2 for the trace elements is that many of the groundwater samples show close associations with each other, except for Tippipah and Topopah spring waters from the NTS. Both Tippipah and Topopah plot at a great distance from the bulk of the other samples on the PCA scatter plot (Fig. 2). (Groundwater samples that plot close to each other on the PCA plots exhibit some type of statistical association with each other, whereas those that plot far from each other are not statistically related.) We interpret the results of the PCA as indication that groundwaters from Tippipah and Topopah springs are closely associated with each other and are not related to the rest of the groundwater samples included in the PCA. Moreover, the PCA indicates that the other groundwater samples are all more closely related to each other than to Tippipah or Topopah Spring waters. This is surprising given the fact that these other samples include groundwaters that discharge from the regional Carbonate aquifer and waters believed to be representative of the tuffaceous aquifers/aquitards of the NTS whereas Tippipah and Topopah Spring waters issue from felsic volcanic rocks on the NTS.

Tippipah and Topopah Springs discharge at the base of the Shoshone Mountains which are composed of tuffaceous volcanic rocks similar to those in which wells J-13, J-12, and ER-30 are completed. Tippipah and Topopah Spring waters are thus believed to be representative of an end member and perched groundwater that has only interacted with these felsic volcanic rocks. This is supported by our REE analyses for the groundwaters shown in Fig. 3. The REE data for these two springs also indicates that these groundwaters have shale-normalized REE signatures that match the felsic volcanic rocks from which they discharge (Johannesson et al., in review). Conversely, groundwater from the Spring Mountains and Pahrnagat Valley, which have only interacted with rocks of the regional carbonate aquifer (Winograd and Thordarson, 1975) have much lower REE concentrations than Tippipah and Topopah Springs and exhibit normalized REE signatures that closely resemble seawater patterns (Johannesson et al., in review). These carbonate rocks were

deposited in a shallow marine setting and, consequently, may have inherited a seawater REE signature.

Other groundwaters, such as the Ash Meadows groundwaters, have REE concentrations similar to the carbonate groundwaters from the Spring Mountains and Pahranaagat Valley but exhibit overall flatter normalized REE patterns (Fig. 3). Ash Meadows groundwater is principally composed of a mixture of Spring Mountain and Pahranaagat Valley groundwaters with a small, additional component originating within the felsic volcanic rocks of the NTS (Winograd and Thordarson, 1975; Johannesson et al., in review). The most striking aspect of these data (and the PCA) is that other groundwaters from the NTS, namely samples from wells J-12, J-13, and ER-30, which are believed to be from felsic volcanic rocks similar to those from which Tippipah and Topopah Springs discharge, have REE concentrations and REE signatures more similar to the carbonate groundwaters than to either Tippipah or Topopah Springs groundwaters. Moreover, J-12, J-13, and ER-30 groundwaters exhibit closer associations with the carbonate waters (Fig. 2) in terms of the trace elements than with either Tippipah or Topopah Spring waters on the PCA diagram.

We interpret these results as evidence that some of the groundwaters from the NTS and Yucca Mountain region generally considered to be entirely from the felsic volcanic rock aquifer/aquitard, also have a significant carbonate aquifer signature. Consequently, these waters are more representative of groundwaters of mixed origins. Because the regional carbonate aquifer is overlain by these felsic volcanic rocks in the vicinity of the NTS (Winograd and Thordarson, 1975) we propose that some amount of upwelling of groundwaters from the underlying carbonate aquifer into the felsic volcanic rock aquifer/aquitard, and that mixes with the volcanic waters, must occur in the vicinity of wells J-12, J-13, and ER-30.

Further evaluation of the trace element PCA as well as the major cation PCA is necessary.

References

Johannesson, K. H., Stetzenbach, K. J., and Hodge, V. F. in review. Rare earth elements as geochemical tracers of regional groundwater flow. *Science*.

Winograd, I. J., and Thordarson, W. 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site. *U. S. Geol. Surv. Prof. Pap. 712-C*, 125 pp.

SCATTERPLOT (SMNTSAMC.STA)

MAJOR ELEMENTS

FIGURE 1

SCATTERPLOT (SMNTSAMT.STA)

TRACE ELEMENTS

FIGURE 2

FIGURE 3