

HYDROGEN AND OXYGEN ISOTOPE GEOCHEMISTRY OF COLD AND WARM  
SPRINGS FROM THE TUSCARORA, NEVADA THERMAL AREA

by

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## INTRODUCTION

The Tuscarora, Nevada Geothermal System has been an area of geological, geophysical and geochemical investigation in recent years for evaluation as a geothermal resource. Of prime importance in this evaluation is the characterization of thermal water chemistry, estimation of subsurface temperatures, definition of recharge areas for the thermal waters, and of the extent of rock-water interaction in the geothermal reservoir. A water sampling program was initiated by the authors in September, 1980 to collect cold springs and thermal waters to provide data for this geochemical analysis. Chemical analysis of dissolved cations and selected anions and oxygen and hydrogen isotope analyses were performed on the eleven cold springs and seven hot springs collected. The water chemistry results and estimates of water temperatures are reported elsewhere ( ). This report presents the results of the hydrogen and oxygen isotope analyses.

### Analytical Procedures

#### Extraction techniques

Water oxygen extraction. The  $^{18}\text{O}/^{16}\text{O}$  ratios of spring and thermal waters were determined by the  $\text{CO}_2$  equilibration technique (Epstein and Mayeda, 1953). The fractionation factor between  $\text{H}_2\text{O}$  and  $\text{CO}_2$  at  $25^\circ\text{C}$  was taken as 1.0412 (O'Neil et al., 1975).

Water hydrogen extraction. Hydrogen gas for D/H measurements was liberated from water samples by reduction over hot ( $800^\circ\text{C}$ ) uranium metal (Friedman, 1953).

## Mass spectrometry

Isotopic measurements for CO<sub>2</sub> gas and H<sub>2</sub> gas were made with Micromass 602 D mass spectrometers, which are double collector, 90° sector magnetic deflection instruments of 6 cm radius. The isotopic data for hydrogen and oxygen are reported relative to SMOW (Craig, 1961a) and for carbon relative to the Chicago PDB standard (Craig, 1957). Analytical error for carbon and oxygen isotope ratios is between 0.1 and 0.2 permil, while that for hydrogen is between 1 and 2 permil.

## Notation

All isotopic data are reported in the delta notation, where

$$\delta X_a = \frac{R_A - R_{std}}{R_{std}} \times 1000.$$

$\delta X$  represents the  $\delta D$  or  $\delta^{18}O$  value of sample A, and R is the D/H or  $^{18}O/^{16}O$  ratio of the sample or standard. For coexisting phases A and B,

$$10^3 \ln \alpha_{A-B} \cong \delta A - \delta B = \Delta A-B$$

where  $\alpha$  is the fractionation factor, defined as

$$\alpha_{A-B} = \frac{R_A}{R_B} = \frac{1000 + \delta X_A}{1000 + \delta X_B}.$$

## Cold Springs

The locations of the cold and hot springs collected are shown in Figure 1. The oxygen and hydrogen isotope results and spring temperatures are presented in Table 1. The isotope results are plotted on a  $\delta D$ - $\delta^{18}O$  diagram shown in Figure 2. In Figure 2, cold springs north of Hot Sulfur Springs (Samples 1A through 4A) are plotted as solid circles, cold springs northwest and southwest of Hot Sulphur Springs (5A through 6A) are plotted as open circles, hot springs south of Hot Sulfur Springs (7A through 7C) are plotted

as solid squares and hot springs from Hot Sulfur Springs are plotted as open squares (8A through 8D).

The cold springs can be divided into two distinct groups. The group of cold springs north of the Hot Sulfur Springs system plot, with two exceptions, close to the meteoric water line, with  $\delta D$  values ranging from -116 to -125 permil and  $\delta^{18}O$  values from -15.3 to -16.8 permil. Samples 3D and 4A have apparently experienced  $^{18}O$  enrichment of 0.5 and 1.3 permil, respectively. Sample 4A comes from a very low-volume seep, consistent with the possibility of evaporation. However the spring temperature is the coolest--8.0°C--of all cold springs sampled and is characterized by the lowest Cl,  $HCO_3$  and TDS contents of all springs sampled (Cole, 1981). Sample 3D is a sample of Hot Creek north of any known warm springs. This water is enriched in both D and  $^{18}O$  relative to spring waters that feed it (e.g., 3A and 3B). As the stream was of rather low rate of discharge at the time sampled, it is possible the enrichments in D and  $^{18}O$  are the result of kinetic evaporation effects.

The cold springs from the NW and SW of Hot Sulphur Springs constitute the second group. These waters have significantly lower  $\delta D$  values (-131 to -135 permil) and plot off the meteoric water line. All these samples (5A through 5C, 6A) have experienced  $^{18}O$  enrichments of at least 1.2 permil. These waters are significantly warmer (14.5 to 17.5°C) and contain generally higher TDS,  $SiO_2$ , Cl and  $SO_4^{=}$  contents. All these springs were low-discharge seeps with the exception of 6A (Pipe Springs), so the  $^{18}O$  enrichment and increased salinity may be in part the result once again of kinetic evaporative effects. However  $\delta D$ - $\delta^{18}O$  trends of low temperature (< 90°C) evaporation (Craig, 1961a) would result in intersection with the meteoric water line at  $\delta D$  values below (<-140 permil) those of any spring water measured by us in the

area or reported for this part of the Basin and Range province (Friedman, 1953; Taylor, 1974; Lawrence and Taylor, 1971). Alternatively, the deviation of these waters from the meteoric water line could result from either:

1. mixture of a small component of  $^{18}\text{O}$ -enriched thermal fluid
2.  $^{18}\text{O}$  enrichment resulting from low temperature water/rock interaction in the ground-water aquifer.

### Warm Springs

All seven warm spring samples plot to the right of the meteoric water line, with  $\delta\text{D}$  values of -128 to -137 permil and  $^{18}\text{O}$  enrichments of 1.3 to 4.3 permil. With the exception of sample 8B ( $\delta^{18}\text{O} = -14.0$  permil), warm springs from the Hot Sulphur Springs area (open squares) and those from the hot springs area to the south (solid squares) are indistinguishable with respect to both hydrogen and oxygen isotope composition.

There is considerable range in temperature of the warm springs from 55 to 95°C.  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values of both cold and hot springs are plotted versus spring temperature in Figure 3. The warm springs and the two groups of cold springs define distinct T -  $\delta\text{D}$  fields as expected. The hottest spring (8B) does have the highest  $\delta^{18}\text{O}$  value, perhaps reflecting more extensive interaction with the high  $\delta^{18}\text{O}$  carbonate rocks at depth. However there is no significant difference in either hydrogen or oxygen isotope composition between the two coolest warm springs (7C and 8C) and the hotter springs, with the exception of 8B.

The two cooler warm springs are not chemically distinct from the remaining warm springs either as shown in Figures 4 and 5. Figure 4 is a plot of  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values versus  $\text{SiO}_2$  content and Figure 5 is an analogous plot versus  $\text{HCO}_3^-$  content. The chemical data used in these two plots are from Cole

(1981). The thermal waters define fields in both figures distinct from the cold springs. However with the exception of the oxygen-isotope composition of sample 88, there are no significant isotopic or chemical differences between the two coolest warm springs and the remaining warm springs. Further there is no apparent correlation between isotope compositions, water chemistry and temperature in any of the figures that would indicate progressive dilution of thermal fluids by cool surface water or evaporation processes. All warm springs are characterized by chloride contents between 8 and 19 ppm, and no type of correlation with temperature,  $\delta D$  or  $\delta^{18}O$  values is observed. The low chloride contents of all warm springs indicate that these waters are not derived from deep high temperature saline brines of formation or connate origin unless they represent steam condensates. However the high pH and comparatively low  $SO_4^{=}$  contents argue against such an origin.

#### Recharge Area for the Thermal Fluids

As the local topographic slope in the area of Hot Sulphur Springs is north to south approximately, recharge areas for the Tuscarora geothermal system might be expected to lie to the north. However all the cold springs sampled north of Hot Sulphur Springs in the Hot Creek drainage and drainages to east (4A) have  $\delta D$  values (-125 permil or heavier) significantly greater than those of the warm springs (-128 to -137 permil). If the thermal waters are derived predominantly from these springs, they must represent steam condensates to explain their lighter  $\delta D$  values. The thermal waters do have low chloride contents characteristic of steam condensates, but the process is not consistent with observed  $SiO_2$  contents, pH values greater than 7.0 or comparatively low  $SO_4^{=}$  contents (Cole, 1981).

The cold springs west-northwest (5A to 5D) and south (6A) of the thermal

springs have  $\delta D$  values equivalent to those of the thermal waters, demonstrating that surface waters exist in the area with appropriate  $\delta D$  values to directly produce the thermal waters. Given the existence of these waters, plus the fact that the chemical characteristics of the thermal waters are not unique to steam condensates, we favor direct generation of the thermal fluids by heating of waters of the type observed discharging from the areas west and south of the Hot Sulphur Springs. Geophysical evidence ( ) does suggest underground water flow from south to north in the area. However further sampling in the areas south and west of the present hot springs area is needed to actually locate the recharge area. The isotope data do indicate that it is unlikely recharge for the geothermal system is to the immediate north of Hot Sulphur Springs.

#### Conclusions

Eighteen cold and warm spring water samples from the Tuscarora, Nevada KGRA have been analyzed for hydrogen and oxygen isotope composition. Cold springs in the area are not isotopically uniform and can be divided both isotopically and geographically into two groups. Cold springs to the north and east of Hot Sulphur Springs plot close (with one exception) to the meteoric water line and have significantly higher  $\delta D$  values than the warm springs. Cold springs to the west and south of the Hot Sulphur Springs are enriched in  $^{18}O$  relative to that expected for their hydrogen isotope compositions and have  $\delta D$  values (-131 to -135 permil) identical to those of the warm springs (-128 to -137 permil). Based on this similarity, the recharge area for the warm springs is unlikely to be to the immediate north and may be to the west and/or south, although further sampling should be done in these latter sectors.

The warm springs show no good correlations between either hydrogen or oxygen isotope composition and water temperature or chemistry, although the hottest spring (8B) has the gr<sup>e</sup>atest  $^{18}\text{O}$  shift. This spring may be the least diluted or have experienced the greatest interaction with the high  $^{-18}\text{O}$  carbonate rocks present in the subsurface in the area. The low  $\delta\text{D}$  and chloride values of the warm springs allow the possibility of some component of steam condensate in these waters, but other chemical characteristics of the hot waters do not support this possibility.



TABLE 1. Hydrogen and oxygen isotope compositions of cold and warm springs from the Tuscarora, Nevada KGRA.

Sample #	$\delta^{18}\text{O}$	$\delta\text{D}$	Spring Temperature ( $^{\circ}\text{C}$ )
Cold Springs			
1A	-16.3	-119	10.5
2A	-16.2, 16.1	-122	11.5
3A	-16.8	-125	15.0
3B	-16.7	-124	16.5
3C	-16.0	-116	10.0
3D	-15.5	-118	9.6
4A	-15.3, -15.2	-123	8.0
5A	-16.9	-135, -138	14.5
5B	-16.1	-131	18.5
5C	-16.7, -16.3	-135	18.5
6A	-16.6, -16.5	-134	20.0
Hot Springs			
7A	-16.1	-136, -138	89.0
7B	-15.6	-129	82.0
7C	-16.6	-133	55.5
8A	-16.1	-128	73.0
8B	-14.0	-137	95.0
8C	-15.7	-136	59.0
8D	-15.8	-135	85.0