



*Tuscarora*

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

by

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by

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# CONTENTS

	<u>Page</u>
ABSTRACT.....	1
INTRODUCTION.....	2
ANALYTICAL PROCEDURES.....	2
Sampling Procedures.....	2
Extraction Techniques.....	2
Water oxygen extraction.....	2
Water hydrogen extraction.....	3
Mass Spectrometry.....	3
Notation.....	3
COLD SPRINGS.....	3
WARM SPRINGS.....	6
RECHARGE AREA FOR THE THERMAL FLUIDS.....	7
CONCLUSIONS.....	9
ACKNOWLEDGEMENTS.....	10
REFERENCES.....	11
APPENDIX A.....	13
FIGURES.....	14
Table 1 Hydrogen and oxygen isotope compositions of cold and warm springs from the Tuscarora, Nevada KGRA.....	5

## ABSTRACT

Eighteen cold and warm spring water samples from the Tuscarora, Nevada KGRA have been analyzed for hydrogen and oxygen isotope composition and fluid chemistry. Warm springs have  $\delta D$  values (-128 to -137 permil) significantly lower than those of cold springs to the north and east of the area, but similar to the  $\delta D$  values of cold springs to the west and south (-131 to -135 permil). The recharge area for the warm springs is unlikely to be to the immediate north, which is the local topographic highland in the area. The hydrogen isotope data would permit recharge from areas to the southwest or from high elevations to the southeast (Independence Mountains), a sector consistent with electrical resistivity evidence of fluid flow.

Warm springs are  $HCO_3^-$ -rich waters, enriched by a factor of 3 to 10 in Na,  $HCO_3^-$  and  $SiO_2$  relative to local cold springs. Average quartz (no steam loss) and Na/K/Ca geothermometer estimates suggest subsurface temperatures of 145° and 196°C, respectively. The warm springs exhibit poor correlations between either hydrogen or oxygen isotope composition and water temperature or chemistry. The absence of such correlations suggests that there is no single coherent pattern of cold water mixing or evaporation in the thermal spring system.

## 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 are the characterization of thermal water chemistry, estimation of subsurface temperatures, definition of recharge areas for the thermal waters, and 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 analyses 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 subsurface water temperatures are reported in Appendix A. This report focuses on the results of the hydrogen and oxygen isotope analyses.

## ANALYTICAL PROCEDURES

### Sampling Procedures

Water samples for hydrogen and oxygen isotope analysis were collected as recommended by Nehring and Truesdell (1977). Water samples for analysis of dissolved constituents were collected as recommended by Presser and Barnes (1974) and Truesdell and Hulston (1980).

### 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°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. Figure 2 shows the locations of the hot springs in more detail based on the geologic base map of Sibbett (1982). 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 3. In Figure 3, cold springs north of Hot Sulfur Springs (Samples 1A through 4A) are plotted as solid circles, cold springs northwest and southwest of Hot Sulfur Springs (5A through 6A) are plotted as open circles, hot springs of Hot Sulfur Springs (7A through 7C) are plotted as solid squares and hot springs north of 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, with two exceptions, plot 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,  $-8.0^{\circ}C$ -, and is characterized by the lowest Cl,  $HCO_3^-$  and TDS contents of all springs sampled (Appendix A). 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 at a rather low rate of discharge at the time sampled, possibly the enrichments in D and  $^{18}O$  are the result of kinetic evaporation effects (Craig et al., 1963).

The cold springs from the northwest and southwest of Hot Sulfur 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  $18.5^{\circ}C$ ) and contain generally higher TDS,  $SiO_2$ , Cl and  $SO_4^-$  contents (Appendix A). All these springs were



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

Sample #	$\delta^{18}O$	$\delta D$	Spring Temperature (°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	85.00

low-discharge seeps with the exception of 6A (Pipe Springs), so the  $^{18}\text{O}$  enrichment and increased salinity may be in part the result once again of kinetic evaporative effects. However  $\delta\text{D}-\delta^{18}\text{O}$  trends of low temperature ( $< 90^\circ\text{C}$ ) evaporation (Craig, 1961b; Craig et al., 1963) would result in intersection with the meteoric water line at  $\delta\text{D}$  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 Sulfur Springs area (solid squares) and those from the hot springs area to the north (open squares) are indistinguishable with respect to both hydrogen and oxygen isotope composition.

There is a considerable range in temperature of the warm springs from  $55$  to  $95^\circ\text{C}$ .  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values of both cold and hot springs are plotted versus spring temperature in Figure 4. 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 present at depths greater than about  $4500$  feet (Sibbett, 1982). 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. Neither are the two cooler warm springs chemically distinct from the remaining warm springs, as shown in Figures 5 and 6. Figure 5 is a plot of  $\delta D$  and  $\delta^{18}O$  values versus  $SiO_2$  content and Figure 6 is an analogous plot versus  $HCO_3^-$  content. The chemical data used in these two plots are in Appendix A. The thermal waters define fields in both figures distinct from the cold springs. However with the exception of the oxygen-isotope composition of sample 8B, 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 Sulfur 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 Sulfur Springs in the Hot Creek drainage and drainages to the northeast (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 (Appendix A).

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. Alternatively, these cooler, low  $\delta D$  fluids may represent the conductively cooled equivalents of thermal fluids that have leaked south and west-northwestward along faults.

Geophysical evidence from a resistivity survey (Mackelprang, 1982) does suggest fluid flow from southeast to northwest in the area. A 2 ohm-meter zone is thought to indicate thermal fluids issuing from aquifers within Tertiary tuffaceous sediments and Paleozoic quartzites, cherts and carbonates at depths in excess of 4000'. The fluids rise to the surface via fracture zones to the Hot Creek and Hot Sulfur Springs area where they exit as hot springs. The presence of a low-resistivity area at the surface northwest of these hot springs indicates that leakage of thermal fluids persists beyond the major existing zones along Hot Creek and Hot Sulfur Creek. These near-surface fluids appear to have cooled approximately 50°C or more but have retained their low  $\delta D$  isotopic signature. Further sampling in the areas southeast and west of the present hot springs area is needed to actually locate the recharge area. The isotope data do indicate that recharge for the geothermal system is unlikely to the immediate north of Hot Sulfur 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 Sulfur 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 Sulfur 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 or in high elevations to the east-southeast, although further sampling should be done in these latter sectors.

The warm springs exhibit poor correlations between either hydrogen or oxygen isotope composition and water temperature or chemistry, although the hottest spring (8B) has the greatest  $^{18}O$  shift. This spring may be the least diluted or have experienced the greatest interaction with the high  $^{-18}O$  carbonate rocks present in the subsurface in the area. The low  $\delta D$  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.

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Appendix A. Summary of chemical compositions and geothermometer temperatures for cold and thermal springs at Tuscarora, Nevada. (a)

	1A	2A	3A	3B	3C	3D	4A	5A	5B	5C	6A
T°C	10.5	11.5	15	16.5	10	9.6	8	14.5	17.5	18.5	21
pH(20°C)	6.1	6.2	6.4	6.2	6.5	6.7	6.4	7.5	7.2	7.0	7.5
Na	7	6	10	7	10	12	4	14	11	19	80
K	3	4	< 2.5	4	4	4	< 2.5	6	< 2.5	7	5
Ca	5	4	6	4	5	8	2	6	14	11	11
Mg	2	1	2	2	2	2	1	2	1	2	3
Fe	0.04	0.13	0.32	0.07	< 0.025	0.04	0.04	< 0.025	< 0.025	0.11	< 0.025
Sr	0.06	0.07	0.06	0.05	0.05	0.08	0.10	0.05	0.19	0.03	0.13
Li	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	< 0.125	0.2
SiO <sub>2</sub>	43	48	40	43	50	41	17	61	25	60	52
SO <sub>4</sub>	5	4	6	4	7	5	2	7	17	< 2	17
Cl	6	4	5	4	5	5	6	7	6	9	13
F	0.2	0.2	0.1	0.2	0.2	0.2	< 0.1	0.2	0.2	0.2	1.6
HCO <sub>3</sub>	33	47	47	54	54	75	22	65	74	77	232
Geothermometers (b)											
Qtz adia.	97	101	94	97	103	95	64	111	77	110	104
Qtz Cond.	95	100	92	95	102	93	57	111	72	111	104
Chalcedony	64	70	61	64	72	62	25	82	40	81	74
α-Crist	45	50	42	45	51	43	9	61	23	60	53
Na/K-A	334	460	311	432	374	348	448	384	299	362	180
Na/K-B	425	554	313	425	408	368	533	425	297	390	142
NaKCa	61	73	56	75	74	66	69	87	41	82	87
NaKCaMg	---	---	---	62	64	---	---	77	---	---	77
NaKCaCO <sub>2</sub>	8	15	5	14	18	22	18	41	2	32	32

	7A	7B	7C	8A	8B	8C	8D	DH 66-5
T°C	89	82	55.5	73	95	59	85	110
pH(20°C)	6.9	7.2	6.9	7.6	7.4	8.0	7.7	8.4
Na	151	152	169	145	148	140	139	163
K	15	15	11	19	20	20	18	25
Ca	10	11	19	17	1	3	8	14
Mg	< 0.5	< 0.5	3	2	< 0.5	< 0.5	< 0.5	2
Fe	< 0.025	0.05	0.09	< 0.025	0.04	0.04	0.05	0.06
Sr	0.61	0.70	0.39	0.59	0.25	0.05	0.34	1.01
Li	0.71	0.77	0.49	0.64	0.64	0.56	0.62	0.7
B	0.8	0.8	0.9	0.9	0.90	0.9	0.9	0.8
SiO <sub>2</sub>	129	126	122	103	104	136	99	109
SO <sub>4</sub>	52	65	34	50	55	45	48	47
Cl	18	18	19	16	6	14	7	26
F	11	11	8.9	8.7	8.2	9	7	8
HCO <sub>3</sub>	352	365	484	382	345	291	355	397
Geothermometers								
Qtz adia.	145	144	142	134	135	148	132	137
Qtz. cond.	152	150	149	139	139	155	137	142
Chalcedony	127	125	123	112	113	131	110	116
α-Crist	101	100	98	88	89	105	86	91
Na/K-A	216	216	183	241	244	250	240	257
Na/K-B	187	186	145	219	222	229	217	239
NaKCa	184	183	159	194	225	216	200	208
NaKCaMg	---	---	108	144	187	186	175	158
NaKCaCO <sub>2</sub>	74	80	61	97	107	125	99	118

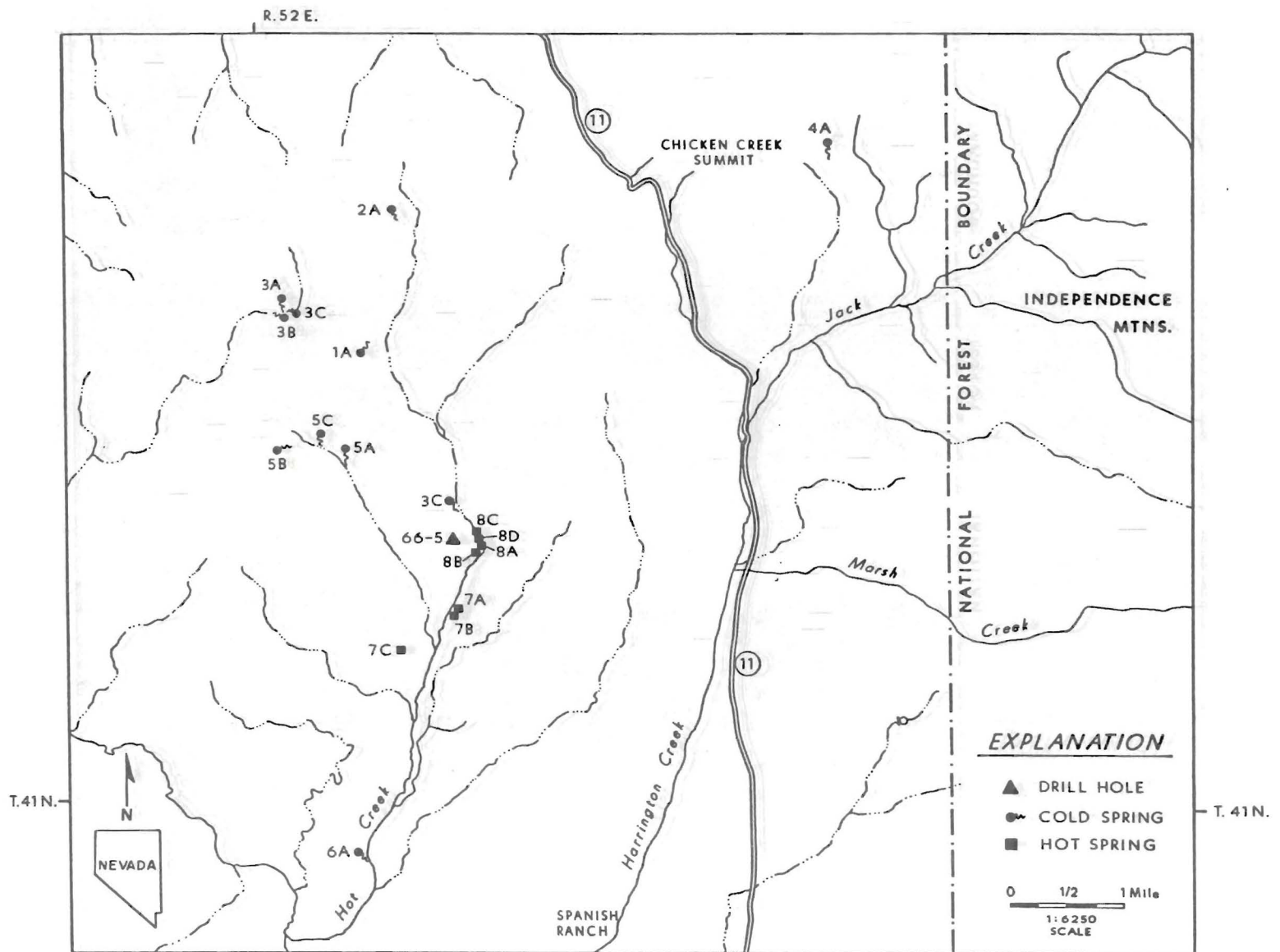
Notes:

- (a) Concentrations in ppm  
 (b) Geothermometer temperatures (°C) were calculated from equations given in Fournier (1981),  
 Qtz adia = Quartz adiabatic geothermometer, Qtz cond = Quartz conductive geothermometer, Na/K-A is from Fournier's equation, Na/K-B is based on Truesdell's equation (see Fournier, 1981).

## Figure Captions

- Figure 1. Location map of cold (solid circles) and hot (solid squares) springs sampled in the Tuscarora, Nevada geothermal area.
- Figure 2. Detailed location map of the hot springs in the Tuscarora geothermal area, based on the geologic map of Sibbett (1982).
- Figure 3. Plot of the  $\delta D$  and  $\delta^{18}O$  values of cold and warm springs water samples from the Tuscarora, Nevada area. The cold springs to the north and east of the Hot Sulfur Springs are plotted as solid circles and those to the northwest and southwest are plotted as open circles. The three samples from Hot Sulfur Springs are plotted as solid squares and the four remaining warm springs are the open squares. The meteoric water line (MW) is included for reference (Craig, 1961b).
- Figure 4. Plot of the  $\delta D$  and  $\delta^{18}O$  values of the spring water samples versus spring temperature. Symbols as in Figure 3.
- Figure 5. Plot of the  $\delta D$  and  $\delta^{18}O$  values versus  $SiO_2$  contents for the spring water samples. Symbols as in Figure 3.
- Figure 6. Plot of the  $\delta D$  and  $\delta^{18}O$  values versus  $HCO_3^-$  contents for the spring water samples. Symbols as in Figure 3.

Figure 1



# EXPLANATION

- QUATERNARY**
- Qss** Siliceous sinter.
  - Qal** Alluvium and talus, recent deposits.
  - Qls** Landslides
  - Qoa** Older Alluvium, currently being eroded but conformable with present geomorphic surface.
  - Qg** Gravel, quartzite boulders, glacial outwash, not graded to present drainage, deformed.
  - Qt** Glacial till deposits.
  - QTg** Gravel, quartzite pebbles to boulders.
- TERTIARY**
- Taf** Porphyritic andesite lava flows with 5-10%, 2-5mm phenocrysts of andesine and augite in a vitric matrix. Overlies Tvt and Tvi.
  - Tvt** Weakly welded ash-flow tuff, 7% 1-3mm sanidine crystals in black vitric matrix.
  - Tvi** Porphyritic quartz latite and dacite lava flows, 20% 2-6mm phenocrysts of K feldspar, andesine, quartz and augite in a red to black felsitic matrix.
- MIOCENE**
- Tia** Porphyritic basaltic-andesite intrusions, 15-25%, 3mm phenocrysts of plagioclase, augite and biotite in a felsitic matrix.
- OLIGOCENE**
- Tal** Porphyritic andesite and basaltic-andesite lava flows, 10-30%, 2-4mm phenocrysts in an olive-gray to black matrix.
  - Tts** Tuffaceous sediments, non-resistant waterlaid tuffs, tuffaceous sands, volcanoclastic conglomerate lenses and interbedded 3 to 6m thick, non-welded tuffs.
  - Ttb** Tuff breccia, heterogeneous vent facies deposit of pyroclastic breccia, lapillistone and ash-flow tuffs. Contains pebble to block-size xenoliths of Paleozoic rocks.
- MISSISSIPPIAN TO PERMIAN**
- Ms** Schoonover Formation (Fagan, 1962).
- PALEOZOIC UNDIFFERENTIATED**
- Pu** Argillite, quartzite, chert and greenstone.
- Contact, dashed where inferred or approximate.
- - - Fault, dashed where inferred, dotted where covered.
- Thrust fault, dashed where inferred.
- 7C ● Spring Sample location



Figure 2

Geology by Sibbett (1982)

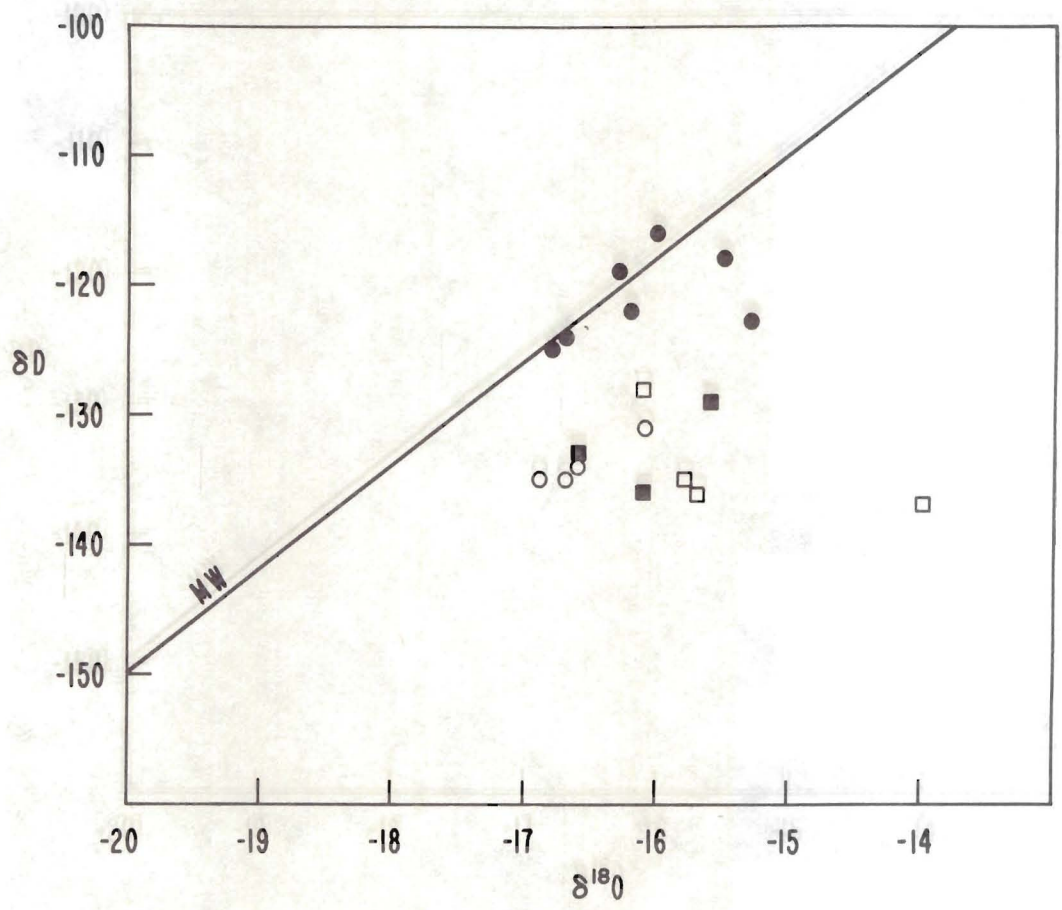


Figure 3

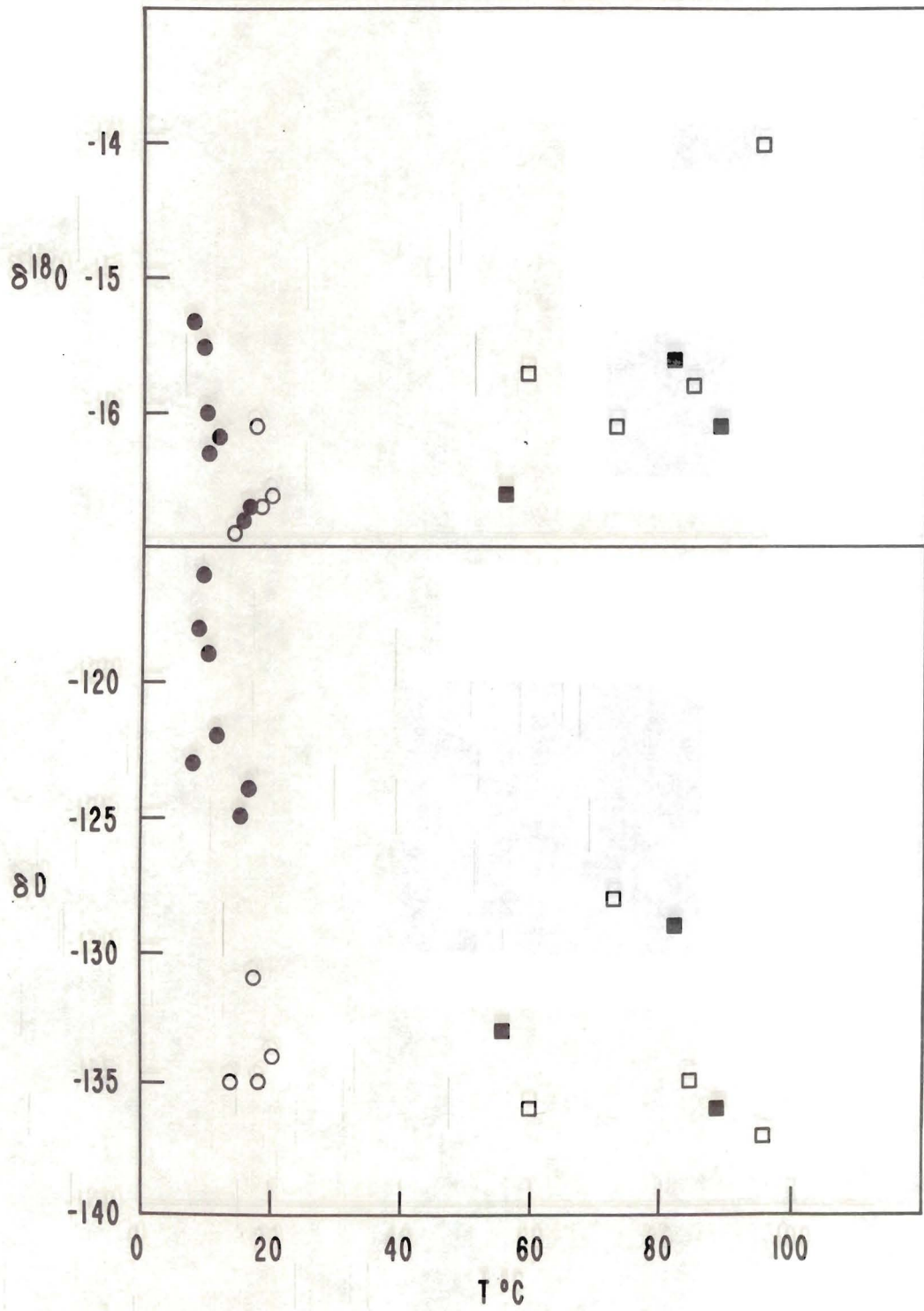


Figure 4

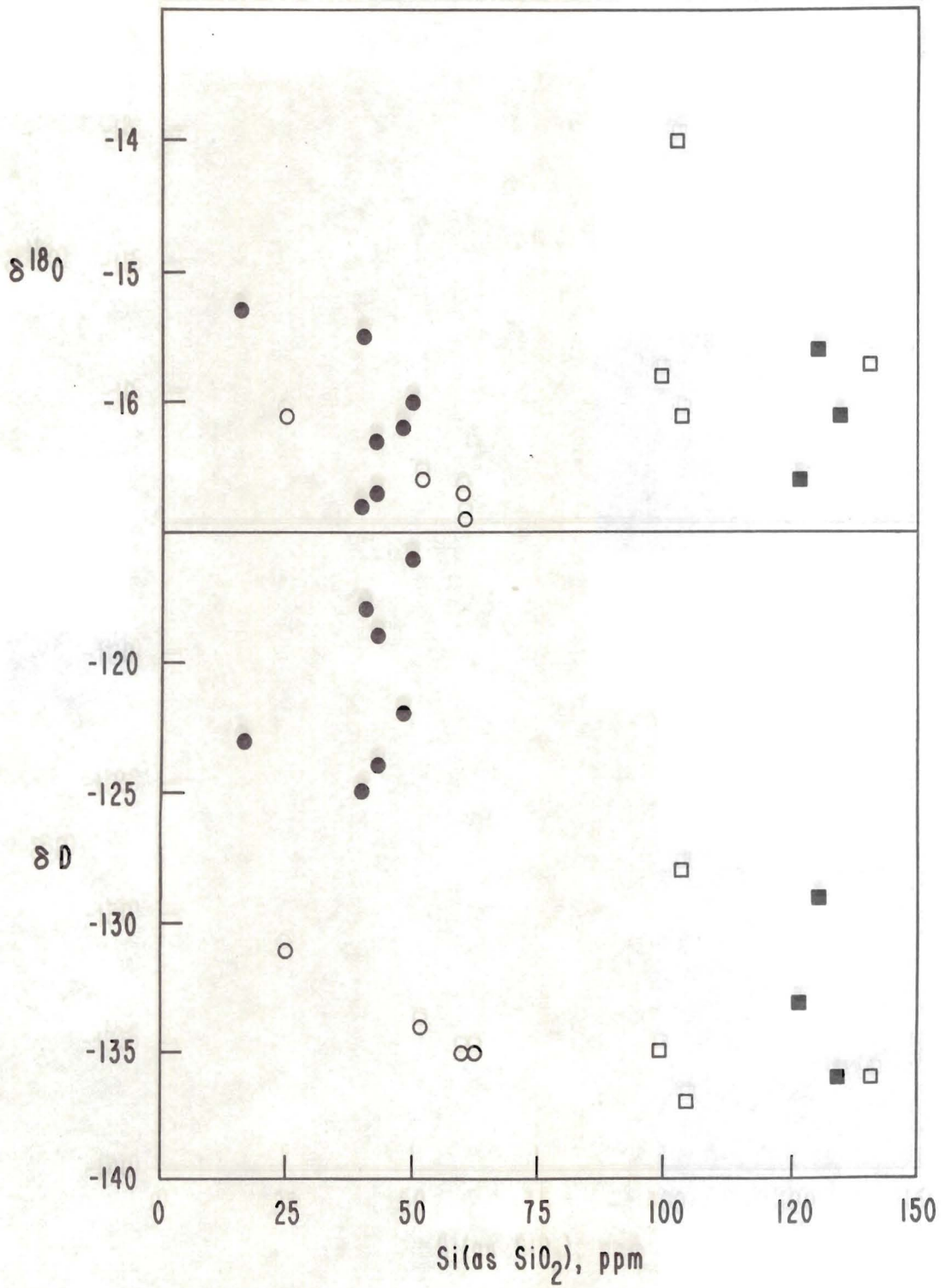


Figure 5

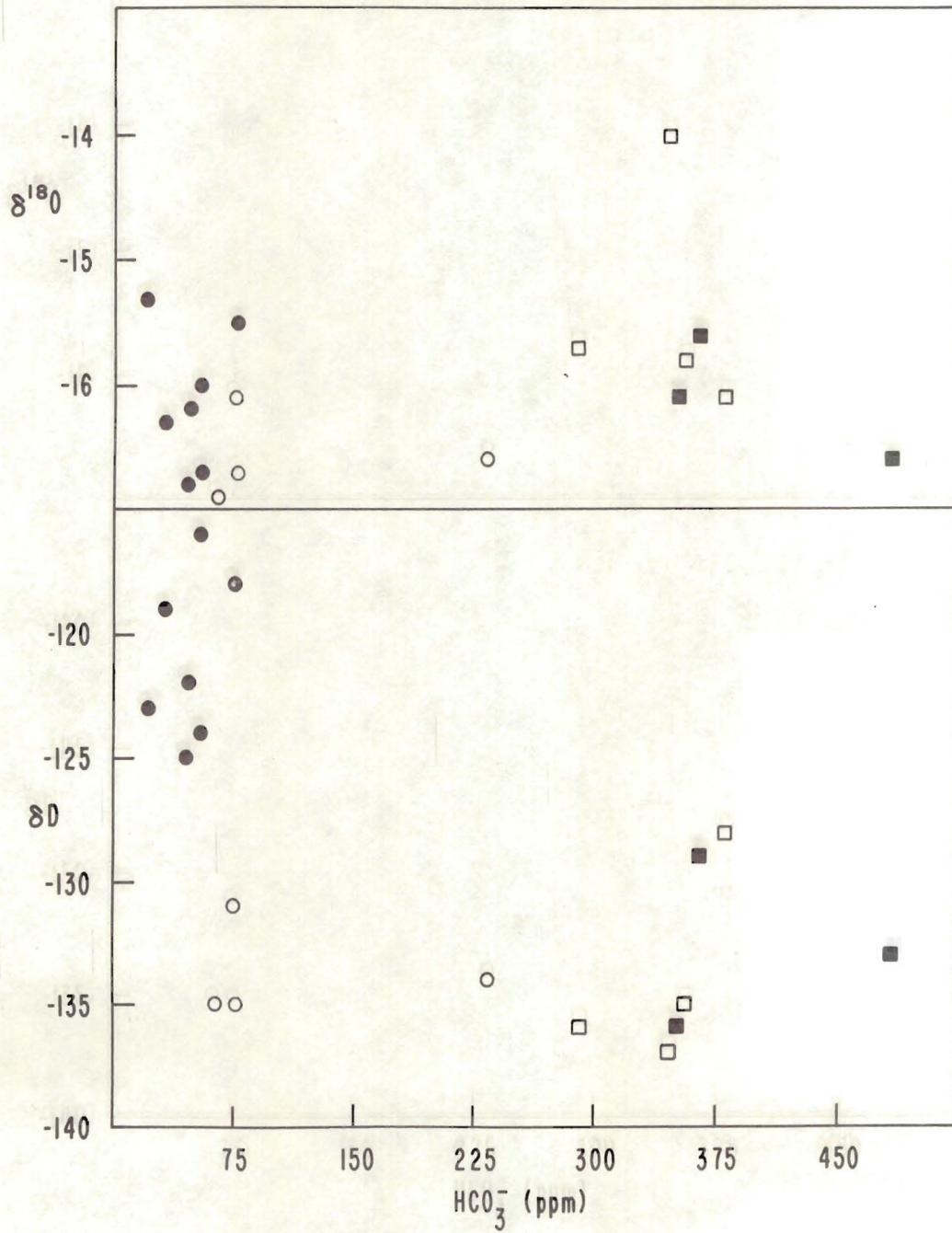


Figure 6