Southland Royalty Company

December 29, 1980

Mr. Joe Fiore
Department of Energy
Nevada Operations Office
P.O. Box 14100
Las Vegas, Nevada 89114

RE: Contract DE-AC08-79ET27006

Dear Mr. Fiore:

I am enclosing for your review the isotope report from the Desert Research Institute. This report is appendix F-4 of the final report on contract DE-AC08-79ET27006. A location map was also received from the Desert Research Institute. Due to the time limitation, I have not included this map. However, it will be included in the final report. Should you have a need for this map during your review, please contact me and a copy will be forwarded.

Sincerely yours,

Dana C. Sanford

Dana C. Sanford
Secretary to Jere Denton
Natural Resources District

/dcs

Enclosure

✓cc: Howard P. Ross

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APPENDIX F-4

H.0 ENVIRONMENTAL ISOTOPE HYDROLOGY OF THE DIXIE VALLEY GEOTHERMAL SYSTEM

H.1 Introduction

H.1.1 Purpose and Scope

The purpose of this portion of the study is to use inferences from the distribution of naturally-occurring isotopes in the waters of the study area to provide insight into the Dixie Valley geothermal system and input to the formulation of a conceptual model of the Dixie Valley hydrothermal system. The isotope distributions and their interpretations can provide information on recharge to the system and can supplement the information derived from the hydrogeochemistry, which was discussed in an earlier report. Most of the emphasis was placed upon the collection and interpretation of the stable isotopes ^{2}H (deuterium or D) and ^{18}O. These isotopes are useful in delineating recharge areas and functioning as fluid flow tracers. The radioactive isotope ^{3}H (tritium) was also utilized to a minor extent. At the inception of the study, it was anticipated that the radioactive isotope ^{14}C would be utilized as well; this environmental isotope would have been used to date the waters from the various parts of the study area. The spatial distribution of fluid ^{14}C dates could then be used to estimate fluid residence times and reservoir volume. However, delays in receiving stable isotope results precluded the collection of ^{14}C data, since the stable isotope information is essential to the proper application of ^{14}C techniques and interpretation of the ^{14}C data.

The study area encompassed the same region as the hydrogeochemical investigations. Most of the work focused on the area of greatest interest to the Southland Royalty Company: the northern half of Dixie Valley (between Dixie Meadows and Sou Hot Springs). Emphasis was placed on the western half of this particular area, i.e., in the vicinity of the Stillwater Range. However, sampling outside this specific area was performed.

H.1.2. Methods and Analytical Techniques

Approximately 100 samples of thermal and non-thermal waters were collected for stable isotope analyses from the study area. In addition, 27 samples were collected for ^{3}H analyses. All isotope samples were collected in 125 ml glass bottles with Teflon-lined plastic caps. The bottles were completely filled and capped underwater (where possible) to insure that no air bubbles would be entrapped. The bottles were then sealed with Parafilm and plastic tape.

Both enriched and unenriched ^3H analyses were performed at the Water Resources Center of the Desert Research Institute. Liquid scintillation was used to measure ^3H activity; selected samples were electrolytically enriched before analysis. The stable isotope (D and ^{18}O) samples were analyzed by the Laboratory of Isotope Geochemistry at the University of Arizona. Mass spectroscopy was used for the analyses.

It should be noted that isotope samples were collected from the same locations (with a few exceptions) as the chemical samples and are labeled accordingly. However, because of cost, not all the collected isotope samples were analyzed. Plate H-1 shows the locations of all chemical and isotope samples collected from the study area.

H.1.3. Previous Work

Very little previous work on the hydrology of Dixie Valley exists. A paper by Zones (1957) describes some of the hydrologic effects of the 1954 Dixie Valley earthquake. He noted that wells in the valley showed temporary increases in artesian heads and flow rates which he attributed to a westward tilting of the confined and semi-confined aquifers penetrated by the wells, a reduction in the porosity of the unconsolidated sediments caused by rearrangement of the grains during the earthquake, and local fracturing of the alluvium which may have increased the upward flow of groundwater from depth. Zones did not observe a rise in water temperatures, so he concluded that if water did move from depth along new fracture zones, it did not come from a great depth. He also noted a temporary increase in the flow rate of Mud Springs in T20N, R34E, Section 5. This was attributed to new movement on the fault zone along which water had been rising. This movement opened fractures which permitted more water to move upward and/or lowered the land surface at the spring areas, which produced a temporary increase in artesian head at the spring orifices. Discharge at Dixie Hot Springs did not appear to be affected by the earthquake; the temperature at one of the orifices was the same (59.4°C) both before and after the earthquake.

A reconnaissance report by Cohen and Everett (1963) provides an overview of the groundwater hydrology of Dixie and Fairview Valleys. Their report described a seven-valley hydrologic system (Dixie, Fairview, Pleasant, Jersey, Eastgate, Cowkick and Stingaree Valleys) that forms a closed hydrologic unit. Dixie Valley is the major groundwater sink for the system; it receives underflow from the other six valleys in the system. The Cohen and Everett report provides information on groundwater chemistry, well yields and inventories, recharge, discharge, aquifer storage and transmissive properties and related data. The report does not purport to be a detailed description of the groundwater hydrology of Dixie Valley and environs.

Additional work of a limited nature was conducted by Mariner, Rapp, Willey and Presser (1974) and Mariner, Presser, Rapp and Willey (1975) who collected chemical, gas and stable isotope data from Dixie Hot Springs, Sou Hot Springs and a few other locations in the study area. No interpretations of the data are given in their reports. Studies were also conducted by GeothermEx, Inc. (1976) and by Keplinger and Associates (1977; 1978). A substantial amount of geochemical sampling, analyses and interpretation were conducted in northern Dixie Valley as part of a multidisciplinary study by the Mackay Minerals Research Institute (1980); the work described herein was performed as part of this investigation.

H.1.4. Hydrologic Framework

The following discussion is a brief description of the groundwater hydrology of Dixie Valley, which will be useful in understanding the interpretations of and inferences from the isotope data. Most of the information can be found in Cohen and Everett (1963).

Insofar as groundwater hydrology is concerned, Dixie Valley is one of seven valleys forming a single closed hydrologic unit. Dixie Valley is topographically the lowest of these valleys; indeed, it contains the lowest point in northern Nevada. The valley is the major groundwater sink for the seven-valley system; it is believed to receive underflow either directly or indirectly from the other six valleys. The groundwater flow into Dixie Valley is southward from Jersey and Pleasant Valleys; westward from Eastgate, Cowkick and Stingaree Valleys into Dixie Valley and then northward to the Humboldt Salt Marsh; and northward from Fairview Valley. In Dixie Valley itself, groundwater moves radially from the valley margins toward the Humboldt Salt Marsh.

Groundwater occurs under confined (artesian), semi-confined and unconfined (water-table) conditions in the unconsolidated sediments comprising the valley fill. The largest area of artesian conditions lies just south of the Humboldt Salt Marsh in the major groundwater discharge area. Semi-confined groundwater occurs in scattered areas throughout the valley. Most of the groundwater occurs in and moves through the interstices of the valley-fill sediments. However, a certain amount undoubtedly occurs as fracture-flow in the consolidated rocks. It is believed that the underflow from Pleasant Valley occurs in this manner. This type of flow is more important with respect to the geothermal reservoir than it is to the shallow groundwater reservoir.

Average annual precipitation in Dixie Valley is estimated to be about 456,000 acre-feet. Of this amount, 6,000 acre-feet is believed to reach the groundwater reservoir as recharge. Most of this recharge is believed to originate as precipitation in the mountainous regions: the Stillwater Range and Clan Alpine Mountains. Some of the mountainous regions receive more than 20 inches of precipitation annually, as compared to about 5 inches on the valley floor. In addition, the valley is believed to receive approximately 7,000 acre-feet of recharge annually as subsurface flow from the six surrounding valleys. Average annual natural discharge by evapotranspiration in Dixie Valley is approximately 16,200 acre-feet. The major discharge area is the Humboldt Salt Marsh, where groundwater is discharged by transpiration and direct evaporation from the water table. It should be noted that these recharge and discharge estimates from Cohen and Everett (1963) result in an average annual discrepancy of 3,200 acre-feet between discharge (16,200 acre-feet) and total recharge (13,000 acre-feet). This discrepancy results from the limited data and the uncertainties inherent in the methods used to estimate natural groundwater discharge and recharge. Since recharge is less than discharge, Dixie Valley which theoretically was in a state of equilibrium at the time of the Cohen and Everett report, could be receiving more recharge via precipitation and/or subsurface inflow from the surrounding valleys. However, it is difficult to draw any substantive conclusions since neither the recharge nor the discharge figure is particularly accurate.

Springs are numerous in the valley; most of them discharge thermal water. In terms of this study, the most important springs are the three major hot spring systems: Dixie Hot Springs, Hyder Hot Springs and Sou Hot Springs. The Dixie Hot Springs system is comprised of about 35 springs and seeps, which emerge from alluvium over an area of about four square miles. The Hyder Hot Springs system emerges in the middle of the valley where the bedrock is apparently covered by thick alluvium. Travertine deposits up to 100 feet thick have been deposited here. The Sou Hot Springs system is found at the northern end of the study area, in a region characterized primarily by bedrock with hot spring deposits.

H.2 Analytical Results

H.2.1 Isotopic Characteristics of Dixie Valley and Surrounding Waters

Table H-1 lists the isotopic (^{2}H or D, ^{18}O and ^{3}H) characteristics of Dixie Valley and surrounding waters. The data for D and ^{18}O are reported as per mil (parts per thousand) variations from Standard Mean Ocean Water (SMOW). The analytical precision is $\pm$ 0.2°/oo for $\delta^{18}O$ and $\pm$ 3°/oo for δD. Tritium data are reported in tritium units (TU); one TU equals one atom of ^{3}H per 10^{18} atoms of ^{1}H.

The geographical distribution of samples can be ascertained by referring to Plate H-1. This plate covers only the area of greatest interest to the Southland Royalty Company. Sample locations not shown on Plate H-1 are listed in Table H-2.

Throughout the rest of this report, references will be made to the hydrogeochemistry of the area. The hydrogeochemical study was

Table H-1. Isotopic Analyses of Dixie Valley and Surrounding Waters.

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
		Intermediate temperature springs in the vicinity of McCoy Ranch				
M	DV5	3-20-79	39.0	-131	-15.8	<10
M	DV6	3-20-79	29.0	-135	-14.6	<100
M	DV7	3-20-79	--	-130	-15.8	<100
M	DV8	3-20-79	--	-134	-15.6	<100
M	DV9	3-20-79	--	-131	-15.2	<100
M	DV11	3-20-79	43.0	-124	-15.4	<100
M	DV116	3-20-79	40.0	-132/-136	-15.7	--
		Exploration well DF45-14				
1	DV69	7-9-79	68.5	-109	-10.5/-10.6	--
1	DV70	7-9-79	75.5	-117	-12.6	--
1	DV71	7-9-79	82.0	-113	-12.8	--
1	DV72A	7-9-79	76.5	-109	-12.6	--
1	DV72B	7-9-79	76.5	-119	-12.6	--
3	DV90	9-12-79	94.0	-114/-117	-14.4	<10
1	DV126	12-5-79	86.5	-121/-118	-14.6	<5
1	DV128	3-15-80	48.0	-119	-14.8	--
		Exploration well DF66-21 and thermal well SR2-A (DV30)				
2	DV81	8-14-79	51.0	-124	-12.6/-12.5	<100
2	DV82	8-14-79	86.0	-126	-12.7	--
2	DV93	9-14-79	83.0	-101	-11.7	--
4	DV94	9-15-79	--	--	--	<10
2	DV125	12-5-79	32.5	-120	-13.9	<5
T	DV30	5-15-79	64.5	-123	-14.3/14.8	--
		Dixie Hot Springs				
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
D	DV23	3-20-79	73.0	-120	-15.3	<10
D	DV24	3-20-79	55.0	-126	-15.3	--
D	DH6	7-23-79	73.0	-125	-15.4	--
D	DH9	7-23-79	73.0	-134	-15.8	--
D	DH15	7-23-79	52.0	-133	-15.8/-15.5	--
D	DH16	7-23-79	26.0	-129	-15.4	--
D	DHS17	7-23-79	20.0	-121	-15.8	--

Table H-1 (con't.)

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
Sou Hot Springs						
S	DV1	3-20-79	55.0	-131	-15.0	300
S	DV2	3-20-79	51.0	-137	-14.7	<100
S	DV35	5-15-79	53.5	-127	-15.3	--
S	DV36	5-15-79	73.0	-123	-15.3	--
Hyder Hot Springs						
H	DV4	3-20-79	63.0	-132	-15.0	<10
H	DV33	5-15-79	65.5	-135	-15.0	--
H	HHS1	7-23-79	75.0	-130	-15.8	--
Artesian wells in the vicinity of Dixie Settlement						
A	DV13	3-20-79	19.0	-134	-16.0	<10
A	DV14	3-20-79	19.0	-133	-16.5	<100
A	DV43	5-15-79	18.3	-127	-16.3	--
A	DV44	5-15-79	18.3	-126	-16.4	--
A	DV65	6-20-79	20.0	-130	-16.7/-16.8	--
Irrigation wells in the northern part of Dixie Valley						
I	DV34	5-15-79	19.5	-122	-15.3	--
I	DV37	5-15-79	16.0	-112/-119	-15.4	--
I	DV38	5-15-79	18.5	-125/-130	-16.0	--
I	DV39	5-15-79	22.5	-125	-16.4	--
I	DV40	5-15-79	15.5	-115	-15.7	--
I	DV100	6-25-79	19.0	-126	-15.4	--
Springs/streams from the eastern slopes of the Stillwater Range						
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
W	DV21	3-20-79	13.0	-117	-14.0	<100
W	DV22	3-20-79	11.0	-112/-115	-15.0	<100
W	DV45	5-15-79	14.0	-116	-14.7	--
W	DV46	5-15-79	15.75	-114	-14.2	--
W	DV47	5-15-79	18.0	-108	-14.0	--
W	DV48	5-15-79	13.5	-107	-14.3	--
W	DV49	5-15-79	15.75	-107	-14.1	--
W	DV53	6-25-79	18.0	-124	-14.1	--
W	DV67	6-25-79	16.0	-114	-14.0/-14.6	--
W	DV78	7-23-79	22.0	-125	-14.0	--
W	DV92	9-12-79	43.0	- 98	-12.0	--
W	DV102	6-25-79	14.0	-115	-13.5	--
W	DV103	6-25-79	14.0	-121	-14.5	--
W	DV110	6-25-79	15.5	-129	-14.9	--

Table H-1 (con't.)

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
Spring/stream from the western slopes of the Stillwater Range (Carson Sink side)						
C	CS1	7-23-79	15.0	-125/-123	-15.4/-15.0	--
C	CS2	7-23-79	16.0	-123	-15.9	--
C	CS3	7-23-79	21.0	-122	-14.7	--
C	CS4	7-23-79	16.0	-122	-15.3/-15.0	--
C	CS6	7-23-79	21.0	-122	-15.7	--
C	CS8	7-23-79	24.0	-121	-14.2	--
Buckbrush seeps						
B	*DV41	5-15-79	28.0	-77/-82	-4.0/-4.2	--
B	DV42	5-15-79	15.0	-124	-16.3	--
Spring/stream from the Clan Alpine and Augusta Mountains						
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
E	DV3	3-20-79	11.0	-121	-15.2/-14.9	<100
E	DV10	3-20-79	15.0	-121/-123	-15.3/-15.0	<100
E	DV12	3-20-79	11.0	-117	-14.3	58
E	DV60	6-25-79	9.0	-113	-14.7	--
E	DV63	6-25-79	18.0	-117/-118	-15.2	--
E	DV64	6-25-79	--	-120	-13.6/-13.3	--
E	DV83	8-10-79	28.0	-128	-16.1/16.1	--
Miscellaneous samples (RS = Dixie Valley rain; DV20 = spring in Pleasant Valley; DV120 = spring in Fairview Valley; ECV = springs in Edwards Creek Valley)						
DR	RS1	11-3-79	--	- 93	-14.0	--
DR	RS2	11-17-79	--	-114	-14.9	--
DR	RS3	12-3-79	--	- 80	-10.7	--
EC	ECV1	10-19-79	13.5	-117	-17.2	--
EC	ECV2	10-19-79	13.0	-112	-15.5	--
EC	ECV3	10-19-79	13.0	-114	-16.6	--
P	DV20	3-20-79	21.0	-126	-15.3	--
F	DV120	10-19-79	12.0	-111	-15.6/-15.7	--

*Stagnant surface water; evaporation undoubtedly responsible for enrichment published as a chapter (Chapter 5) of the Mackay Minerals Research Institute (MMRI, 1980).

Table H-2. Sample Locations Outside The Area Covered by Plate H-1.

Sample Number	Location
DV 66	T21N,R35E, Sec. 7
DV 67, LL 109	T21N,R34E, Sec. 6
DV 120	T17N,R35E
ECV1	T21N,R39E, Sec. 3
ECV2	T21N,R39E, Sec. 18
ECV3	T19N,R37E, Sec. 11
CS1	T27N,R37E, Sec. 30dd
CS2	T26N,R37E, Sec. 5ba
CS3	T26N,R36E, Sec. 18b
CS4	T26N,R37E, Sec. 5ba
CS6	T23N,R34E, Sec. 20
CS7	T23N,R33E, Sec. 24ad
CS8	T22N,R33E, Sec. 11ad

Figure H-1 shows the meteoric water line (MWL), $\delta D = 8(\delta^{18}O)+10$ by Craig (1961) for world wide precipitation. The exact composition is dependent upon the temperature of water condensation and, as is the case with rain in arid environments, how much evaporation the precipitation is subjected to during its descent. Precipitation under cold conditions (high altitude snow) is more depleted with respect to both D and ^{18}O and plots on the lower portion of the MWL (Figure H-1) conversely precipitation under warmer conditions (low elevation rain) is more enriched with respect to D and ^{18}O and plots higher on the MWL (Figure H-1).

The isotopic composition of water can be altered by several processes. The most common is by evaporation. Figure H-1 shows the evaporation trend lines for a water at point A being subjected to evaporation under atmospheric conditions. The resulting water will lie on a line emanating from A. The particular slope of the line is dependent upon several factors, the most important of which is the temperature at which evaporation takes place.

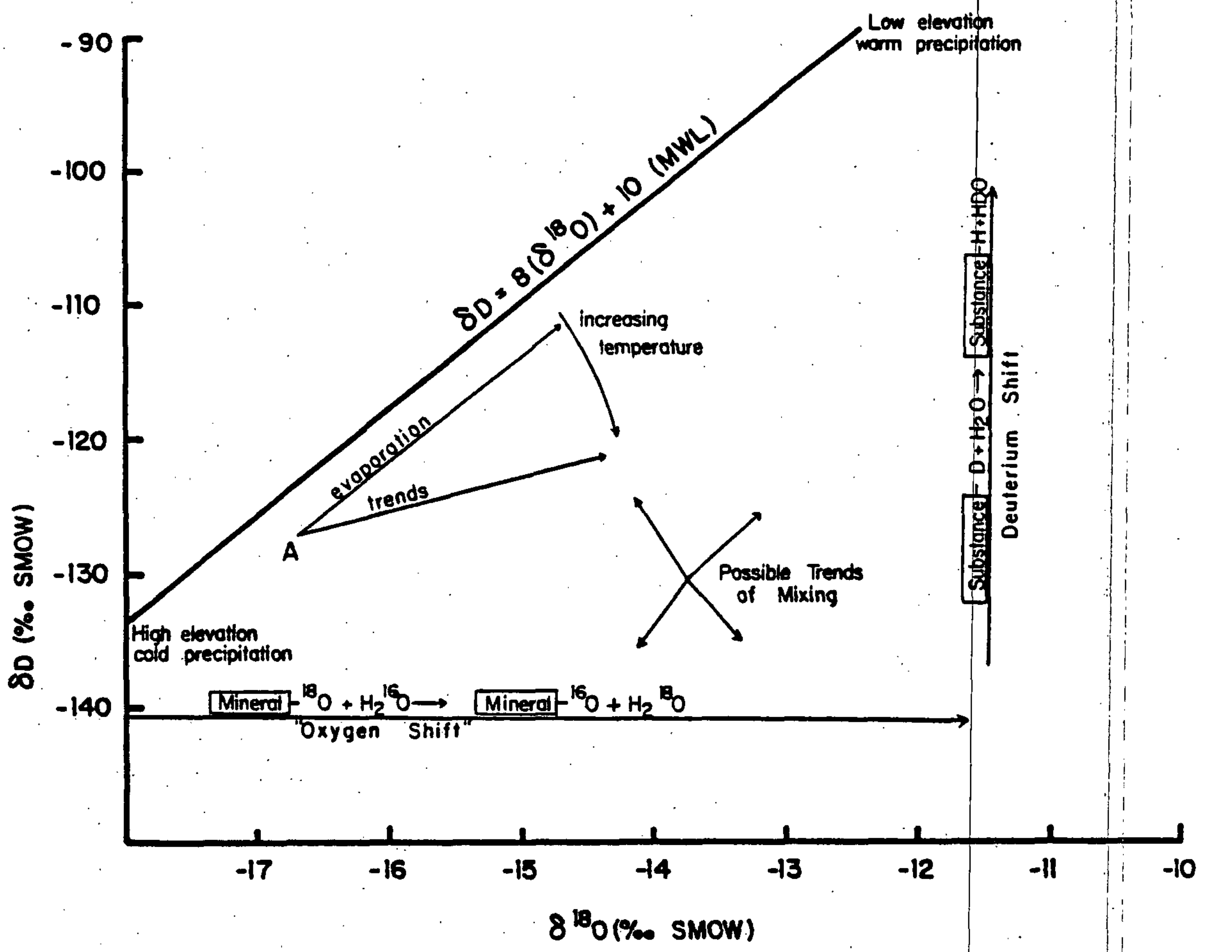

Figure H-1. General Principles of Stable Isotope Data Interpretation.

Once a water has been infiltrated and incorporated into the groundwater system, the isotopic composition will not change unless it is subjected to high temperature such as in a geothermal system. The most common, and widely accepted process which can alter the isotopic composition, occurs during water-rock reaction with respect to Oxygen-18 as shown on Figure H-1. A less common process which is also less accepted is a so-called deuterium shift. The chemical reaction is analagous to the oxygen shift. The water must react with hydrogen-bearing rocks (clays), H_2S or organic substances.

Another process by which isotopic composition can be altered is through mixing. The mixing of two waters of a different isotopic composition will produce a water of an intermediate isotopic composition. If mixing is done in varying proportions mixing lines can be developed on a δD vs $\delta^{18}O$ graph which are usually linear. Mixing can involve any water of any isotopic composition.

H.2.2. Dixie Hot Springs

Seven samples from Dixie Hot Springs were analyzed for stable isotopes. The springs have wide variations in temperature and earlier work (MMRI, 1980) indicated wide variations in chemistry (TDS levels ranging from 638 to 1470 ppm). The $\delta^{18}O$ values show relatively small variations, whereas variations in δD are significant, although no boiling springs occur. Figure H-2 shows a plot of deuterium and oxygen-18 compositions. Spring temperatures are in parenthesis next to the sample number. Deuterium values range between those characteristic of high elevation waters such as the artesian wells (Section H.2.5., Figure H-5) and low elevation waters, such as those from the Stillwater Range (Section H.2.6, Figure H-6).

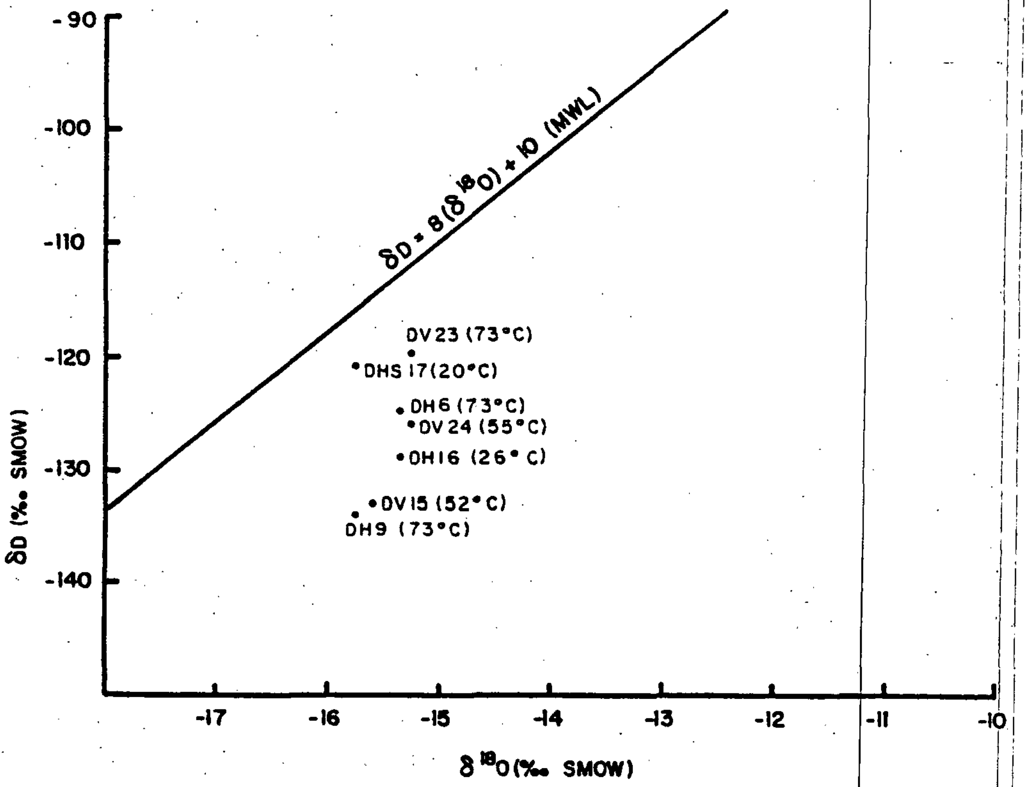

Figure H-2. Deuterium and Oxygen-18 Compositions of Dixie Hot Springs.

Apparently a high elevation water similar in isotopic composition to that from the artesian wells is heated, resulting in a slight oxygen shift. This type of water is probably the original contributor to the Dixie Hot Springs system, which undergoes various degrees of mixing with cold water from the Stillwater Range. Variations in the process of cooling probably account for the differences in temperature.

The Dixie Hot Springs system is located at the intersection of the Dixie Meadows and Mississippi faults (Plate IV, MMRI, 1980). Since the artesian wells are also in the vicinity of the Mississippi fault it lends support to the hypothesis that waters of an isotopic composition similar to that of the artesian wells is mixed with water from the Stillwater Range.

H.2.3. Hyder Hot Springs

The Hyder Hot Springs system is a group of approximately twenty hot springs issuing from a travertine mound in the north central part of Dixie Valley. A thick cover of alluvium apparently exists in this portion of the valley. Hydrogeochemical evidence (relatively constant TDS contents and ioinic concentrations among the various orifices) indicated that the Hyder system is relatively homogeneous with little mixing. The springs probably issue from a single source via a well defined fault-controlled flow system. The isotopic evidence (Figure H-3) tends to support this hypothesis, although there are only three samples. There is little variation in δD or $\delta^{18}O$, indicating a probable lack of mixing with shallow groundwater.

H.2.4 Hot Springs in the Vicinity of McCoy Ranch

The isotopic compositions of these waters are relatively homogeneous (Figure H-4). The small variations are probably due to mechanisms similar to those described for the Dixie Hot Spring system. All the springs in this area seem to be associated with the Dyer Fault system (Plate IV in MMRI, 1980), which probably accounts for their isotopic and chemical homogeneity. Most of the springs seem to be similar in chemistry and deuterium composition to Hyder Hot Springs, although Hyder is apparently related to a different fault system.

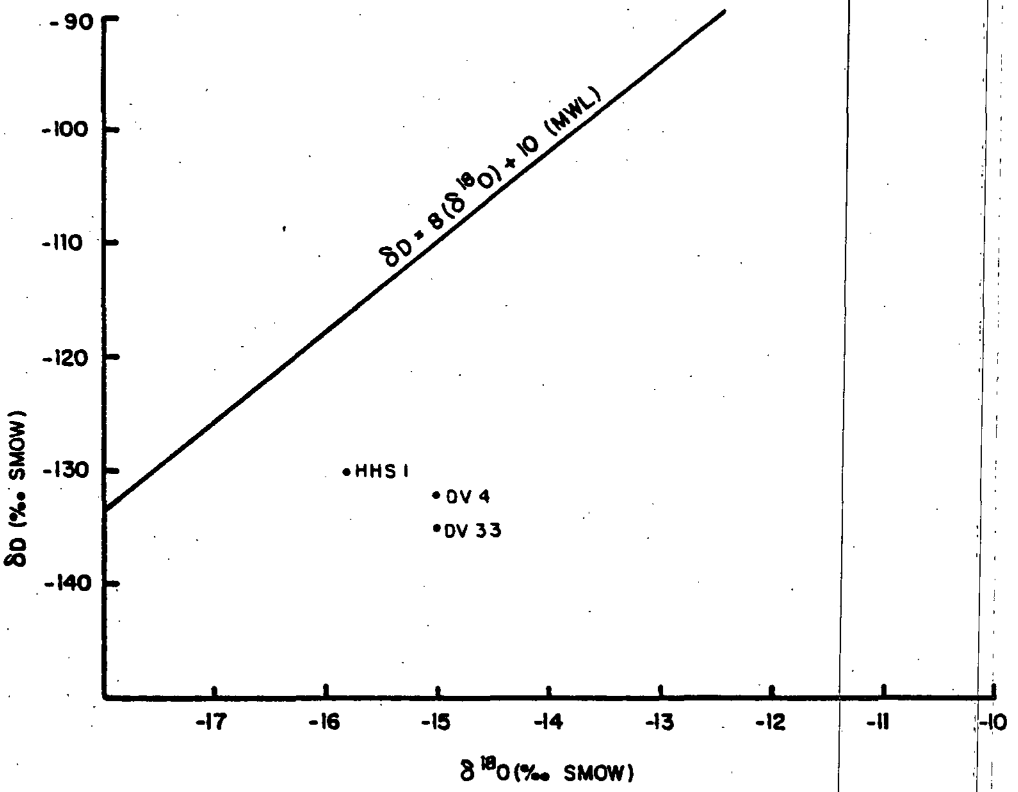

Figure H-3. Deuterium and Oxygen-18 Compositions of Hyder Hot Springs.

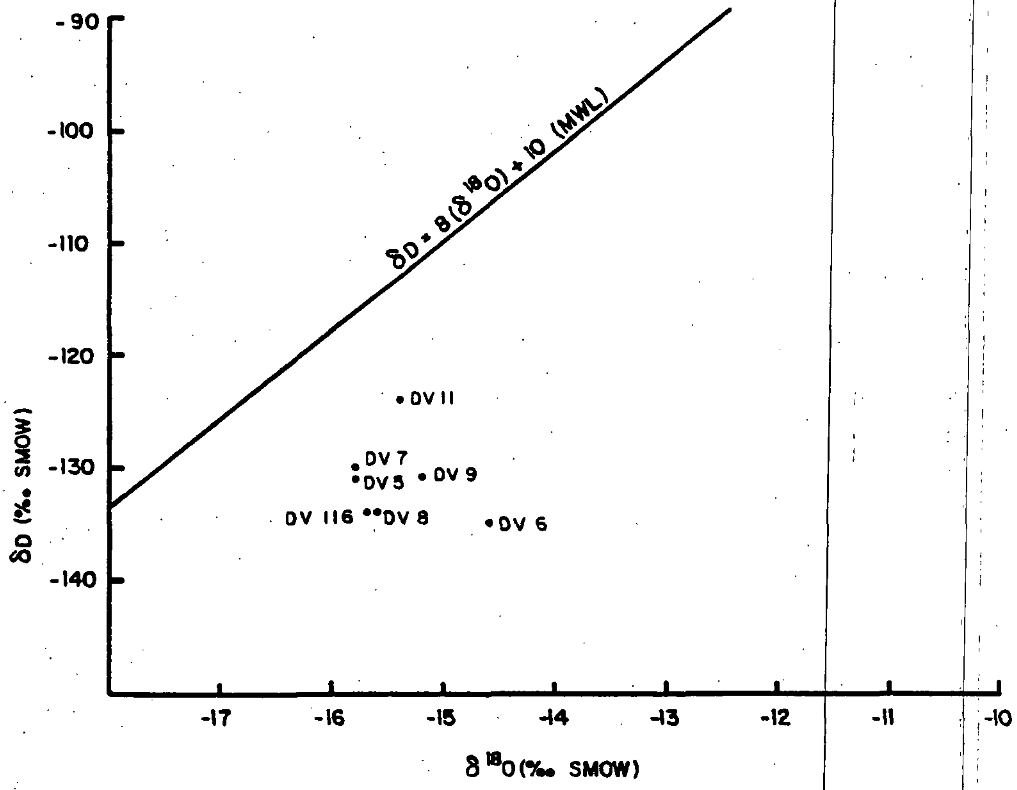

Figure H-4. Deuterium and Oxygen-18 Compositions of Hot Springs in the Vicinity of McCoy Ranch.

H.2.5 Artesian Wells at Dixie Settlement and Waters from the Eastern Mountain Ranges.

Both sets of waters were originally considered similar with respect to their chemical composition (MMRI, 1980). For this reason the Clan Alpine Mountains were, at least partially, considered as the recharge area for the waters discharged from the artesian wells. The isotopic composition of waters from the eastern mountains is variable and indicates low elevation waters (Figure H-5). Only one sample (DV83 from Shoshone Spring) plots within the range of the artesian wells, which are all high elevation waters.

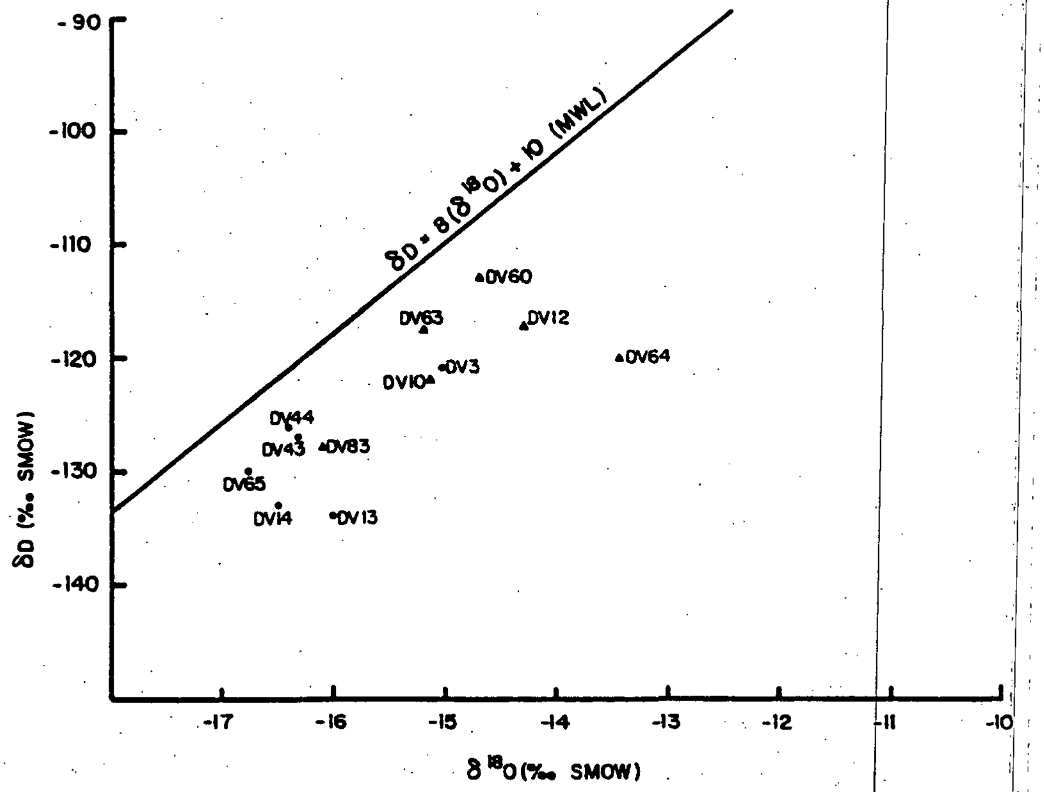

Figure H-5. Deuterium and Oxygen-18 Compositions of Artesian Wells at Dixie Settlement (•) and Waters from the Eastern Mountain Ranges (▲).

According to water chemistry Shoshone Spring is an anomaly within all the other waters in the eastern mountains (DV91 in MMRI, 1980). It is a warm spring (32°C) and its chemical similarity to the artesian wells originally led to the conclusion that the artesian wells are recharged from the Clan Alpine Mountains. However, despite their chemical and isotopic similarity it remains questionable whether there is a hydrologic connection between Shoshone Spring and the artesian wells, since they are about fifteen miles apart on opposite sides of a mountain range. Shoshone Spring remains an anomaly in the Clan Alpine Mountains, in that it constitutes a manifestation of thermal water at an altitude 1500 feet above the bottom of Dixie Valley.

H.2.6 Waters from the Stillwater Range

Variations in $\delta^{18}O$ and δD are significant in this area (Figure H-6). Some of the variations can be explained readily. DV92 is very likely affected by evaporation due to heating since it was diverted across the valley in a PVC-pipe to the site of DF66-21. Variations due to evaporation might also apply to some of the samples from Cottonwood Creek and the west side of the Stillwater Range. On the other hand, samples which were also likely subjected to evaporation, such as those from White Rock Canyon Creek (e.g. DV45 to DV49) do not

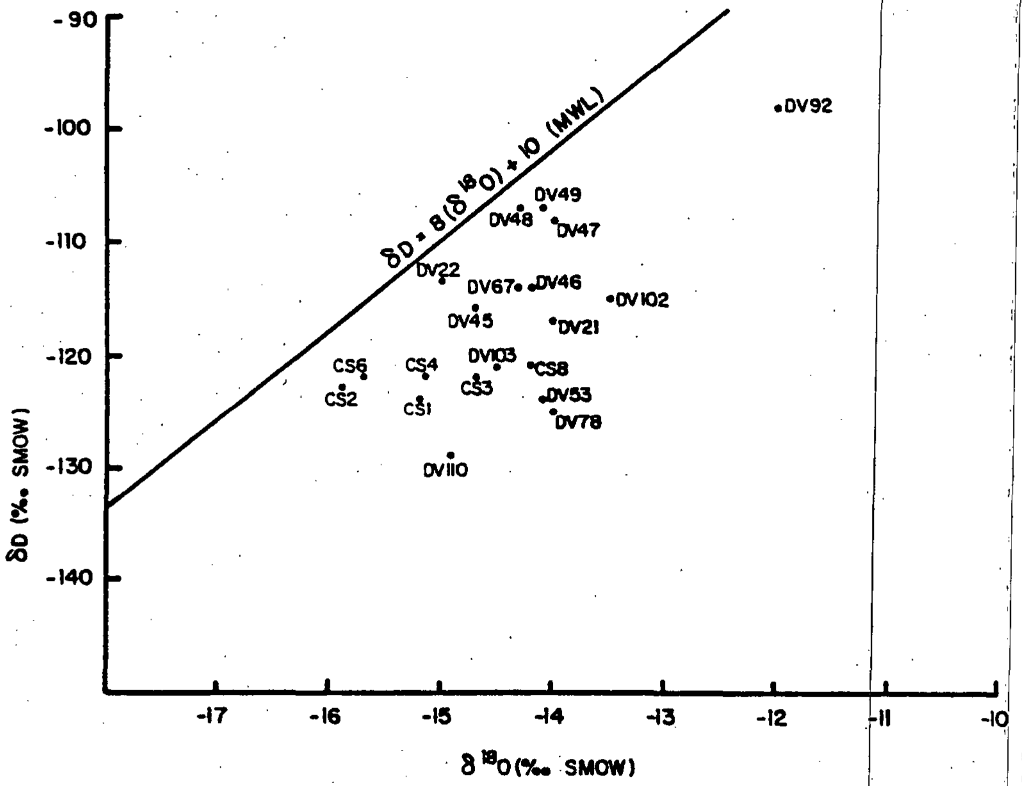

Figure H-6. Deuterium and Oxygen-18 Compositions of Waters from the Stillwater Range.

display variations that could be interpreted as evaporation. Generally variations in isotopic compositions from the Stillwater Range are due to evaporation and different elevations of precipitation and no oxygen shifts due to temperature can be recognized.

In the hydrogeochemical investigation it was found that all the streams in the Stillwater Range deposit $CaCO_3$ and that their TDS and calculated CO_2-pressures were anamalously high. However, the isotopic values are as expected for this type of terrain. Nevertheless, because of the chemical anomalies more work on hydrogeochemistry and isotopes should be undertaken.

H.2.7 Sou Hot Springs

The four samples from Sou Hot Springs (DV1, DV2, DV35 and DV36) exhibit little variation in $\delta^{18}O$ among themselves, but large variations in δD do exist--as much as in Dixie Hot Springs (Figure H-7). DV2 is the most depleted in δD of any individual hot spring sample. The low δD values indicate a high elevation recharge source for the Sou

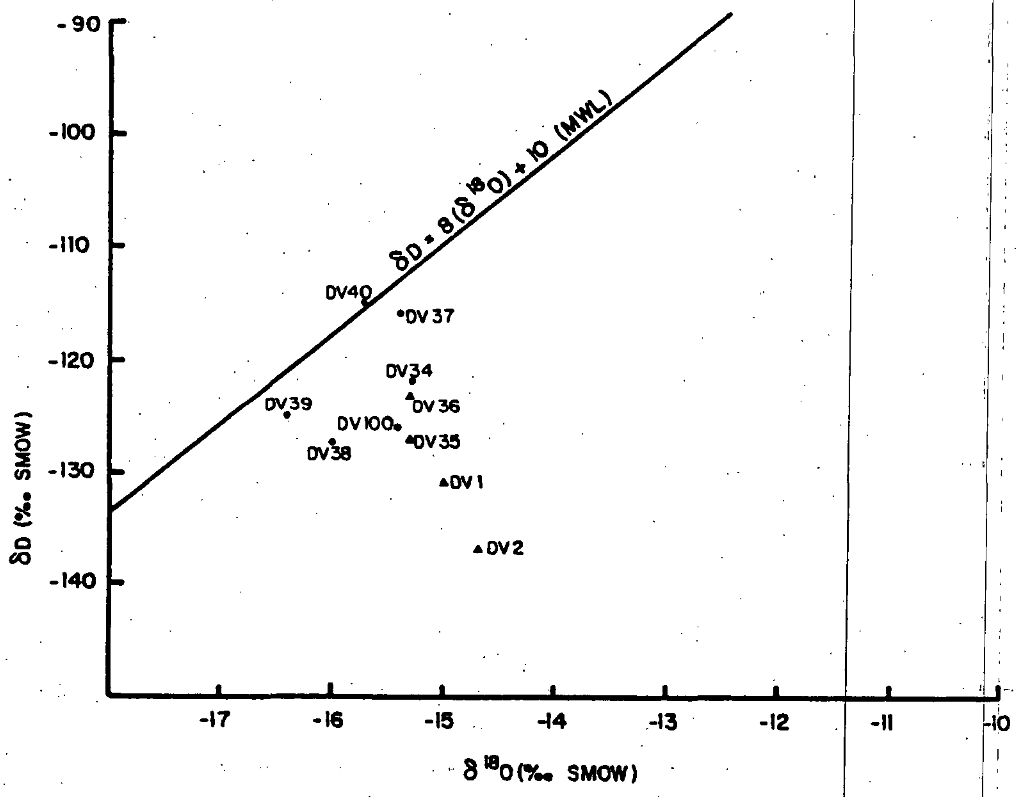

Figure H-7. Deuterium and Oxygen-18 Compositions of the Irrigation Wells (•) and Sou Hot Springs (▴).

system. The variation in δD between DV2 and DV35, which were taken from the same orifice two months apart, implies different degrees of mixing between thermal ^{18}O shifted waters and shallow groundwater at different times. The groundwater found in the irrigation wells to the east of Sou Hot Springs (DV34, DV37 and DV40) may be similar to the water that mixes with the thermal water derived at high elevations.

H.2.8. Deep Wells DF45-14 and DF66-21

Isotopic analyses of representative samples from these two wells would undoubtedly provide a wealth of information on the nature of the Dixie Valley geothermal system. A total of 12 samples (7 from DF45-14 and 5 from DF66-21) were collected from these wells. Unfortunately the validity of some of these samples is questionable. Possible casing ruptures and subsequent contamination by shallow groundwater, drilling fluid contamination, incomplete flushing of the wells, etc. cast doubts on the validity of the isotopic analyses from these wells. The following discussion must therefore be read in light of the aforementioned potential sources of contamination.

The initial sample (DV69) from DF45-14 exhibited the largest ^{18}O shift of any sample collected during the project (Figure H-8). However, DV69 as well as all the other samples taken from DF45-14 on that same day (DV70 to DV72) were very likely contaminated with water from temperature gradient hole SR2-A, which was used for flushing. Subsequent sampling of this well showed a gradual diminishing in the magnitude of this shift. The last sample from this well, DV126 (collected in December 1979) showed little ^{18}O shift. This same trend was observed in DF66-21, although the shift was not as pronounced. This reduction in ^{18}O shift probably represents a mixing/contamination of the original geothermal fluid with shallow groundwater, spring waters and/or drilling fluids (DV93 is probably contaminated with water represented by DV92-Figure H-8). Little change is apparent in samples collected between September (DV90) and December (DV126) of 1979. This implies that the mixing/contamination has reached equilibrium.

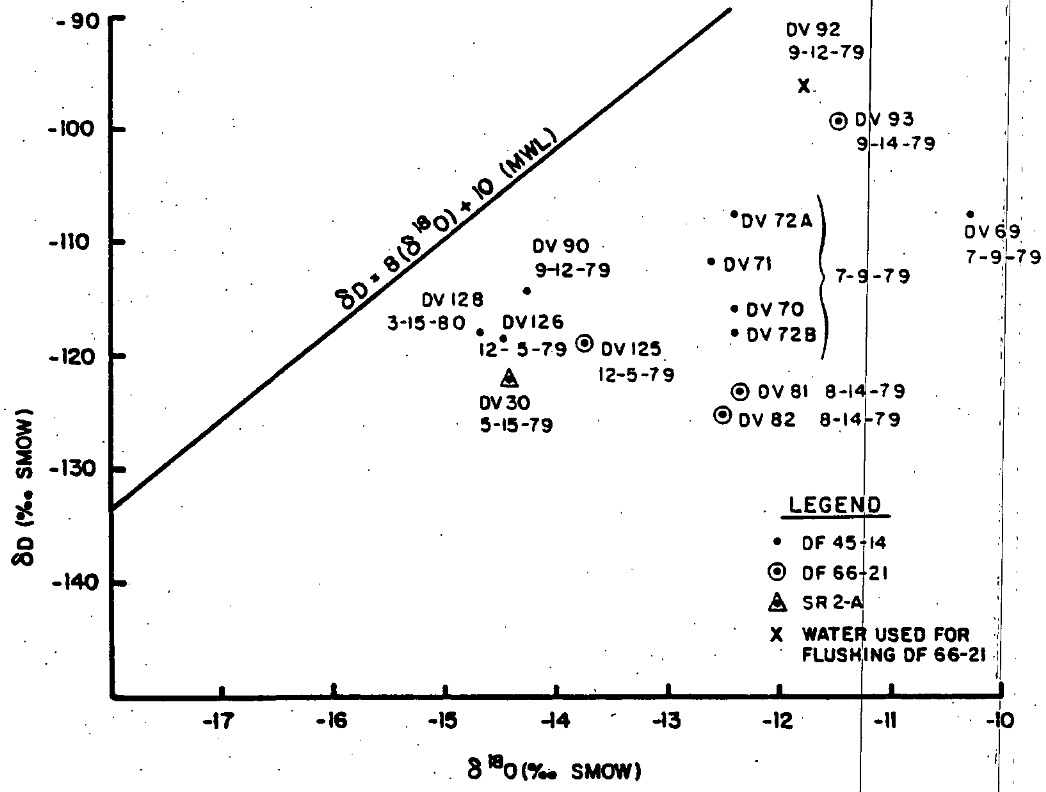

Figure H-8. Deuterium and Oxygen-18 Compositions of Deep Wells DF45-14 and DF66-21.

The last samples from these wells (DV90, DV125, DV126) plot near the waters from the eastern slopes of the Stillwater Range (DV45, DV46, DV67) and waters from the Clan Alpine Mountains (DV10, DV3, DV63). This indicates that waters of this isotopic composition are mixing with/contaminating the geothermal fluids.

The initially high deuterium contents in DF45-14 could be the results of a "deuterium shift" (Panichi and Confiantini, 1978). Shifts in deuterium contents are generally not as common as ^{18}O shifts because rocks normally contain more oxygen than hydrogen. Notable exceptions are rocks with clay and micaceous minerals (Ellis and Mahon, 1977) and those containing organic matter. The fracture zones (see Bard, MMRI 1980) encountered in DF45-14 were encountered in the organic-rich fine-grained metasiltstone/metashale, which could be responsible for the initially high levels of deuterium in this well. However, deuterium shifts are not well accepted or documented. White (1973, p. 553) stated that water-rock reactions and membrane filtration of isotopes have not been effective in changing the deuterium content of meteoric water that flows through these systems.

Isotopic exchange between H_2S and H_2O may occur in nature (Hitchon, 1963) thereby providing another mechanism for deuterium content variations. Hydrogen sulfide was noticeable in DF45-14, although no quantitative measurements of H_2S concentrations were made. Nevertheless, the possibility of contamination with shallow groundwater must still be kept in mind.

Assuming that the fluid from DF45-14 underwent a deuterium shift (DV69) to a more deuterium enriched water, and that fluids from DF66-21 were mixed with shallow groundwater, the trend lines of changing composition can be extrapolated backwards to determine an original composition for the fluid (Figure H-9). When this is done, the intersection of these two trend lines yields a hypothetical composition of an original geothermal fluid (H in Figure H-9). This hypothetical fluid has a deuterium composition which is similar to the fluids derived from the hot springs and the artesian wells. This implies recharge for the deep geothermal system from high elevation waters which underwent a significant oxygen shift (a horizontal shift is inferred assuming no boiling occurred at depth).

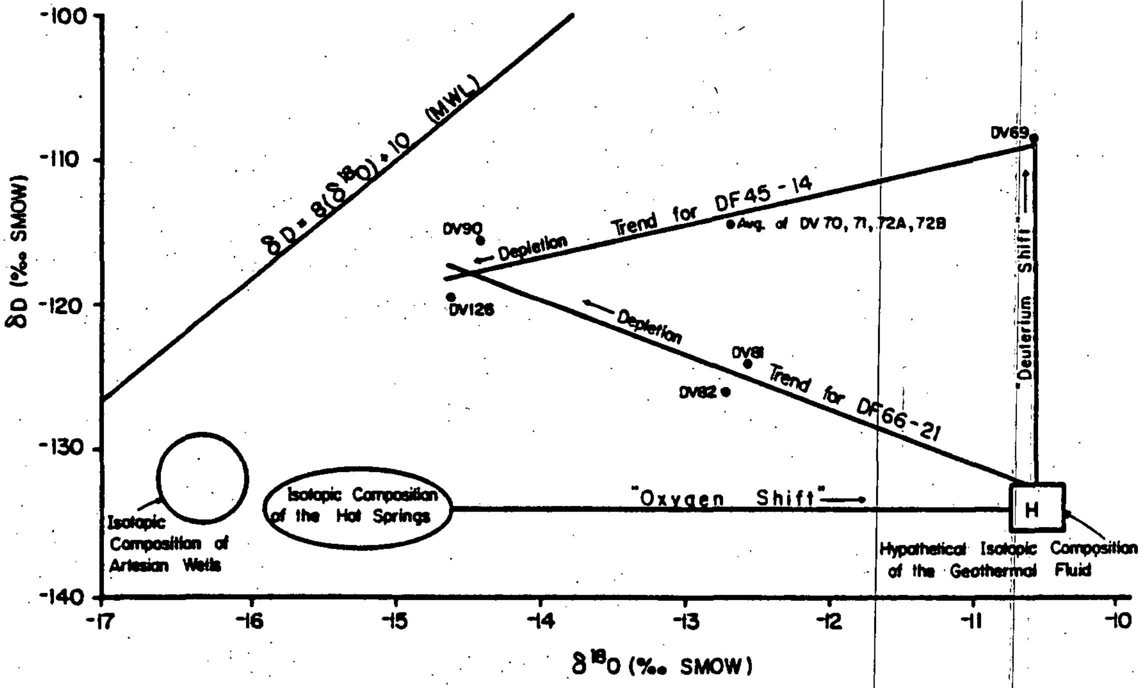

Figure H-9. Inferred Trend Lines of Changes in Isotopic Composition of Samples taken from DF45-14 and DF-66-21, and the Isotopic Composition of a Hypothetical Geothermal Fluid.

H.2.9 Interpretations of Stable Isotope and Hydrogeochemical Data.

Figure H-10 is a plot containing all isotope data collected (see Table H-3 for location codes). It allows comparisons between the various geographical groups of samples. Aside from seasonal variations, a geographical grouping is vaguely discernible.

Assuming that lower δD values indicate relatively high elevations (Figure H-1) as sources of groundwater and vice-versa, changes on the vertical axis should permit some conclusions on the sources of water and the hydrologic system as such. Hyder Hot Springs, Sou Hot Springs, the artesian wells at Dixie Settlement, most of the hot springs in the vicinity of McCoy Hot Springs and parts of Dixie Hot Springs have, in comparison to all the other samples, the highest elevations as sources. They are all discharged in the lower part of Dixie Valley. However, the samples from the surrounding mountain ranges have lower elevations as sources. Unfortunately, no snow samples from the tops of these mountains have been collected. Thus they could possibly have deuterium values comparable with those found in the waters from the lower parts of the valley.

The fact that high elevation waters discharge in the lower parts of the valley is in agreement with the classical models of arid basin hydrogeology (e.g. Maxey, 1968 and Mifflin, 1968). Figure H-11 shows that high elevation waters (with long flow paths) discharge in the center of the valley. All waters that are apparently derived from high elevations have one or another feature that indicates geothermal activity, which is another hint of deep flow (Figure H-11). Thus, it is very likely that recharge waters from the Stillwater Range, the Clan Alpine and Augusta Mountains penetrates to various depths and undergoes varying oxygen shifts under different temperature regimes. This water mixes to various degrees in the shallow subsurface with water originating from relatively lower elevations, and discharges in hot springs and wells in Dixie Valley. Systematic collection of stable isotope data of snow at various elevations from the surrounding mountains could substantiate this hypothesis.

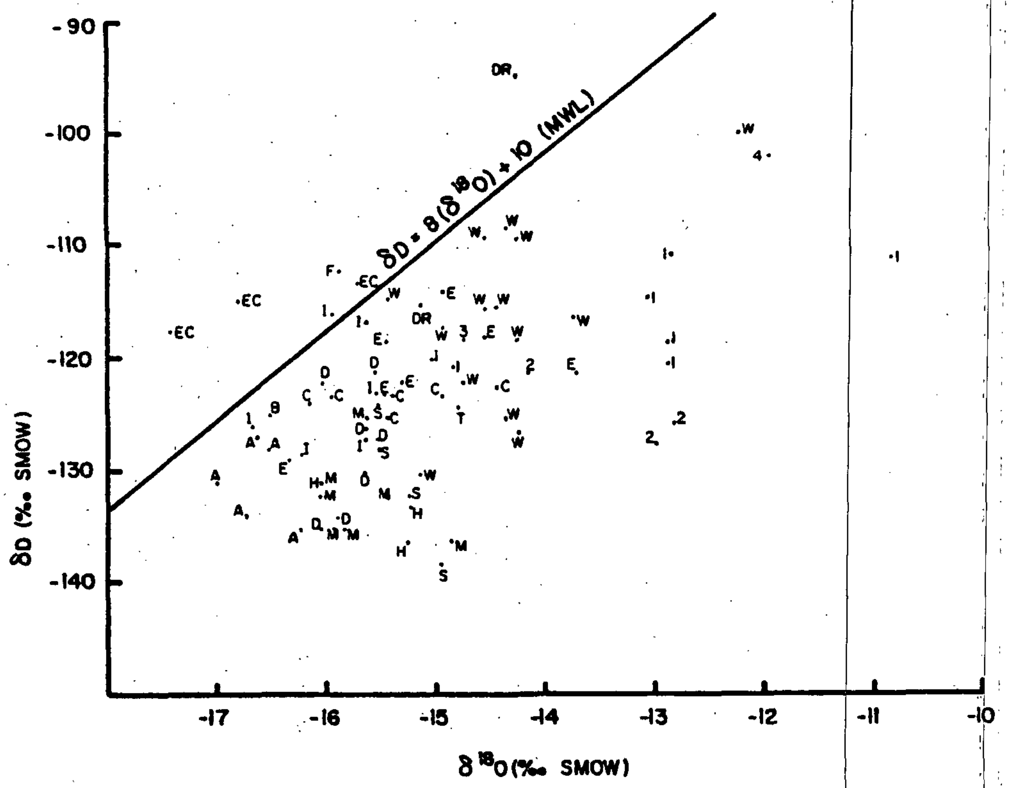

Figure H-10. Deuterium and Oxygen-18 Compositions of Dixie Valley and Surrounding Waters.

Table H-3. Location Codes for Figure H-10.

Code	Description
A	Artesian wells in the vicinity of Dixie Settlement
B	Buckbrush Seeps
C	Carson Sink (western slopes of the Stillwater Range)
D	Dixie Hot Springs
DR	Dixie Valley rain
E	Spring or stream from the eastern mountain ranges (Clan Alpine and Augusta Mountains)
EC	Edwards Creek Valley
F	Fairview Valley
H	Hyder Hot Springs
I	Irrigation wells in the northern part of Dixie Valley
M	Intermediate temperature springs around McCoy Ranch
P	Pleasant Valley
S	Sou Hot Springs
T	Temperature Gradient Hole SR2-A
W	Spring or stream from the Stillwater Range
1	DF 45-14
2	DF 66-21
3	DF 45-14
4	DF 66-21

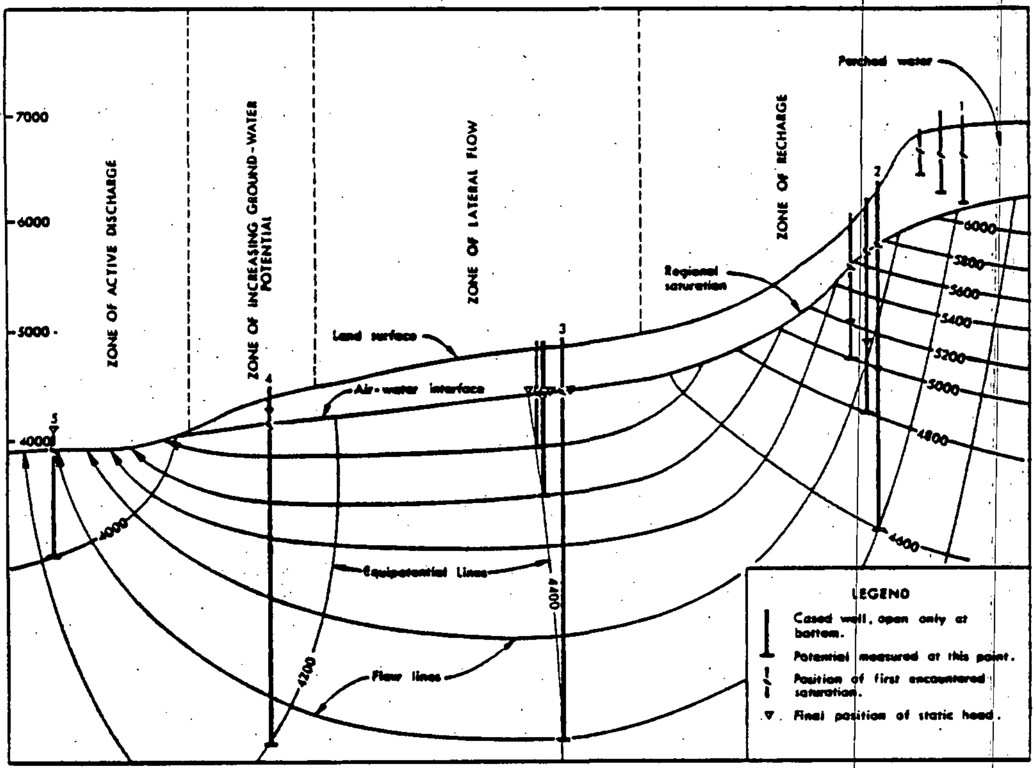

Figure H-11. Sketch of Observed Relationship in a Typical Desert Basin Flow System (after Mifflin, 1968)

However, it should be pointed out that similar deuterium values for the hot springs and geothermal wells does not necessarily imply that they are hydraulically connected. It rather implies that they are all recharged from one common source or a set of similar sources.

All waters that display geothermal characteristics are also associated with various major fault systems (Plate IV in MMRI, 1980). In general the chemical characteristics between the hot spring systems are variable, whereas their deuterium levels are similar. An exception is Hyder Hot Springs which is chemically similar to the hot springs distributed across the northeastern part of the valley, although Hyder is associated with a different fault system.

In several cases the grouping displayed in Figure H-11 has a surprising similarity with the one used earlier in the hydrogeochemical interpretation (MMRI, 1980). This supports the hypothesis that particular geographic areas are dominated by certain hydrologic, chemical and thermal regimes.

A comparison between isotopes and hydrogeochemistry also poses some contradictions. Waters from the Stillwater Range and some waters from the eastern mountains (DV10) have comparatively high TDS levels for mountain spring waters. Contrary to that, the waters discharged in the artesian wells in the center of the valley have some of the lowest TDS levels in the area. This is surprising, since the low deuterium values indicate high elevation waters with relatively long flow paths (Figure H-11) that would cause high levels of TDS.

The occurrence of a warm spring in the mountains (Shoshone Spring) discharging water that was derived from a higher elevation than the surrounding mountain springs suggests the possibility of the emergence of diluted thermal waters in some of the mountain canyons. The unusually high CO_2 pressures in most mountain springs and extensive sinter deposition in the Stillwater Range seem to support this hypothesis.

H.2.10 Tritium Concentrations

Tritium (^3H) samples were collected along with the stable isotope and chemical samples at each collection site. Due to the lack of detectable tritium in the samples and the cost of tritium analyses, they were soon terminated. Twenty-seven samples were run unenriched, a process yielding lower detection limits of 100 tritium units (TU). Only one sample, DV1, had detectable amounts. DV1 was taken from a pool in a large travertine crater at Sou Hot Springs which has no apparent discharge. It is assumed that the high reading is due to the pooling of precipitation of higher tritium content than the hot spring water and evaporation. This analysis also has an inherently large analytical error (300 ± 240 TU), which makes conclusive interpretation almost impossible.

A spring in Dyer Canyon on the western slope of the Clan Alpine Mountains did have a significant tritium level (58 ± 8 TU). No hot spring, artesian well, or deep well showed detectable quantities, indicating that the deep ground water and thermal systems are pre-bomb test (1954) waters. Some mountain spring and shallow groundwater, however, must be post-bomb water as the spring in Dyer Canyon (DV12 indicates.

H.3 Conclusions

Two of the three major hot spring systems, Dixie and Sou Hot Springs, discharge a mixture of two waters, each of which is characterized by its own isotopic composition. One type of water is more depleted with respect to deuterium ($\delta D = - 134^{0}/oo$) and originates at high elevations (> 7000 feet). This water moves downward, is heated and shifts toward a more enriched ^{18}O content. The second type of water is a non - ^{18}O shifted water that plots close to the MWL at about $\delta D = 122^{0}/oo$. This water is derived from precipitation at lower elevations (< 7000 feet) than the first water. These waters mix in differing proportions, resulting in the composition of the waters discharging at Dixie and Sou Hot Springs. The waters from the artesian wells near Dixie Settlement and the hot springs in the vicinity of McCoy Hot Springs also exhibit this same pattern. Hyder Hot Springs is dissimilar to the above systems. The isotopic results are similar to the hydrogeochemical results in that they suggest that the Hyder system is relatively homogeneous, isolated from the other systems and emanates from a different reservoir. Very little mixing with shallow groundwater occurs in the Hyder system. Recharge is derived from high elevation snows, probably at about the same elevation as the deuterium-depleted component of the waters at Dixie and Sou Hot Springs.

The waters from DF45-14 and DF66-31 are derived from high elevations (> 7000 feet) snows. These waters become heated at depth and acquire the characteristic ^{18}O shift. In addition, the water from DF45-14 may experience a deuterium shift after reacting with clay minerals, hydrogen sulfide and organic matter. Waters from both wells probably mix with shallow groundwater, either naturally and/or by contamination during drilling. It is difficult to draw valid inferences from the DF45-14 and DF66-21 samples because of possible contamination; the samples obtained may not be representative of the geothermal fluids in the system.

In summary Dixie Valley represents a major groundwater sink for the surrounding basins. Recharge occurs in the mountains. Water infiltrated at the highest elevations is discharged in the lowest parts of the valley either in hot springs, geothermal wells, in low temperature artesian wells and by evapotranspiration in the Humboldt Marsh.

Contrary to accepted beliefs, here groundwaters with high TDS contents are discharged in the mountains whereas low TDS waters are discharged in some parts of the central valley. It is also possible that waters with geothermal features are discharged in some parts of the mountains.

H.4 References

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APPENDIX F-4

H.0 ENVIRONMENTAL ISOTOPE HYDROLOGY OF THE DIXIE VALLEY GEOTHERMAL SYSTEM

H.1 Introduction

H.1.1 Purpose and Scope

The purpose of this portion of the study is to use inferences from the distribution of naturally-occurring isotopes in the waters of the study area to provide insight into the Dixie Valley geothermal system and input to the formulation of a conceptual model of the Dixie Valley hydrothermal system. The isotope distributions and their interpretations can provide information on recharge to the system and can supplement the information derived from the hydrogeochemistry, which was discussed in an earlier report. Most of the emphasis was placed upon the collection and interpretation of the stable isotopes ^{2}H (deuterium or D) and ^{18}O. These isotopes are useful in delineating recharge areas and functioning as fluid flow tracers. The radioactive isotope ^{3}H (tritium) was also utilized to a minor extent. At the inception of the study, it was anticipated that the radioactive isotope ^{14}C would be utilized as well; this environmental isotope would have been used to date the waters from the various parts of the study area. The spatial distribution of fluid ^{14}C dates could then be used to estimate fluid residence times and reservoir volume. However, delays in receiving stable isotope results precluded the collection of ^{14}C data, since the stable isotope information is essential to the proper application of ^{14}C techniques and interpretation of the ^{14}C data.

The study area encompassed the same region as the hydrogeochemical investigations. Most of the work focused on the area of greatest interest to the Southland Royalty Company: the northern half of Dixie Valley (between Dixie Meadows and Sou Hot Springs). Emphasis was placed on the western half of this particular area, i.e., in the vicinity of the Stillwater Range. However, sampling outside this specific area was performed.

H.1.2. Methods and Analytical Techniques

Approximately 100 samples of thermal and non-thermal waters were collected for stable isotope analyses from the study area. In addition, 27 samples were collected for ^{3}H analyses. All isotope samples were collected in 125 ml glass bottles with Teflon-lined plastic caps. The bottles were completely filled and capped underwater (where possible) to insure that no air bubbles would be entrapped. The bottles were then sealed with Parafilm and plastic tape.

Both enriched and unenriched ^{3}H analyses were performed at the Water Resources Center of the Desert Research Institute. Liquid scintillation was used to measure ^{3}H activity; selected samples were electrolytically enriched before analysis. The stable isotope (D and ^{18}O) samples were analyzed by the Laboratory of Isotope Geochemistry at the University of Arizona. Mass spectroscopy was used for the analyses.

It should be noted that isotope samples were collected from the same locations (with a few exceptions) as the chemical samples and are labeled accordingly. However, because of cost, not all the collected isotope samples were analyzed. Plate H-1 shows the locations of all chemical and isotope samples collected from the study area.

H.1.3. Previous Work

Very little previous work on the hydrology of Dixie Valley exists. A paper by Zones (1957) describes some of the hydrologic effects of the 1954 Dixie Valley earthquake. He noted that wells in the valley showed temporary increases in artesian heads and flow rates which he attributed to a westward tilting of the confined and semi-confined aquifers penetrated by the wells, a reduction in the porosity of the unconsolidated sediments caused by rearrangement of the grains during the earthquake, and local fracturing of the alluvium which may have increased the upward flow of groundwater from depth. Zones did not observe a rise in water temperatures, so he concluded that if water did move from depth along new fracture zones, it did not come from a great depth. He also noted a temporary increase in the flow rate of Mud Springs in T20N, R34E, Section 5. This was attributed to new movement on the fault zone along which water had been rising. This movement opened fractures which permitted more water to move upward and/or lowered the land surface at the spring areas, which produced a temporary increase in artesian head at the spring orifices. Discharge at Dixie Hot Springs did not appear to be affected by the earthquake; the temperature at one of the orifices was the same (59.4°C) both before and after the earthquake.

A reconnaissance report by Cohen and Everett (1963) provides an overview of the groundwater hydrology of Dixie and Fairview Valleys. Their report described a seven-valley hydrologic system (Dixie, Fairview, Pleasant, Jersey, Eastgate, Cowkick and Stingaree Valleys) that forms a closed hydrologic unit. Dixie Valley is the major groundwater sink for the system; it receives underflow from the other six valleys in the system. The Cohen and Everett report provides information on groundwater chemistry, well yields and inventories, recharge, discharge, aquifer storage and transmissive properties and related data. The report does not purport to be a detailed description of the groundwater hydrology of Dixie Valley and environs.

Additional work of a limited nature was conducted by Mariner, Rapp, Willey and Presser (1974) and Mariner, Presser, Rapp and Willey (1975) who collected chemical, gas and stable isotope data from Dixie Hot Springs, Sou Hot Springs and a few other locations in the study area. No interpretations of the data are given in their reports. Studies were also conducted by GeothermEx, Inc. (1976) and by Keplinger and Associates (1977; 1978). A substantial amount of geochemical sampling, analyses and interpretation were conducted in northern Dixie Valley as part of a multidisciplinary study by the Mackay Minerals Research Institute (1980); the work described herein was performed as part of this investigation.

H.1.4. Hydrologic Framework

The following discussion is a brief description of the groundwater hydrology of Dixie Valley, which will be useful in understanding the interpretations of and inferences from the isotope data. Most of the information can be found in Cohen and Everett (1963).

Insofar as groundwater hydrology is concerned, Dixie Valley is one of seven valleys forming a single closed hydrologic unit. Dixie Valley is topographically the lowest of these valleys; indeed, it contains the lowest point in northern Nevada. The valley is the major groundwater sink for the seven-valley system; it is believed to receive underflow either directly or indirectly from the other six valleys. The groundwater flow into Dixie Valley is southward from Jersey and Pleasant Valleys; westward from Eastgate, Cowkick and Stingaree Valleys into Dixie Valley and then northward to the Humboldt Salt Marsh; and northward from Fairview Valley. In Dixie Valley itself, groundwater moves radially from the valley margins toward the Humboldt Salt Marsh.

Groundwater occurs under confined (artesian), semi-confined and unconfined (water-table) conditions in the unconsolidated sediments comprising the valley fill. The largest area of artesian conditions lies just south of the Humboldt Salt Marsh in the major groundwater discharge area. Semi-confined groundwater occurs in scattered areas throughout the valley. Most of the groundwater occurs in and moves through the interstices of the valley-fill sediments. However, a certain amount undoubtedly occurs as fracture-flow in the consolidated rocks. It is believed that the underflow from Pleasant Valley occurs in this manner. This type of flow is more important with respect to the geothermal reservoir than it is to the shallow groundwater reservoir.

Average annual precipitation in Dixie Valley is estimated to be about 456,000 acre-feet. Of this amount, 6,000 acre-feet is believed to reach the groundwater reservoir as recharge. Most of this recharge is believed to originate as precipitation in the mountainous regions: the Stillwater Range and Clan Alpine Mountains. Some of the mountainous regions receive more than 20 inches of precipitation annually, as compared to about 5 inches on the valley floor. In addition, the valley is believed to receive approximately 7,000 acre-feet of recharge annually as subsurface flow from the six surrounding valleys. Average annual natural discharge by evapotranspiration in Dixie Valley is approximately 16,200 acre-feet. The major discharge area is the Humboldt Salt Marsh, where groundwater is discharged by transpiration and direct evaporation from the water table. It should be noted that these recharge and discharge estimates from Cohen and Everett (1963) result in an average annual discrepancy of 3,200 acre-feet between discharge (16,200 acre-feet) and total recharge (13,000 acre-feet). This discrepancy results from the limited data and the uncertainties inherent in the methods used to estimate natural groundwater discharge and recharge. Since recharge is less than discharge, Dixie Valley which theoretically was in a state of equilibrium at the time of the Cohen and Everett report, could be receiving more recharge via precipitation and/or subsurface inflow from the surrounding valleys. However, it is difficult to draw any substantive conclusions since neither the recharge nor the discharge figure is particularly accurate.

Springs are numerous in the valley; most of them discharge thermal water. In terms of this study, the most important springs are the three major hot spring systems: Dixie Hot Springs, Hyder Hot Springs and Sou Hot Springs. The Dixie Hot Springs system is comprised of about 35 springs and seeps, which emerge from alluvium over an area of about four square miles. The Hyder Hot Springs system emerges in the middle of the valley where the bedrock is apparently covered by thick alluvium. Travertine deposits up to 100 feet thick have been deposited here. The Sou Hot Springs system is found at the northern end of the study area, in a region characterized primarily by bedrock with hot spring deposits.

H.2 Analytical Results

H.2.1 Isotopic Characteristics of Dixie Valley and Surrounding Waters

Table H-1 lists the isotopic (^{2}H or D, ^{18}O and ^{3}H) characteristics of Dixie Valley and surrounding waters. The data for D and ^{18}O are reported as per mil (parts per thousand) variations from Standard Mean Ocean Water (SMOW). The analytical precision is $\pm$ 0.2^{o}/oo for δ^{18}O and $\pm$ 3^{o}/oo for δD. Tritium data are reported in tritium units (TU); one TU equals one atom of ^{3}H per 10^{18} atoms of ^{1}H.

The geographical distribution of samples can be ascertained by referring to Plate H-1. This plate covers only the area of greatest interest to the Southland Royalty Company. Sample locations not shown on Plate H-1 are listed in Table H-2.

Throughout the rest of this report, references will be made to the hydrogeochemistry of the area. The hydrogeochemical study was

Table H-1. Isotopic Analyses of Dixie Valley and Surrounding Waters.

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
		Intermediate temperature springs in the vicinity of McCoy Ranch				
M	DV5	3-20-79	39.0	-131	-15.8	<10
M	DV6	3-20-79	29.0	-135	-14.6	<100
M	DV7	3-20-79	--	-130	-15.8	<100
M	DV8	3-20-79	--	-134	-15.6	<100
M	DV9	3-20-79	--	-131	-15.2	<100
M	DV11	3-20-79	43.0	-124	-15.4	<100
M	DV116	3-20-79	40.0	-132/-136	-15.7	--
		Exploration well DF45-14				
1	DV69	7-9-79	68.5	-109	-10.5/-10.6	--
1	DV70	7-9-79	75.5	-117	-12.6	--
1	DV71	7-9-79	82.0	-113	-12.8	--
1	DV72A	7-9-79	76.5	-109	-12.6	--
1	DV72B	7-9-79	76.5	-119	-12.6	--
3	DV90	9-12-79	94.0	-114/-117	-14.4	<10
1	DV126	12-5-79	86.5	-121/-118	-14.6	<5
1	DV128	3-15-80	48.0	-119	-14.8	--
		Exploration well DF66-21 and thermal well SR2-A (DV30)				
2	DV81	8-14-79	51.0	-124	-12.6/-12.5	<100
2	DV82	8-14-79	86.0	-126	-12.7	--
2	DV93	9-14-79	83.0	-101	-11.7	--
4	DV94	9-15-79	--	--	--	<10
2	DV125	12-5-79	32.5	-120	-13.9	<5
T	DV30	5-15-79	64.5	-123	-14.3/14.8	--
		Dixie Hot Springs				
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
D	DV23	3-20-79	73.0	-120	-15.3	<10
D	DV24	3-20-79	55.0	-126	-15.3	--
D	DH6	7-23-79	73.0	-125	-15.4	--
D	DH9	7-23-79	73.0	-134	-15.8	--
D	DH15	7-23-79	52.0	-133	-15.8/-15.5	--
D	DH16	7-23-79	26.0	-129	-15.4	--
D	DHS17	7-23-79	20.0	-121	-15.8	--

Table H-1 (con't.)

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	$\delta^{18}O$ (^{o}/oo)	^{3}H (TU)
Sou Hot Springs						
S	DV1	3-20-79	55.0	-131	-15.0	300
S	DV2	3-20-79	51.0	-137	-14.7	<100
S	DV35	5-15-79	53.5	-127	-15.3	--
S	DV36	5-15-79	73.0	-123	-15.3	--
Hyder Hot Springs						
H	DV4	3-20-79	63.0	-132	-15.0	<10
H	DV33	5-15-79	65.5	-135	-15.0	--
H	HHS1	7-23-79	75.0	-130	-15.8	--
Artesian wells in the vicinity of Dixie Settlement						
A	DV13	3-20-79	19.0	-134	-16.0	<10
A	DV14	3-20-79	19.0	-133	-16.5	<100
A	DV43	5-15-79	18.3	-127	-16.3	--
A	DV44	5-15-79	18.3	-126	-16.4	--
A	DV65	6-20-79	20.0	-130	-16.7/-16.8	--
Irrigation wells in the northern part of Dixie Valley						
I	DV34	5-15-79	19.5	-122	-15.3	--
I	DV37	5-15-79	16.0	-112/-119	-15.4	--
I	DV38	5-15-79	18.5	-125/-130	-16.0	--
I	DV39	5-15-79	22.5	-125	-16.4	--
I	DV40	5-15-79	15.5	-115	-15.7	--
I	DV100	6-25-79	19.0	-126	-15.4	--
Springs/streams from the eastern slopes of the Stillwater Range						
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	$\delta^{18}O$ (^{o}/oo)	^{3}H (TU)
W	DV21	3-20-79	13.0	-117	-14.0	<100
W	DV22	3-20-79	11.0	-112/-115	-15.0	<100
W	DV45	5-15-79	14.0	-116	-14.7	--
W	DV46	5-15-79	15.75	-114	-14.2	--
W	DV47	5-15-79	18.0	-108	-14.0	--
W	DV48	5-15-79	13.5	-107	-14.3	--
W	DV49	5-15-79	15.75	-107	-14.1	--
W	DV53	6-25-79	18.0	-124	-14.1	--
W	DV67	6-25-79	16.0	-114	-14.0/-14.6	--
W	DV78	7-23-79	22.0	-125	-14.0	--
W	DV92	9-12-79	43.0	- 98	-12.0	--
W	DV102	6-25-79	14.0	-115	-13.5	--
W	DV103	6-25-79	14.0	-121	-14.5	--
W	DV110	6-25-79	15.5	-129	-14.9	--

Table H-1 (con't.)

Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
Spring/stream from the western slopes of the Stillwater Range (Carson Sink side)						
C	CS1	7-23-79	15.0	-125/-123	-15.4/-15.0	--
C	CS2	7-23-79	16.0	-123	-15.9	--
C	CS3	7-23-79	21.0	-122	-14.7	--
C	CS4	7-23-79	16.0	-122	-15.3/-15.0	--
C	CS6	7-23-79	21.0	-122	-15.7	--
C	CS8	7-23-79	24.0	-121	-14.2	--
Buckbrush seeps						
B	*DV41	5-15-79	28.0	-77/-82	-4.0/-4.2	--
B	DV42	5-15-79	15.0	-124	-16.3	--
Spring/stream from the Clan Alpine and Augusta Mountains						
Code	Sample Number	Sampling Date	T (^{o}C)	δD (^{o}/oo)	δ^{18}O (^{o}/oo)	^{3}H (TU)
E	DV3	3-20-79	11.0	-121	-15.2/-14.9	<100
E	DV10	3-20-79	15.0	-121/-123	-15.3/-15.0	<100
E	DV12	3-20-79	11.0	-117	-14.3	58
E	DV60	6-25-79	9.0	-113	-14.7	--
E	DV63	6-25-79	18.0	-117/-118	-15.2	--
E	DV64	6-25-79	--	-120	-13.6/-13.3	--
E	DV83	8-10-79	28.0	-128	-16.1/16.1	--
Miscellaneous samples (RS = Dixie Valley rain; DV20 = spring in Pleasant Valley; DV120 = spring in Fairview Valley; ECV = springs in Edwards Creek Valley)						
DR	RS1	11-3-79	--	- 93	-14.0	--
DR	RS2	11-17-79	--	-114	-14.9	--
DR	RS3	12-3-79	--	- 80	-10.7	--
EC	ECV1	10-19-79	13.5	-117	-17.2	--
EC	ECV2	10-19-79	13.0	-112	-15.5	--
EC	ECV3	10-19-79	13.0	-114	-16.6	--
P	DV20	3-20-79	21.0	-126	-15.3	--
F	DV120	10-19-79	12.0	-111	-15.6/-15.7	--

*Stagnant surface water; evaporation undoubtedly responsible for enrichment published as a chapter (Chapter 5) of the Mackay Minerals Research Institute (MMRI, 1980).

Table H-2. Sample Locations Outside The Area Covered by Plate H-1.

Sample Number	Location
DV 66	T21N,R35E, Sec. 7
DV 67, LL 109	T21N,R34E, Sec. 6
DV 120	T17N,R35E
ECV1	T21N,R39E, Sec. 3
ECV2	T21N,R39E, Sec. 18
ECV3	T19N,R37E, Sec. 11
CS1	T27N,R37E, Sec. 30dd
CS2	T26N,R37E, Sec. 5ba
CS3	T26N,R36E, Sec. 18b
CS4	T26N,R37E, Sec. 5ba
CS6	T23N,R34E, Sec. 20
CS7	T23N,R33E, Sec. 24ad
CS8	T22N,R33E, Sec. 11ad

Figure H-1 shows the meteoric water line (MWL), $\delta D = 8(\delta^{18}O)+10$ by Craig (1961) for world wide precipitation. The exact composition is dependent upon the temperature of water condensation and, as is the case with rain in arid environments, how much evaporation the precipitation is subjected to during its descent. Precipitation under cold conditions (high altitude snow) is more depleted with respect to both D and ^{18}O and plots on the lower portion of the MWL (Figure H-1) conversely precipitation under warmer conditions (low elevation rain) is more enriched with respect to D and ^{18}O and plots higher on the MWL (Figure H-1).

The isotopic composition of water can be altered by several processes. The most common is by evaporation. Figure H-1 shows the evaporation trend lines for a water at point A being subjected to evaporation under atmospheric conditions. The resulting water will lie on a line emanating from A. The particular slope of the line is dependent upon several factors, the most important of which is the temperature at which evaporation takes place.

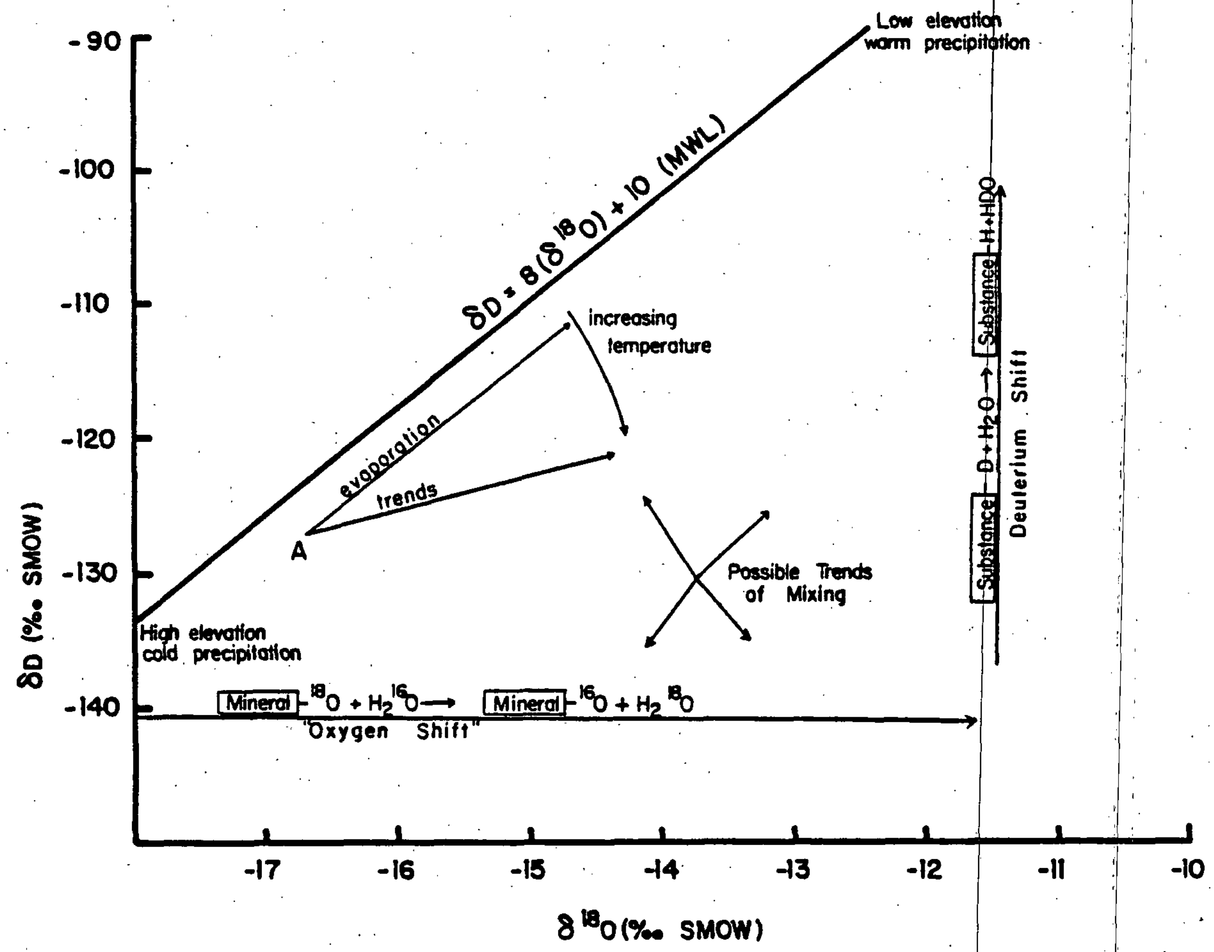

Figure H-1. General Principles of Stable Isotope Data Interpretation.

Once a water has been infiltrated and incorporated into the groundwater system, the isotopic composition will not change unless it is subjected to high temperature such as in a geothermal system. The most common, and widely accepted process which can alter the isotopic composition, occurs during water-rock reaction with respect to Oxygen-18 as shown on Figure H-1. A less common process which is also less accepted is a so-called deuterium shift. The chemical reaction is analagous to the oxygen shift. The water must react with hydrogen-bearing rocks (clays), H_2S or organic substances.

Another process by which isotopic composition can be altered is through mixing. The mixing of two waters of a different isotopic composition will produce a water of an intermediate isotopic composition. If mixing is done in varying proportions mixing lines can be developed on a δD vs $\delta^{18}O$ graph which are usually linear. Mixing can involve any water of any isotopic composition.

H.2.2. Dixie Hot Springs

Seven samples from Dixie Hot Springs were analyzed for stable isotopes. The springs have wide variations in temperature and earlier work (MMRI, 1980) indicated wide variations in chemistry (TDS levels ranging from 638 to 1470 ppm). The $\delta^{18}O$ values show relatively small variations, whereas variations in δD are significant, although no boiling springs occur. Figure H-2 shows a plot of deuterium and oxygen-18 compositions. Spring temperatures are in parenthesis next to the sample number. Deuterium values range between those characteristic of high elevation waters such as the artesian wells (Section H.2.5., Figure H-5) and low elevation waters, such as those from the Stillwater Range (Section H.2.6, Figure H-6).

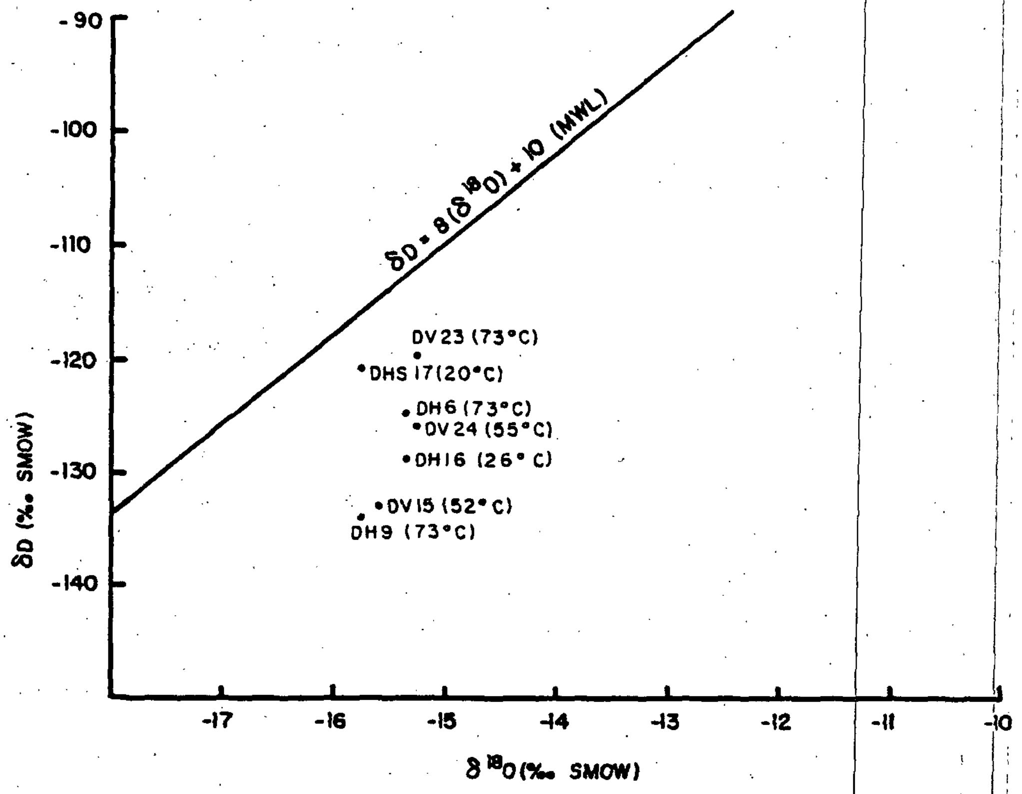

Figure H-2. Deuterium and Oxygen-18 Compositions of Dixie Hot Springs.

Apparently a high elevation water similar in isotopic composition to that from the artesian wells is heated, resulting in a slight oxygen shift. This type of water is probably the original contributor to the Dixie Hot Springs system, which undergoes various degrees of mixing with cold water from the Stillwater Range. Variations in the process of cooling probably account for the differences in temperature.

The Dixie Hot Springs system is located at the intersection of the Dixie Meadows and Mississippi faults (Plate IV, MMRI, 1980). Since the artesian wells are also in the vicinity of the Mississippi fault it lends support to the hypothesis that waters of an isotopic composition similar to that of the artesian wells is mixed with water from the Stillwater Range.

H.2.3. Hyder Hot Springs

The Hyder Hot Springs system is a group of approximately twenty hot springs issuing from a travertine mound in the north central part of Dixie Valley. A thick cover of alluvium apparently exists in this portion of the valley. Hydrogeochemical evidence (relatively constant TDS contents and ioinic concentrations among the various orifices) indicated that the Hyder system is relatively homogeneous with little mixing. The springs probably issue from a single source via a well defined fault-controlled flow system. The isotopic evidence (Figure H-3) tends to support this hypothesis, although there are only three samples. There is little variation in δD or $\delta^{18}O$, indicating a probable lack of mixing with shallow groundwater.

H.2.4 Hot Springs in the Vicinity of McCoy Ranch

The isotopic compositions of these waters are relatively homogeneous (Figure H-4). The small variations are probably due to mechanisms similar to those described for the Dixie Hot Spring system. All the springs in this area seem to be associated with the Dyer Fault system (Plate IV in MMRI, 1980), which probably accounts for their isotopic and chemical homogeneity. Most of the springs seem to be similar in chemistry and deuterium composition to Hyder Hot Springs, although Hyder is apparently related to a different fault system.

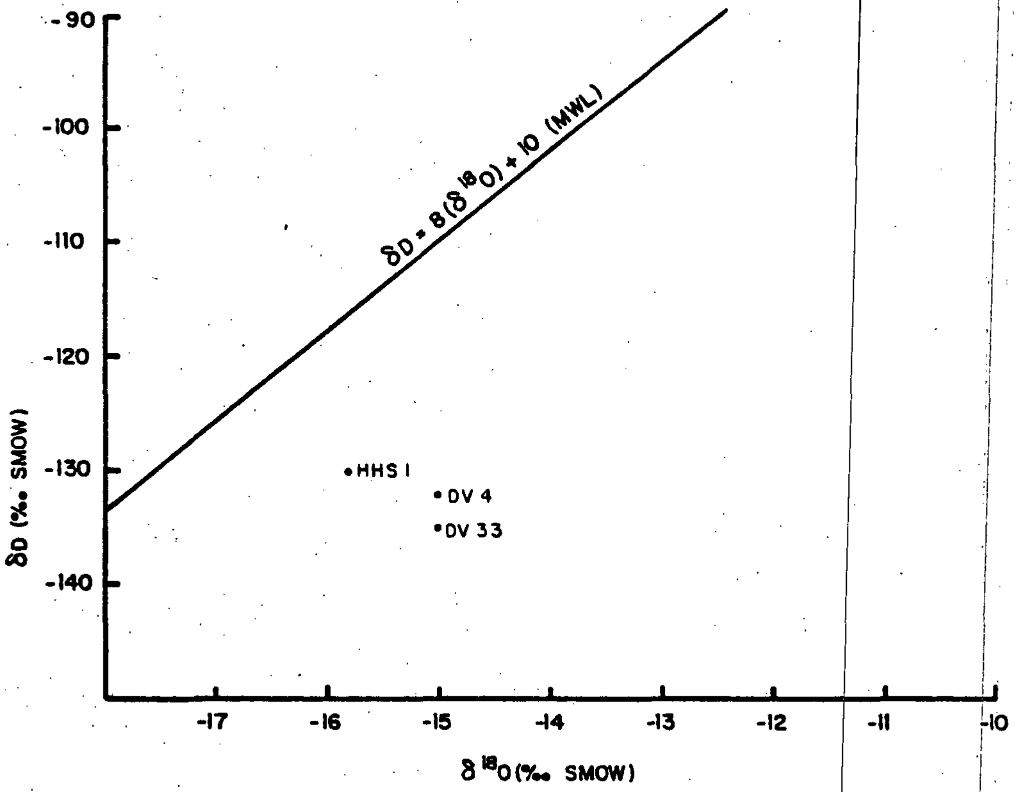

Figure H-3. Deuterium and Oxygen-18 Compositions of Hyder Hot Springs.

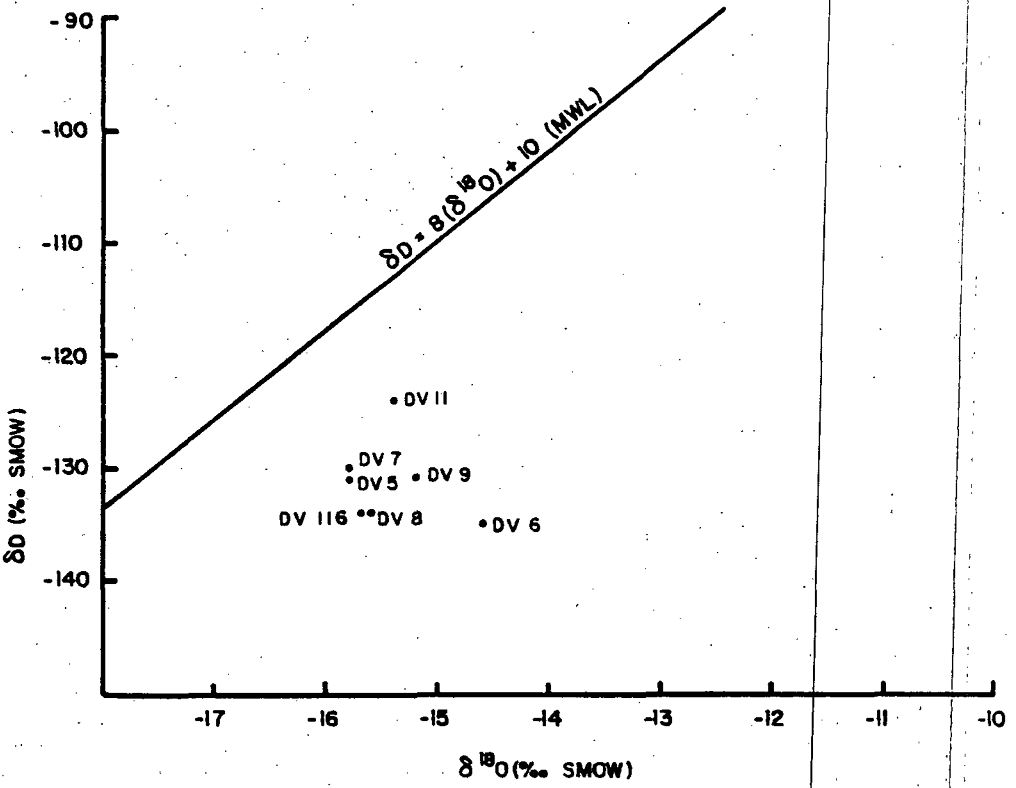

Figure H-4. Deuterium and Oxygen-18 Compositions of Hot Springs in the Vicinity of McCoy Ranch.

H.2.5 Artesian Wells at Dixie Settlement and Waters from the Eastern Mountain Ranges.

Both sets of waters were originally considered similar with respect to their chemical composition (MMRI, 1980). For this reason the Clan Alpine Mountains were, at least partially, considered as the recharge area for the waters discharged from the artesian wells. The isotopic composition of waters from the eastern mountains is variable and indicates low elevation waters (Figure H-5). Only one sample (DV83 from Shoshone Spring) plots within the range of the artesian wells, which are all high elevation waters.

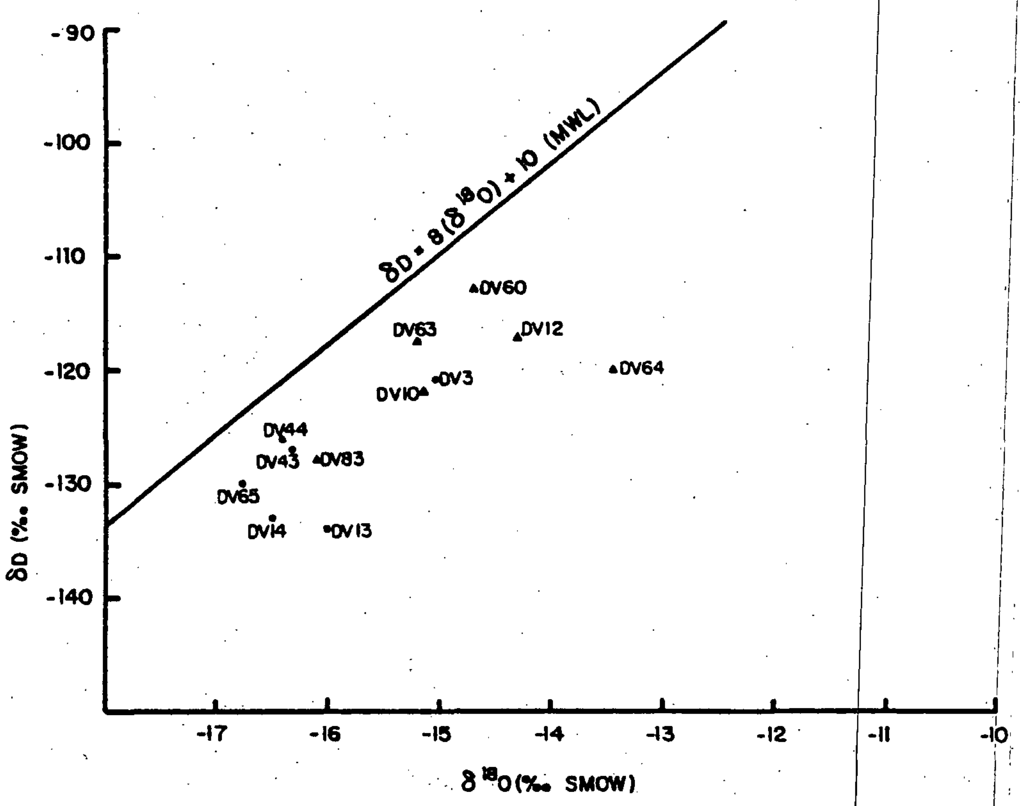

Figure H-5. Deuterium and Oxygen-18 Compositions of Artesian Wells at Dixie Settlement (•) and Waters from the Eastern Mountain Ranges (▴).

According to water chemistry Shoshone Spring is an anomaly within all the other waters in the eastern mountains (DV91 in MMRI, 1980). It is a warm spring (32°C) and its chemical similarity to the artesian wells originally led to the conclusion that the artesian wells are recharged from the Clan Alpine Mountains. However, despite their chemical and isotopic similarity it remains questionable whether there is a hydrologic connection between Shoshone Spring and the artesian wells, since they are about fifteen miles apart on opposite sides of a mountain range. Shoshone Spring remains an anomaly in the Clan Alpine Mountains, in that it constitutes a manifestation of thermal water at an altitude 1500 feet above the bottom of Dixie Valley.

H.2.6 Waters from the Stillwater Range

Variations in $\delta^{18}O$ and δD are significant in this area (Figure H-6). Some of the variations can be explained readily. DV92 is very likely affected by evaporation due to heating since it was diverted across the valley in a PVC-pipe to the site of DF66-21. Variations due to evaporation might also apply to some of the samples from Cottonwood Creek and the west side of the Stillwater Range. On the other hand, samples which were also likely subjected to evaporation, such as those from White Rock Canyon Creek (e.g. DV45 to DV49) do not

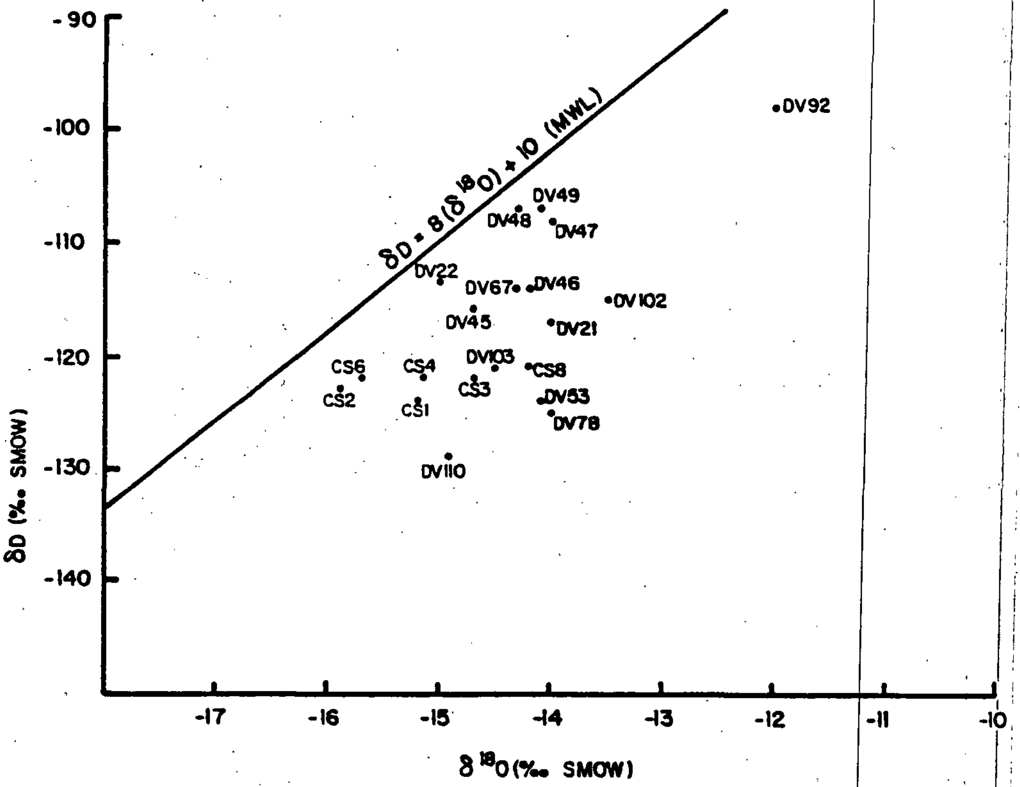

Figure H-6. Deuterium and Oxygen-18 Compositions of Waters from the Stillwater Range.

display variations that could be interpreted as evaporation. Generally variations in isotopic compositions from the Stillwater Range are due to evaporation and different elevations of precipitation and no oxygen shifts due to temperature can be recognized.

In the hydrogeochemical investigation it was found that all the streams in the Stillwater Range deposit $CaCO_3$ and that their TDS and calculated CO_2-pressures were anamalously high. However, the isotopic values are as expected for this type of terrain. Nevertheless, because of the chemical anomalies more work on hydrogeochemistry and isotopes should be undertaken.

H.2.7 Sou Hot Springs

The four samples from Sou Hot Springs (DV1, DV2, DV35 and DV36) exhibit little variation in $\delta^{18}O$ among themselves, but large variations in δD do exist--as much as in Dixie Hot Springs (Figure H-7). DV2 is the most depleted in δD of any individual hot spring sample. The low δD values indicate a high elevation recharge source for the Sou

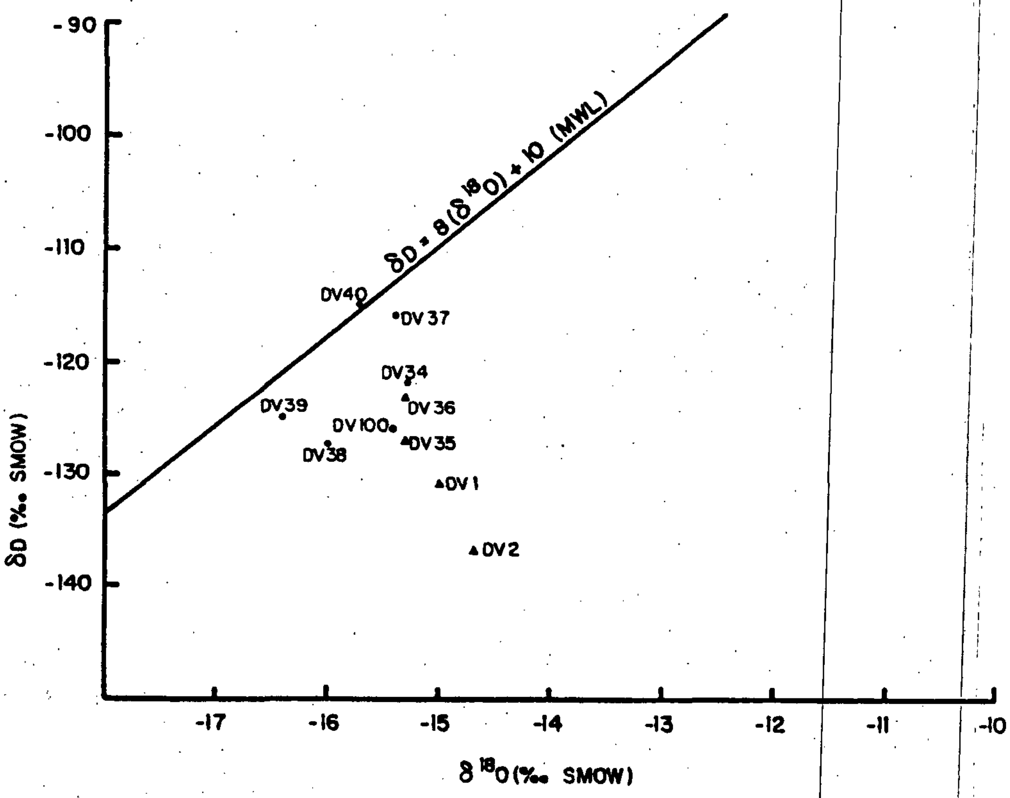

Figure H-7. Deuterium and Oxygen-18 Compositions of the Irrigation Wells (•) and Sou Hot Springs (▴).

system. The variation in δD between DV2 and DV35, which were taken from the same orifice two months apart, implies different degrees of mixing between thermal ^{18}O shifted waters and shallow groundwater at different times. The groundwater found in the irrigation wells to the east of Sou Hot Springs (DV34, DV37 and DV40) may be similar to the water that mixes with the thermal water derived at high elevations.

H.2.8. Deep Wells DF45-14 and DF66-21

Isotopic analyses of representative samples from these two wells would undoubtedly provide a wealth of information on the nature of the Dixie Valley geothermal system. A total of 12 samples (7 from DF45-14 and 5 from DF66-21) were collected from these wells. Unfortunately the validity of some of these samples is questionable. Possible casing ruptures and subsequent contamination by shallow groundwater, drilling fluid contamination, incomplete flushing of the wells, etc. cast doubts on the validity of the isotopic analyses from these wells. The following discussion must therefore be read in light of the aforementioned potential sources of contamination.

The initial sample (DV69) from DF45-14 exhibited the largest ^{18}O shift of any sample collected during the project (Figure H-8). However, DV69 as well as all the other samples taken from DF45-14 on that same day (DV70 to DV72) were very likely contaminated with water from temperature gradient hole SR2-A, which was used for flushing. Subsequent sampling of this well showed a gradual diminishing in the magnitude of this shift. The last sample from this well, DV126 (collected in December 1979) showed little ^{18}O shift. This same trend was observed in DF66-21, although the shift was not as pronounced. This reduction in ^{18}O shift probably represents a mixing/contamination of the original geothermal fluid with shallow groundwater, spring waters and/or drilling fluids (DV93 is probably contaminated with water represented by DV92-Figure H-8). Little change is apparent in samples collected between September (DV90) and December (DV126) of 1979. This implies that the mixing/contamination has reached equilibrium.

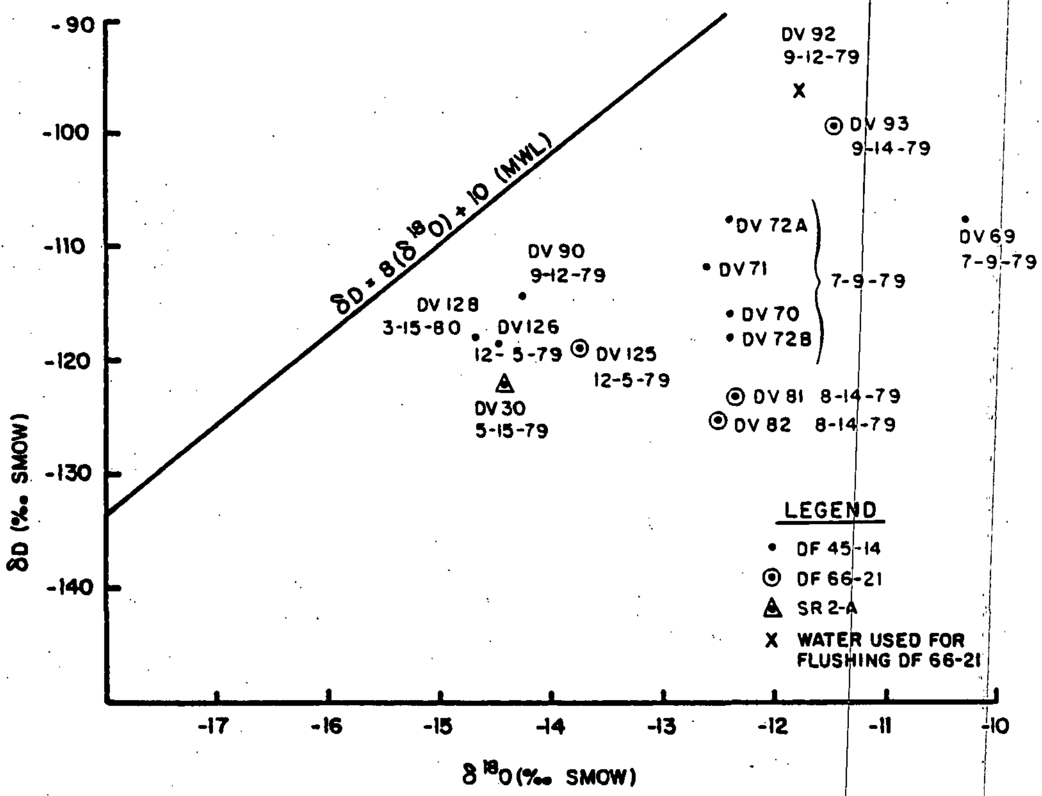

Figure H-8. Deuterium and Oxygen-18 Compositions of Deep Wells DF45-14 and DF66-21.

The last samples from these wells (DV90, DV125, DV126) plot near the waters from the eastern slopes of the Stillwater Range (DV45, DV46, DV67) and waters from the Clan Alpine Mountains (DV10, DV3, DV63). This indicates that waters of this isotopic composition are mixing with/contaminating the geothermal fluids.

The initially high deuterium contents in DF45-14 could be the results of a "deuterium shift" (Panichi and Confiantini, 1978). Shifts in deuterium contents are generally not as common as ^{18}O shifts because rocks normally contain more oxygen than hydrogen. Notable exceptions are rocks with clay and micaceous minerals (Ellis and Mahon, 1977) and those containing organic matter. The fracture zones (see Bard, MMRI 1980) encountered in DF45-14 were encountered in the organic-rich fine-grained metasiltstone/metashale, which could be responsible for the initially high levels of deuterium in this well. However, deuterium shifts are not well accepted or documented. White (1973, p. 553) stated that water-rock reactions and membrane filtration of isotopes have not been effective in changing the deuterium content of meteoric water that flows through these systems.

Isotopic exchange between H_2S and H_2O may occur in nature (Hitchon, 1963) thereby providing another mechanism for deuterium content variations. Hydrogen sulfide was noticeable in DF45-14, although no quantitative measurements of H_2S concentrations were made. Nevertheless, the possibility of contamination with shallow groundwater must still be kept in mind.

Assuming that the fluid from DF45-14 underwent a deuterium shift (DV69) to a more deuterium enriched water, and that fluids from DF66-21 were mixed with shallow groundwater, the trend lines of changing composition can be extrapolated backwards to determine an original composition for the fluid (Figure H-9). When this is done, the intersection of these two trend lines yields a hypothetical composition of an original geothermal fluid (H in Figure H-9). This hypothetical fluid has a deuterium composition which is similar to the fluids derived from the hot springs and the artesian wells. This implies recharge for the deep geothermal system from high elevation waters which underwent a significant oxygen shift (a horizontal shift is inferred assuming no boiling occurred at depth).

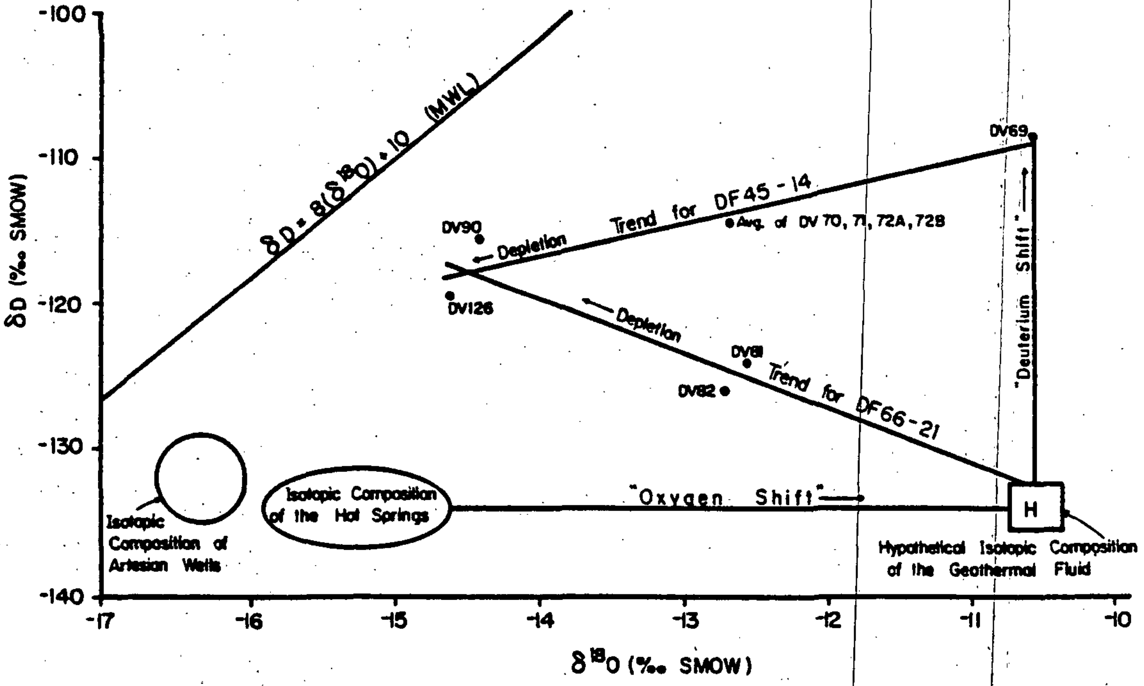

Figure H-9. Inferred Trend Lines of Changes in Isotopic Composition of Samples taken from DF45-14 and DF-66-21, and the Isotopic Composition of a Hypothetical Geothermal Fluid.

H.2.9 Interpretations of Stable Isotope and Hydrogeochemical Data.

Figure H-10 is a plot containing all isotope data collected (see Table H-3 for location codes). It allows comparisons between the various geographical groups of samples. Aside from seasonal variations, a geographical grouping is vaguely discernible.

Assuming that lower δD values indicate relatively high elevations (Figure H-1) as sources of groundwater and vice-versa, changes on the vertical axis should permit some conclusions on the sources of water and the hydrologic system as such. Hyder Hot Springs, Sou Hot Springs, the artesian wells at Dixie Settlement, most of the hot springs in the vicinity of McCoy Hot Springs and parts of Dixie Hot Springs have, in comparison to all the other samples, the highest elevations as sources. They are all discharged in the lower part of Dixie Valley. However, the samples from the surrounding mountain ranges have lower elevations as sources. Unfortunately, no snow samples from the tops of these mountains have been collected. Thus they could possibly have deuterium values comparable with those found in the waters from the lower parts of the valley.

The fact that high elevation waters discharge in the lower parts of the valley is in agreement with the classical models of arid basin hydrogeology (e.g. Maxey, 1968 and Mifflin, 1968). Figure H-11 shows that high elevation waters (with long flow paths) discharge in the center of the valley. All waters that are apparently derived from high elevations have one or another feature that indicates geothermal activity, which is another hint of deep flow (Figure H-11). Thus, it is very likely that recharge waters from the Stillwater Range, the Clan Alpine and Augusta Mountains penetrates to various depths and undergoes varying oxygen shifts under different temperature regimes. This water mixes to various degrees in the shallow subsurface with water originating from relatively lower elevations, and discharges in hot springs and wells in Dixie Valley. Systematic collection of stable isotope data of snow at various elevations from the surrounding mountains could substantiate this hypothesis.

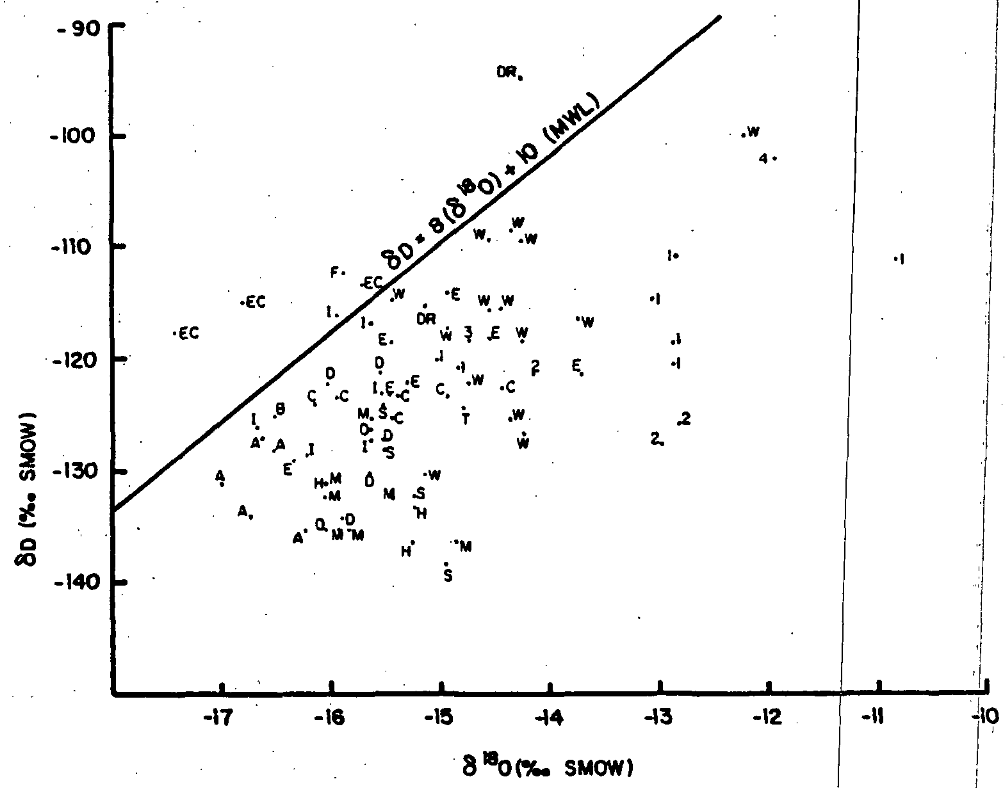

Figure H-10. Deuterium and Oxygen-18 Compositions of Dixie Valley and Surrounding Waters.

Table H-3. Location Codes for Figure H-10.

Code	Description
A	Artesian wells in the vicinity of Dixie Settlement
B	Buckbrush Seeps
C	Carson Sink (western slopes of the Stillwater Range)
D	Dixie Hot Springs
DR	Dixie Valley rain
E	Spring or stream from the eastern mountain ranges (Clan Alpine and Augusta Mountains)
EC	Edwards Creek Valley
F	Fairview Valley
H	Hyder Hot Springs
I	Irrigation wells in the northern part of Dixie Valley
M	Intermediate temperature springs around McCoy Ranch
P	Pleasant Valley
S	Sou Hot Springs
T	Temperature Gradient Hole SR2-A
W	Spring or stream from the Stillwater Range
1	DF 45-14
2	DF 66-21
3	DF 45-14
4	DF 66-21

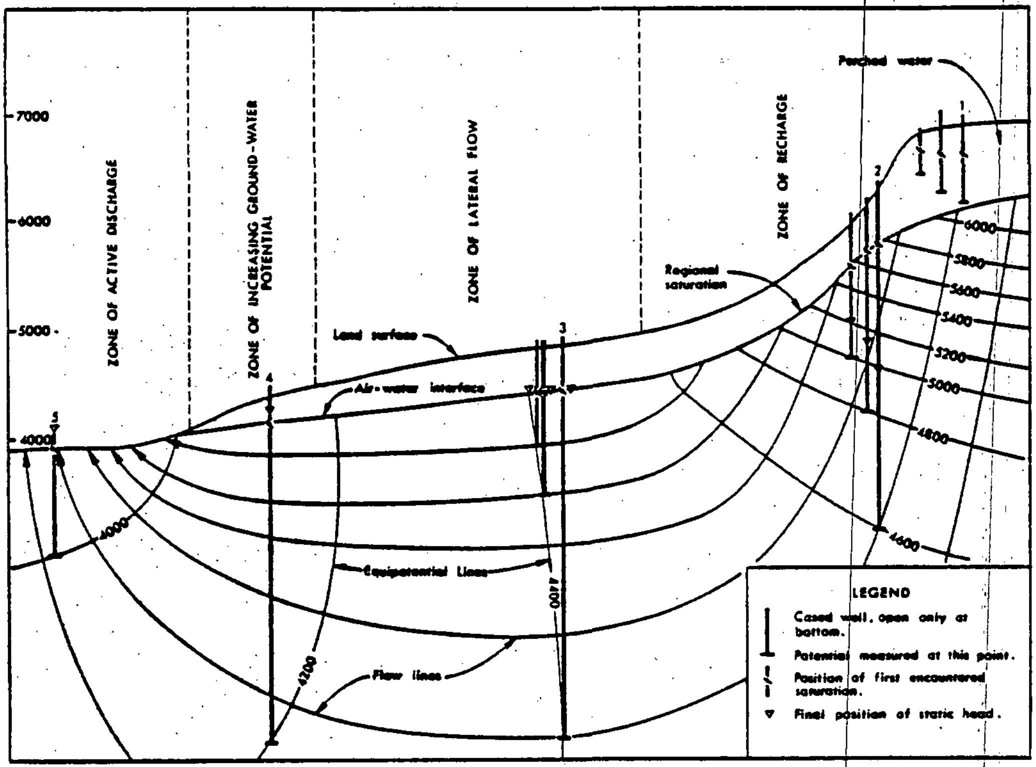

Figure H-11. Sketch of Observed Relationship in a Typical Desert Basin Flow System (after Mifflin, 1968)

However, it should be pointed out that similar deuterium values for the hot springs and geothermal wells does not necessarily imply that they are hydraulically connected. It rather implies that they are all recharged from one common source or a set of similar sources.

All waters that display geothermal characteristics are also associated with various major fault systems (Plate IV in MMRI, 1980). In general the chemical characteristics between the hot spring systems are variable, whereas their deuterium levels are similar. An exception is Hyder Hot Springs which is chemically similar to the hot springs distributed across the northeastern part of the valley, although Hyder is associated with a different fault system.

In several cases the grouping displayed in Figure H-11 has a surprising similarity with the one used earlier in the hydrogeochemical interpretation (MMRI, 1980). This supports the hypothesis that particular geographic areas are dominated by certain hydrologic, chemical and thermal regimes.

A comparison between isotopes and hydrogeochemistry also poses some contradictions. Waters from the Stillwater Range and some waters from the eastern mountains (DV10) have comparatively high TDS levels for mountain spring waters. Contrary to that, the waters discharged in the artesian wells in the center of the valley have some of the lowest TDS levels in the area. This is surprising, since the low deuterium values indicate high elevation waters with relatively long flow paths (Figure H-11) that would cause high levels of TDS.

The occurrence of a warm spring in the mountains (Shoshone Spring) discharging water that was derived from a higher elevation than the surrounding mountain springs suggests the possibility of the emergence of diluted thermal waters in some of the mountain canyons. The unusually high CO_2 pressures in most mountain springs and extensive sinter deposition in the Stillwater Range seem to support this hypothesis.

H.2.10 Tritium Concentrations

Tritium (^3H) samples were collected along with the stable isotope and chemical samples at each collection site. Due to the lack of detectable tritium in the samples and the cost of tritium analyses, they were soon terminated. Twenty-seven samples were run unenriched, a process yielding lower detection limits of 100 tritium units (TU). Only one sample, DV1, had detectable amounts. DV1 was taken from a pool in a large travertine crater at Sou Hot Springs which has no apparent discharge. It is assumed that the high reading is due to the pooling of precipitation of higher tritium content than the hot spring water and evaporation. This analysis also has an inherently large analytical error (300 ± 240 TU), which makes conclusive interpretation almost impossible.

A spring in Dyer Canyon on the western slope of the Clan Alpine Mountains did have a significant tritium level (58 ± 8 TU). No hot spring, artesian well, or deep well showed detectable quantities, indicating that the deep ground water and thermal systems are pre-bomb test (1954) waters. Some mountain spring and shallow groundwater, however, must be post-bomb water as the spring in Dyer Canyon (DV12 indicates.

H.3 Conclusions

Two of the three major hot spring systems, Dixie and Sou Hot Springs, discharge a mixture of two waters, each of which is characterized by its own isotopic composition. One type of water is more depleted with respect to deuterium ($\delta D = - 134^{o}/oo$) and originates at high elevations (> 7000 feet). This water moves downward, is heated and shifts toward a more enriched ^{18}O content. The second type of water is a non - ^{18}O shifted water that plots close to the MWL at about $\delta D = 122^{o}/oo$. This water is derived from precipitation at lower elevations (< 7000 feet) than the first water. These waters mix in differing proportions, resulting in the composition of the waters discharging at Dixie and Sou Hot Springs. The waters from the artesian wells near Dixie Settlement and the hot springs in the vicinity of McCoy Hot Springs also exhibit this same pattern. Hyder Hot Springs is dissimilar to the above systems. The isotopic results are similar to the hydrogeochemical results in that they suggest that the Hyder system is relatively homogeneous, isolated from the other systems and emanates from a different reservoir. Very little mixing with shallow groundwater occurs in the Hyder system. Recharge is derived from high elevation snows, probably at about the same elevation as the deuterium-depleted component of the waters at Dixie and Sou Hot Springs.

The waters from DF45-14 and DF66-31 are derived from high elevations (> 7000 feet) snows. These waters become heated at depth and acquire the characteristic ^{18}O shift. In addition, the water from DF45-14 may experience a deuterium shift after reacting with clay minerals, hydrogen sulfide and organic matter. Waters from both wells probably mix with shallow groundwater, either naturally and/or by contamination during drilling. It is difficult to draw valid inferences from the DF45-14 and DF66-21 samples because of possible contamination; the samples obtained may not be representative of the geothermal fluids in the system.

In summary Dixie Valley represents a major groundwater sink for the surrounding basins. Recharge occurs in the mountains. Water infiltrated at the highest elevations is discharged in the lowest parts of the valley either in hot springs, geothermal wells, in low temperature artesian wells and by evapotranspiration in the Humboldt Marsh.

Contrary to accepted beliefs, here groundwaters with high TDS contents are discharged in the mountains whereas low TDS waters are discharged in some parts of the central valley. It is also possible that waters with geothermal features are discharged in some parts of the mountains.

H.4 References

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Department of Geological Sciences

December 9, 1980

Mr. Howard Ross
University Utah Research Institute
Earth Science Laboratory
420 Chipeta Way, Suite 120
Salt Lake City, Utah 84108

Dear Howard:

Enclosed please find copies of seven pages of the volume 3, Soil Geochemistry and Petrochemistry report of the Dixie Valley Geothermal Case Study. These pages should be substituted for the appropriate pages in the copy you have prior to reproducing the report for public release.

The mylars for the plates of the report are being sent under separate cover by UPS and should arrive shortly. I hope that no delay occurs during shipping to alter the public release date for this report.

If I can be of any further assistance, please do not hesitate to contact me.

Best regards,

Elaine J. Bell
Geologist/Research Associate

enc.

Table 3-2

Successive Mercury Analyses at One-Week Intervals

Sample Number	Mercury Values (in ppb) 1	2	3	4
15	88	82	50	63
36	232	170	305	280
65	28	10	21	15
85	116	109	124	125
98	376	308	366	343
125	52	87	48	85
160	272	240	350	248
193	156	135	130	120
242	40	25	50	20
287	156	165	120	115
310	28	55	38	35
362	84	70	62	75
401	16	10	10	12

Table 3-3

Successive Arsenic Analyses at Four-Month Interval

Sample Number	Arsenic in ppm (9-6-1979)	Arsenic in ppm (3-4-1980)
1-10	11	10
1-35	14	15
2-5	15	15
2-15	12	10
2-35	16	10
3-15	46	50
3-35	25	30
3-45	24	20

spring issuing from the range front, or it may be due to water migrating up from deeper zones along permeable structures. This latter possibility is supported by the convergence of several of the major fault systems in the area: the Stillwater, Marsh and Dixie Meadows faults (Plate III). Additionally the southernmost, probably southeast trending, margin of the Humboldt gabbroic complex probably occurs very near this point in the valley. An area of abnormal aeromagnetic gradients also terminates at or near this area and may be related to the gabbro.

3.2.4.7 Dixie Meadows Fault (Section 32, T24N, R36E)

The Dixie Meadows fault describes an arcuate path to the northeast from Section 36 (T24N, R36E). In the southeast corner of Section 32 (T24N, R36E) an area of anomalous temperatures measured at one meter depth (Campana and others, 1980) occurs near the fault trace. This area is near the 455 m (1500 ft) gradient hole drilled by Southland Royalty Company in 1978 which showed an average gradient of approximately 7.5°C/100 m (4.1°F/100 ft). Both arsenic and mercury show high anomalous values in this area with fairly linear northwesterly trends (Plates I and II) near the postulated trace of the Dixie Meadows fault. Follow-up sampling was done in this area at 30 m (100 ft) intervals along a traverse (Line A-A'; Plate III) transecting the Dixie Meadows fault; the results are shown in Figure 3-13. A dominant mercury peak appears to be spatially associated with the approximate trace of the Dixie Meadows fault. Arsenic values tend to mimic the mercury particularly west of the fault trace. While indicated by only three points on the traverse mercury values appear to fall off rather rapidly to background levels east of the fault trace. This may be due to the presence of finer-grained sediments to the east. The correlation between arsenic and mercury is very weak for this traverse ($r = -0.02$) and, as at White Rock Canyon (Line B-B'; Plate III), may be due to the effects of hydromorphic processes upon arsenic.

The fault zone in this area may be relatively wide thus accounting for the rather broad band of anomalous mercury. This is supported by a wide area of lineaments and other fault related features identified on low-sun-angle aerial photography (Whitney, 1980). While structural control of the observed geochemical trend across profile A-A' is likely,

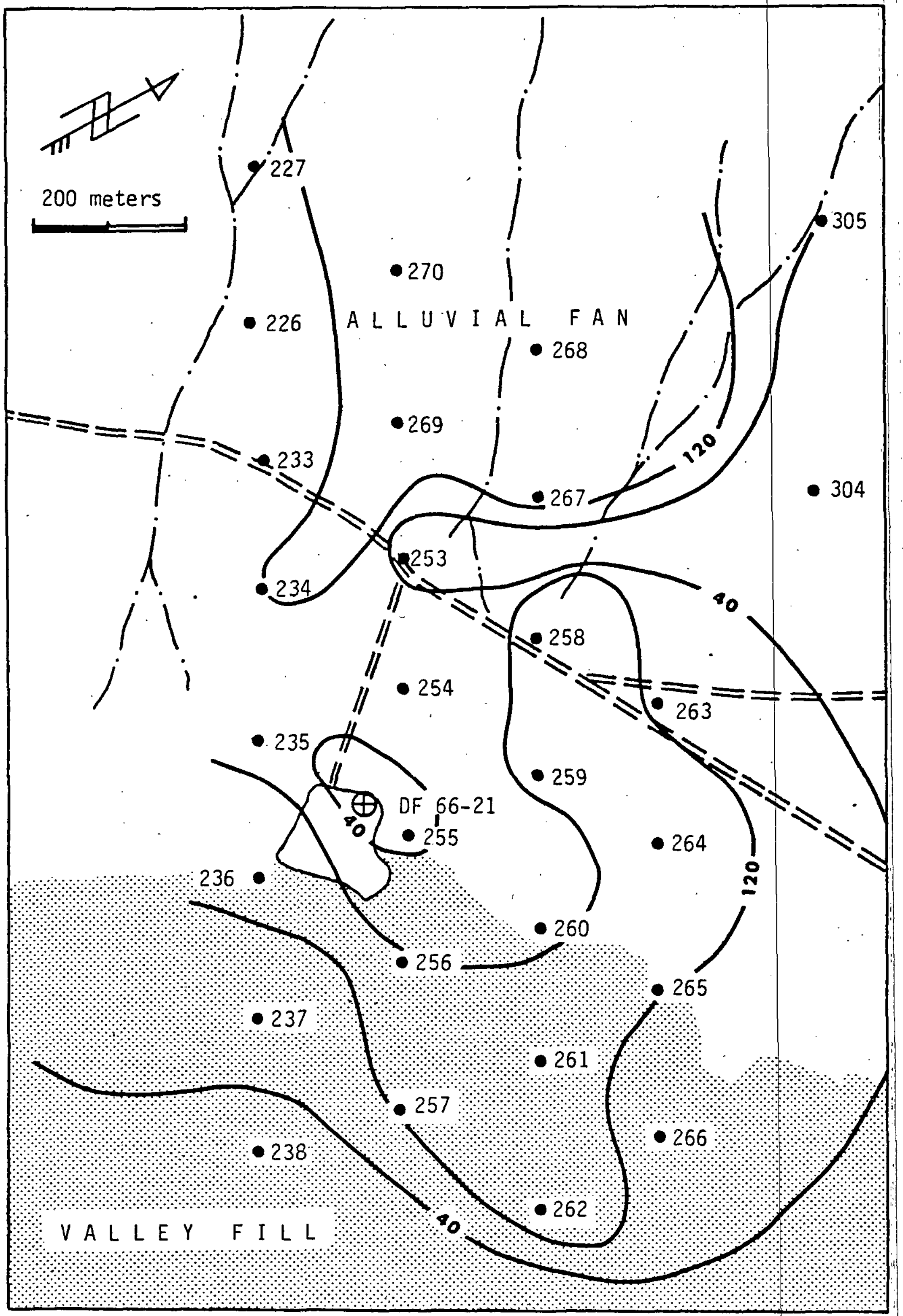

Figure 3-15a. Contoured mercury geochemical surface in vicinity of DF 66-21. Values indicated by contours; sampling sites indicated by solid circles; extent of geomorphic surfaces indicated by shading.

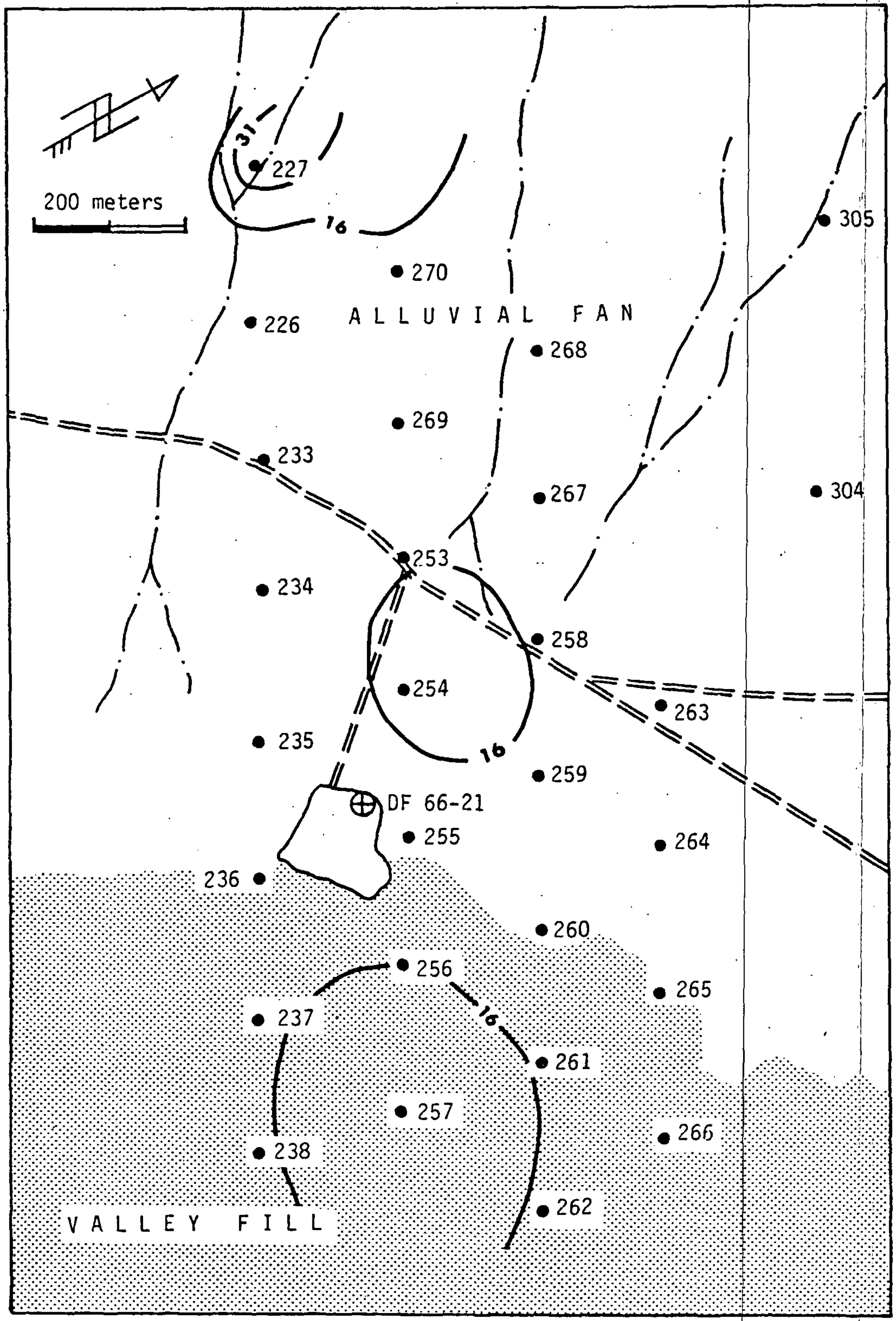

Figure 3-15b. Contoured arsenic geochemical surface in vicinity of DF 66-21. Values indicated by contours; sampling sites indicated by solid sircles; extent of geomorphic surfaces indicated by shading.

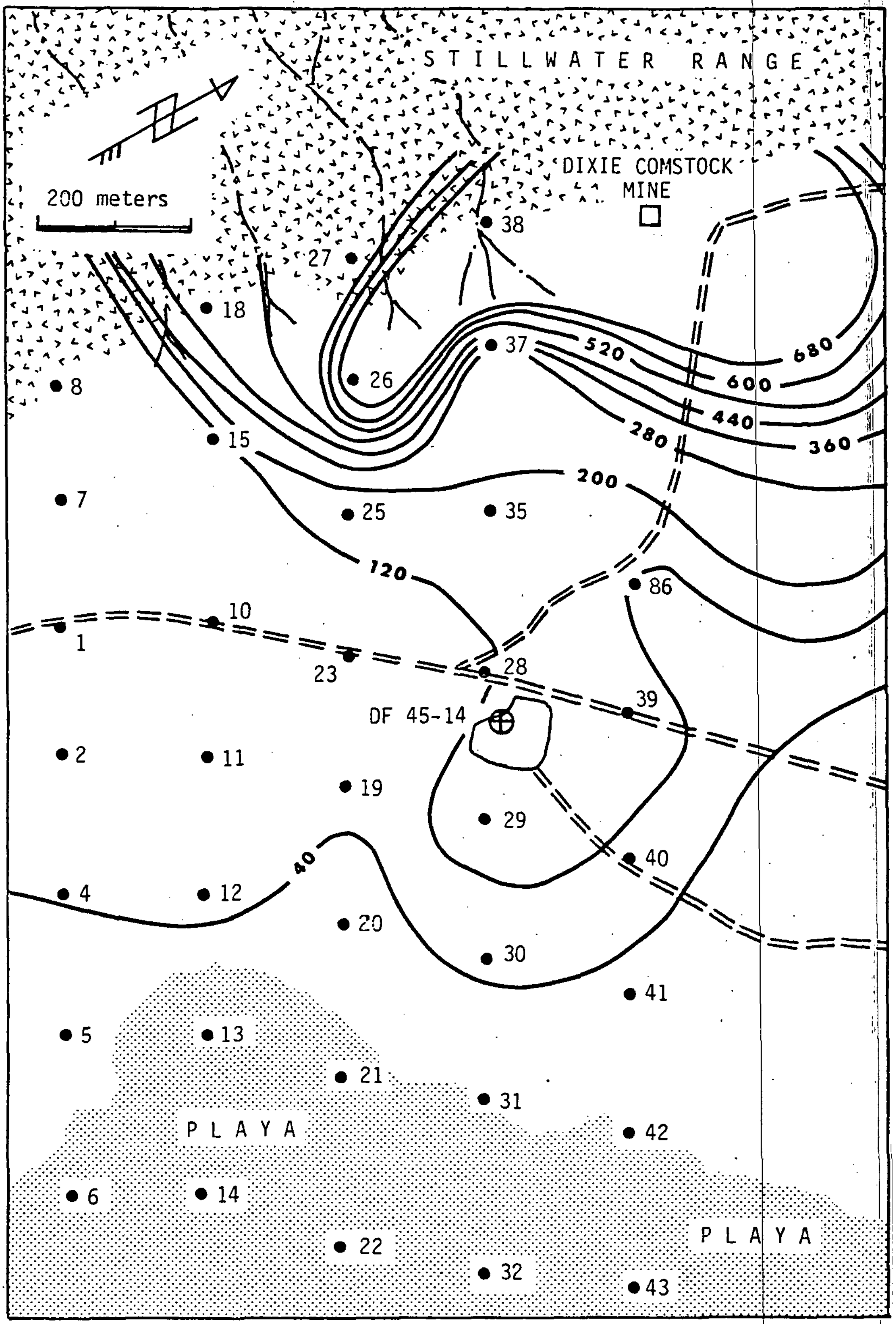

Figure 3-16a. Contoured mercury geochemical surface in vicinity of DF 45-14. Values indicated by contours; sampling sites indicated by solid circles; extent of geomorphic surfaces indicated by shading.

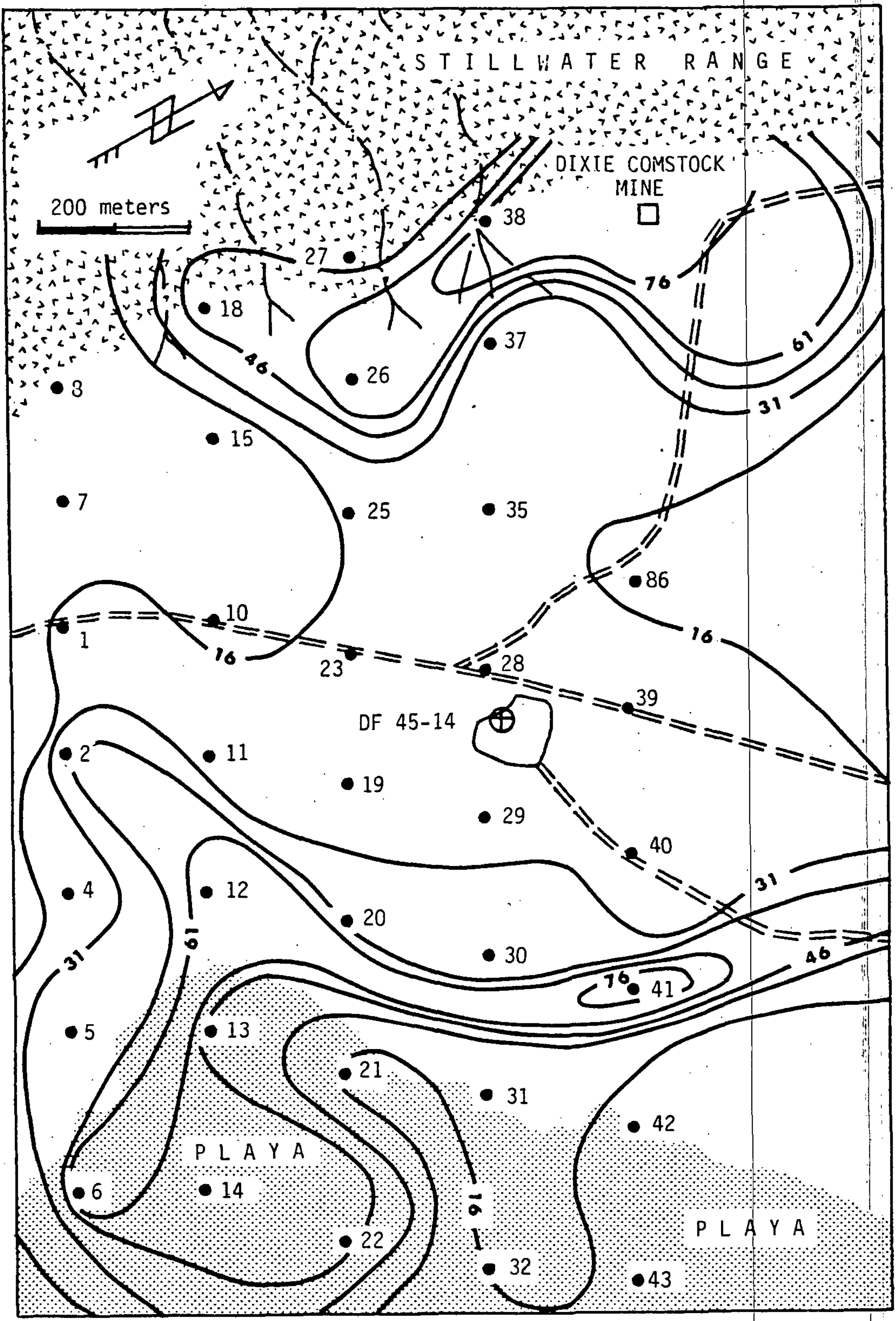

Figure 3-16b. Contoured arsenic geochemical surface in vicinity of DF 45-14. Values indicated by contours; sampling sites indicated by solid circles; extent of geomorphic surfaces indicated by shading.

signature. The anomalous lead (7500 ppm) and mercury (9.0 ppm) concentrations in the interval 2200 to 2400 feet (Figure 4-13) associated with the top of a red clay-alluvial sequence are interpreted as being deposited from aqueous solutions or adsorbed from vapor transport by +3.3 heavy mineral phases at the low-permeability boundary produced by the clay content. The source for the lead and mercury is uncertain; there may be an unrecognized fracture system in the overlying alluvial sequence, or more likely, thermal fluids released in the alluvium may be flowing through the ground water system with downward percolation inhibited by the impermeable clay.

From the lowermost portion of the clay-alluvial sequence to the total depth of the well at 9780 feet, the rocks show an increasingly pervasive influence of the geothermal system: silicate minerals (primarily epidote) with minor pyrite are replaced by a pyrite dominated assemblage. Within the silicate dominated zone is a major active fault system between 4800 and 5400 feet. An anomalous concentration of zinc (10,800 ppm) marks the most active portion of the fault zone where, during drilling, hot fluids under high pressure were encountered. The most significant indication of mineralization in this interval is the presence of flakes of native gold in the heavy mineral fraction sample. A halo of mercury with anomalous concentrations ranging from 6.3 to 39.0 ppm overlies the fault zone, with maximum concentrations occurring in the lowermost portion of the red clay-alluvium sequence. These maximum mercury concentrations are the result of adsorption of the vapor transported mercury by fine-grained +3.3 mineral phases in the base of the clay sequence, with upward migration of the volatile mercury limited by the impermeability of the clay.

Below 5400 feet are four zones containing anomalous element concentrations (Figure 4-13) interpreted as being the result of active migration of thermal fluids through fracture zones. Anomalous lead (11,500 ppm), antimony (1300 ppm) and mercury (9.4 ppm) concentrations are associated with a mineralized fracture zone in the interval 7400 to 7600 feet. A 250 ppm zinc and 3.2 ppm mercury anomaly is associated with a fracture zone identified at 8000 to 8100 feet. The fracture zone encountered at the bottom of the well (9780 feet) is associated with anomalous concentrations of zinc (600 ppm) and mercury (4.6 ppm). The range of concentrations for lead (4000 to 11,500 ppm), zinc (250 to 10,800 ppm), and