GEOTHERMAL BRANCH

INTER-OFFICE MEMORANDUM

SUBJECT: Preliminary Geochemical Analysis
Bully Creek Area, Oregon

DATE: June 7, 1982

TO: H. J. Olson

FROM: H. D. Pilkington

The first AMAX report on geochemistry of the Bully Creek area was done by Frank Dellechaie in 1975, and included only data from Jordan (Neals) Hot Spring. Jordan Hot Spring is actively depositing siliceous sinter which contains over 90% SiO_2. Quaternary terrace gravels immediately north and west of the hot springs are well cemented by silica which suggests the geothermal system has been active for a considerable period of time. The area contains numerous northwest trending zones of silicification in the form of tan to buff colored chalcedonic quartz. The silica veins extend about 9km northwest from the hot springs.

GEOCHEMICAL DATA BASE

Within the area of the Bully Creek property, Dellechaie (1975) reported analyses on four water samples. In May of 1976 Pilkington collected five additional water samples which Dellechaie never wrote up as far as I can determine.

Mariner et al (1974 & 1975) report analyses for Neals Hot Spring (Jordan Hot Springs) and Vale Hot Springs. The chemical analyses from all sources are shown in Table I. The sample locations for AMAX waters are shown on Figure 1.

GEOCHEMICAL CHARACTERISTICS

The Bully Creek area waters are shown graphically on a trilinear diagram (Fig. 2). The thermal waters are sodium bicarbonate waters with variable proportions of sulfate and chloride. The non-thermal waters range from sodium-calcium-bicarbonate waters to calcium-sodium-bicarbonate waters. The waters shown as thermal waters include Coyote Spring which has no thermal signature, only a high sodium content. Likewise those waters shown as non-thermal include waters from a $30^{\circ}C$ aquifer within the Chalk Butte formation which do not exhibit a thermal signature in their chemistry.

Isotopic Studies

Only a limited amount of isotopic data is available in the Bully Creek area (Fig. 3). The analyses for the Bully Creek waters, with the exception of the Vale Hot Springs (from Dellechaie 1975) fall near a horizontal line for $\delta D = -137$ per mil, a value which agrees very well with the eight values published by Mariner, et al, 1975 for Malheur County springs. The strong shift in δD values for the Vale Hot Springs reported by Dellechaie (1975) suggests the point may represent an "analytical bust" or that each of the various hot springs at Vale is fed from a different reservoir-recharge system. The δO^{18} values (Fig. 3) show a pronounced shift to the right of the meteoric line. If we assume the same reservoir rocks for the Bully Creek and Vale areas, then the stronger δO^{18} shift for the Vale waters could indicate that those waters originate from a reservoir with a higher subsurface temperature. However, the oxygen-isotope shift can also be explained by a difference in reservoir rocks, and/or different recharge areas, and/or a difference in the age of the system.

W10232, 9, 91, 91
<0.2 <0.1 0.2, 3.1

W10233 12, 94, 53
0.2, <0.1   0.2, 2.1

W10230, 12, 90, 58
<0.2, <0.1   0.2, 1.9

W14500, 14, 82, 76
<0.2, <0.1   0.2, 0.6

W15502 30, 111, 82
<0.2, <0.1   0.5, 2.8

W10231 12, 110, —
<0.2, <0.1 0.2, 2.8

W10074   19, 94, 43
<0.2, <0.1   0.7, 23.0

W10234 30, 107, 73
0.2, <0.1   0.5, 4.0

W10075 17.5, 81, 91
<0.2, <0.1   0.9, 10.0

X89828 96, 167, 183
4.3, 0.3   9.2, 140.0

AMAX EXPLORATION, INC.
DENVER, COLORADO

Hydrogeochemical Map
BULLY CREEK
Sample #   T~B~, T~Li~, T~Na-Ca-K~
B, Li   F, Cl
Figure 1.

Table I. Chemical Analyses of Water Samples from the Bully Creek Area, Oregon.

	X89828 Jordan H.S. NENWS9T18SR43E	X89844 Vale H.S. SWSES20T18SR45E	W10074 Bully Creek C.S. NWSWS28T17SR43E	W10075 Coyote Spring SENWS5T18SR43E
Temp^{o}C	96.0	91.0	19.0	17.5
Flow (gpm)	100.0	25.0	1.0	2.0
pH	7.59	7.78	8.1	7.6
Cl	140.0	340.0	23.0	10.0
F	9.2	6.2	0.7	0.9
SO_4	110.0	120.0	18.0	75.0
HCO_3	198.0	151.0	126.0	197.0
CO_3	0	0	0	0
SiO_2	196.0	120.0	75.0	60.0
Na	218.0	320.0	23.0	490.0
K	17.0	15.0	4.1	8.5
Ca	6.0	19.0	40.0	50.0
Mg	0.3	0.5	9.0	16.0
Li	0.3	0.3	0.1	0.1
B	4.3	9.0	0.2	0.2
TDS	901.0	982.0	319.1	907.7
Ec(k)	---	---	---	---
$TqSiO_2$	167.0	142.0	120.0	1110.0
$TcSiO_2$	157.0	122.0	94.0	81.0
TNa-K	197.0	160.0	272.0*	102.0
TNa-K-Ca	183.0	153.0	43.0	91.0
TNa/Li	94.0*	73.0	177.0*	9.0*
TLi	116.0*	116.0	86.0	86.0
Cl/HCO_3	1.22	3.88	0.31	0.91
Cl/SO_4	3.45	7.68	3.46	0.36

*Values probably do not reflect true subsurface temperatures.

Table I. Continued

	W10230 Bannock Corral Spr. SWNES23T17SR42E	W10231 Grouse Spr. SWNWS27T17SR42E	W10232 Boston Horse Camp Spr. SESES31T16SR42E	W10233 Rattlesnake Spr SESWS6T17SR42E
Temp^{o}C	12.0	12.0	9.0	12.0
Flow (gpm)	2.0	2.3	2.0	7.8
pH	7.2	6.7	6.7	7.1
Cl	1.9	2.8	3.1	2.1
F	0.2	0.2	0.2	0.2
SO_4	12.0	12.0	10.0	10.0
HCO_3	34.0	38.0	43.0	68.0
CO_3	0	0	0	0
SiO_2	71.0	99.0	72.0	76.0
Na	5.9	6.2	8.4	13.0
K	3.5	1.0	4.8	3.4
Ca	7.0	13.0	7.0	13.0
Mg	2.0	3.0	3.0	5.0
Li	0.1	0.1	0.1	0.1
B	0.2	0.2	0.2	0.2
TDS	137.8	175.5	151.8	191.0
Ec(k)	---	---	---	---
$TqSiO_2$	117.0	132.0	118.0	120.0
$TcSiO_2$	90.0	110.0	91.0	94.0
TNa-K	439.0*	262.0*	432.0*	316.0*
TNa-K-Ca	58.0	16.0*	71.0	53.0
TNa/Li	340.0*	322.0*	287.0*	234.0*
TLi	86.0	86.0	86.0	86.0
Cl/HCO_3	0.1	0.13	0.12	0.05
Cl/SO_4	0.43	0.63	0.84	0.57

Table I. Continued

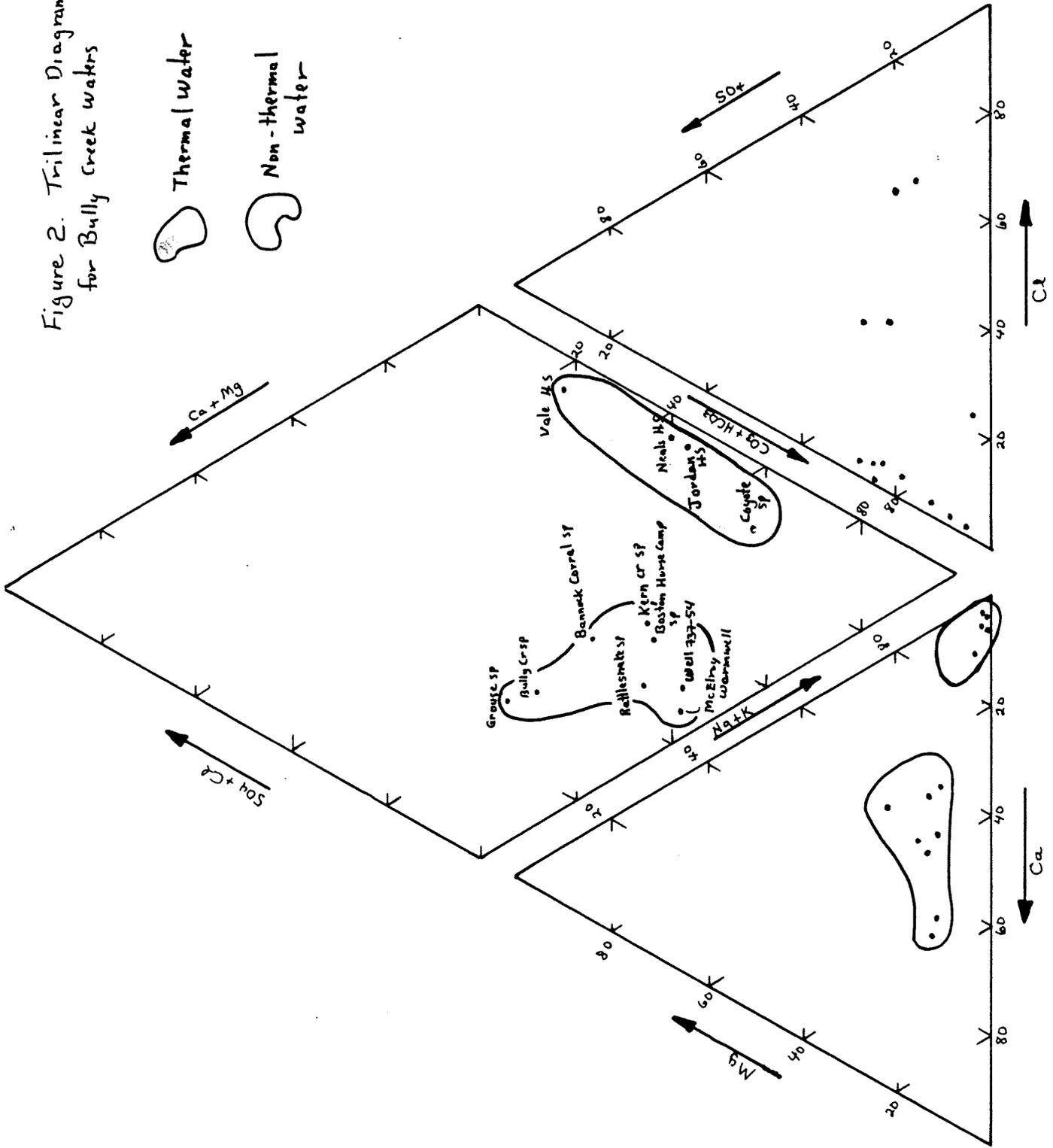|	W10234 Warm Well NENWS1T18SR42E	W14500 Kern Cr. Sprs. NWNES24T17SR42E	W15502 737-54 NENWS25T17SR42E
Temp^{o}C	30.0	14.0	30.0
Flow (gpm)	150.0+	2-3	10.0
pH	7.3	7.2	8.6
Cl	4.0	0.6	2.8
F	0.5	0.2	0.5
SO_4	10.0	13.0	17.0
HCO_3	185.0	40.0	188.0
CO_3	0	0	16.0
SiO_2	94.0	61.0	100.0
Na	36.0	6.0	29.0
K	9.8	5.6	9.1
Ca	38.0	5.7	20.0
Mg	13.0	2.0	16.0
Li	0.1	0.1	0.1
B	0.2	0.2	0.2
TDS	390.6	134.4	398.7
Ec(K)	---	96.0	436.0
$TqSiO_2$	130.0	111.0	133.0
$TcSiO_2$	107.0	82.0	111.0
TNa-K	321.0*	531.0*	340.0*
TNa-K-Ca	73.0	76.0	82.0
TNa/Li	141.0	337.0*	155.0
TLi	86.0	86.0	86.0
Cl/HCO_3	0.04	0.03	0.03
Cl/SO_4	1.08	0.13	0.45

*Do not reflect true subsurface temperatures.

Table I. Continued

	Mariner et al, 1975 Neal Hot Spring NENWS9T18SR43E	Mariner et al, 1975 Vale Hot Spring SWSES20T18SR45E
Temp^{o}C	87.0	73.0
Flow (gpm)	---	---
pH	7.32	7.47
Cl	120.0	360.0
F	9.4	6.1
SO$_4$	120.0	100.0
HCO$_3$	198.0	143.0
CO$_3$	1.0	0.0
SiO$_2$	180.0	130.0
Na	190.0	310.0
K	16.0	16.0
Ca	8.8	19.0
Mg	0.2	0.8
Li	0.3	0.3
B	4.1	9.4
TDS	847.8	1094.6
Ec(K)	1010.0	1530.0
TqSiO$_2$	162.0	145.0
TcSiO$_2$	151.0	128.0
TNa-K	359.0	311.0
TNa-K-Ca	181.0	157.0
TNa/Li	103.0	75.0
TLi	116.0	116.0
Cl/HCO$_3$	1.04	4.33
Cl/SO$_4$	2.71	9.75

Figure 2. Trilinear Diagram for Bully Creek waters

Thermal water

Non-thermal water

Grouse sp
Bully Cr sp
Bannock Corral sp
Rattlesnake sp
Kern cr sp
Boston Horse Camp sp
Well 733-54
McElroy Warmwell

Vale HS
Neals HS
Jordan HS
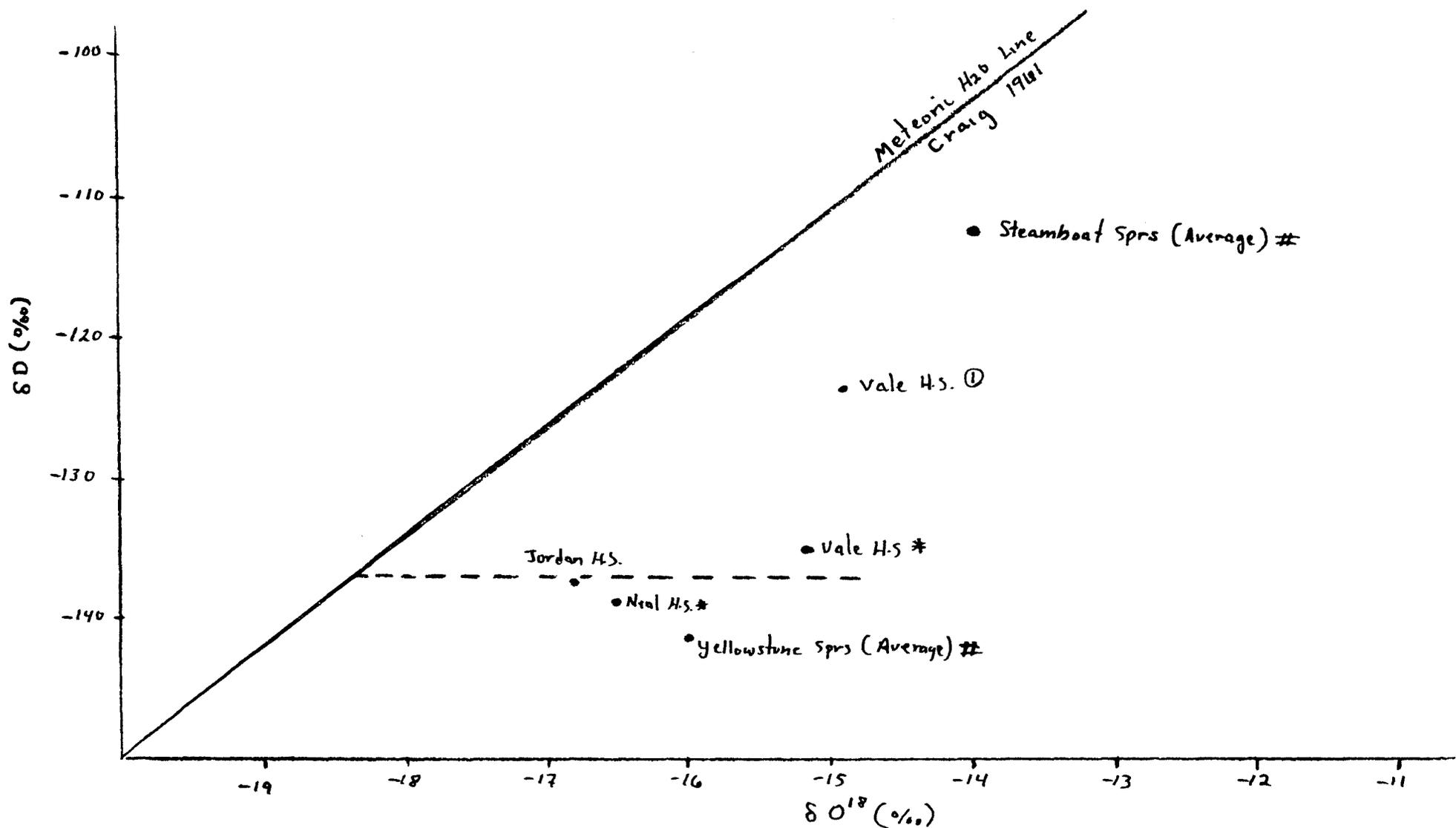Coyote sp

Ca + Mg
Cl + SO4
SO4
CO3 + HCO3
Cl
Na + K
Ca
Mg

Figure 3. Isotopic composition of some Bully Creek area waters. The * denotes analyses from Mariner et al, 1975. The # analyses are from Craig 1963 and the remaining are from Dellechaie, 1975. The ① value value from Dellechaie is probably in error.

The amount of isotopic data available makes it difficult to speculate on the history of the geothermal waters. A much more complete sampling and analytical program will be required to unravel the water history.

Mixed Waters

There are several lines of evidence which suggest mixing of the thermal and non-thermal waters in the Bully Creek area. The isotopic data has been discussed previously. The discrepencies found between the silica geothermometer and the alkali geothermometers (Table I) may be explained by mixing of geothermal waters and meteoric waters. A plot of boron versus sodium for the Bully Creek waters is shown in Figure 4. If the geothermal system represents one reservoir fluid with progressive dilution by meteoric waters we should see a constant B/Na slope from meteoric waters near the origin to the thermal waters. Such a line drawn for the Jordan Hot Springs will not pass through the points for Vale Hot Springs. Therefore, it would appear that the Bully Creek waters represent one geothermal system with progressive dilution while the Vale Hot Springs represent a separate geothermal system.

A plot of boron vs chlorine for the Bully Creek waters (Fig. 5) shows the same relationships as seen for the B/Na plot. Note that the point for Coyote Spring on the B/Cl diagram falls with the rest of the meteoric waters and not with the thermal waters as it did on the trilinear diagram (Fig. 2). On the B/Na plot the point for Coyote Spring falls way off the B/Na constant slope line for the Jordan Hot Springs which suggests its chemistry is not controlled by simple mixing.

The final plot which emphasizes the role of mixed waters is shown on the SiO_2 versus Cl/HCO_3 mole ratio plot shown in Figure 6. A line drawn through the non-thermal springs and Jordan Hot Springs shows one possible group of related waters. Note that the Vale waters fall way off said line indicating they represent a separate geothermal system. The scatter of points around the line suggest that the water chemistry is also affected by water-rock reactions.
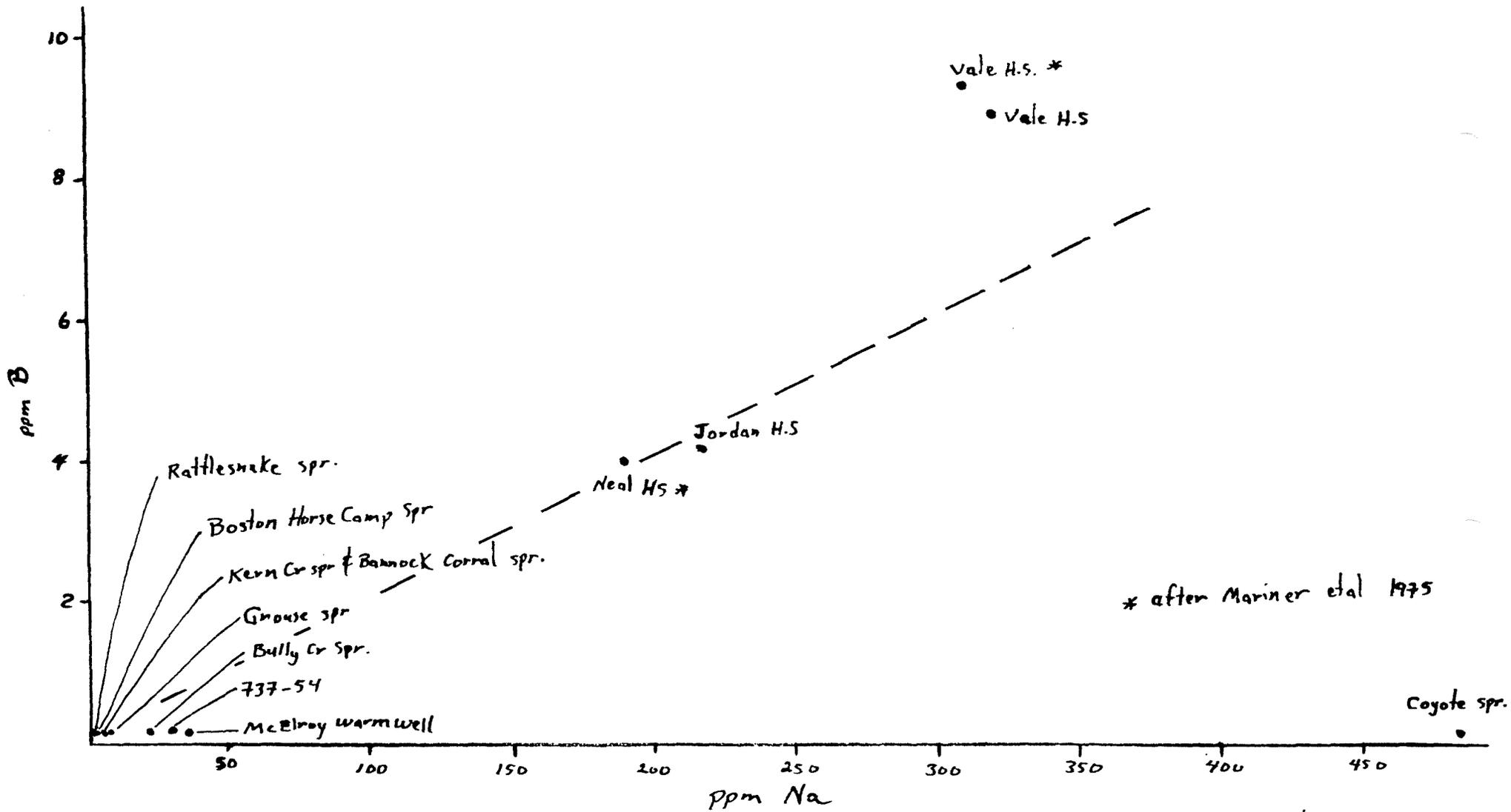
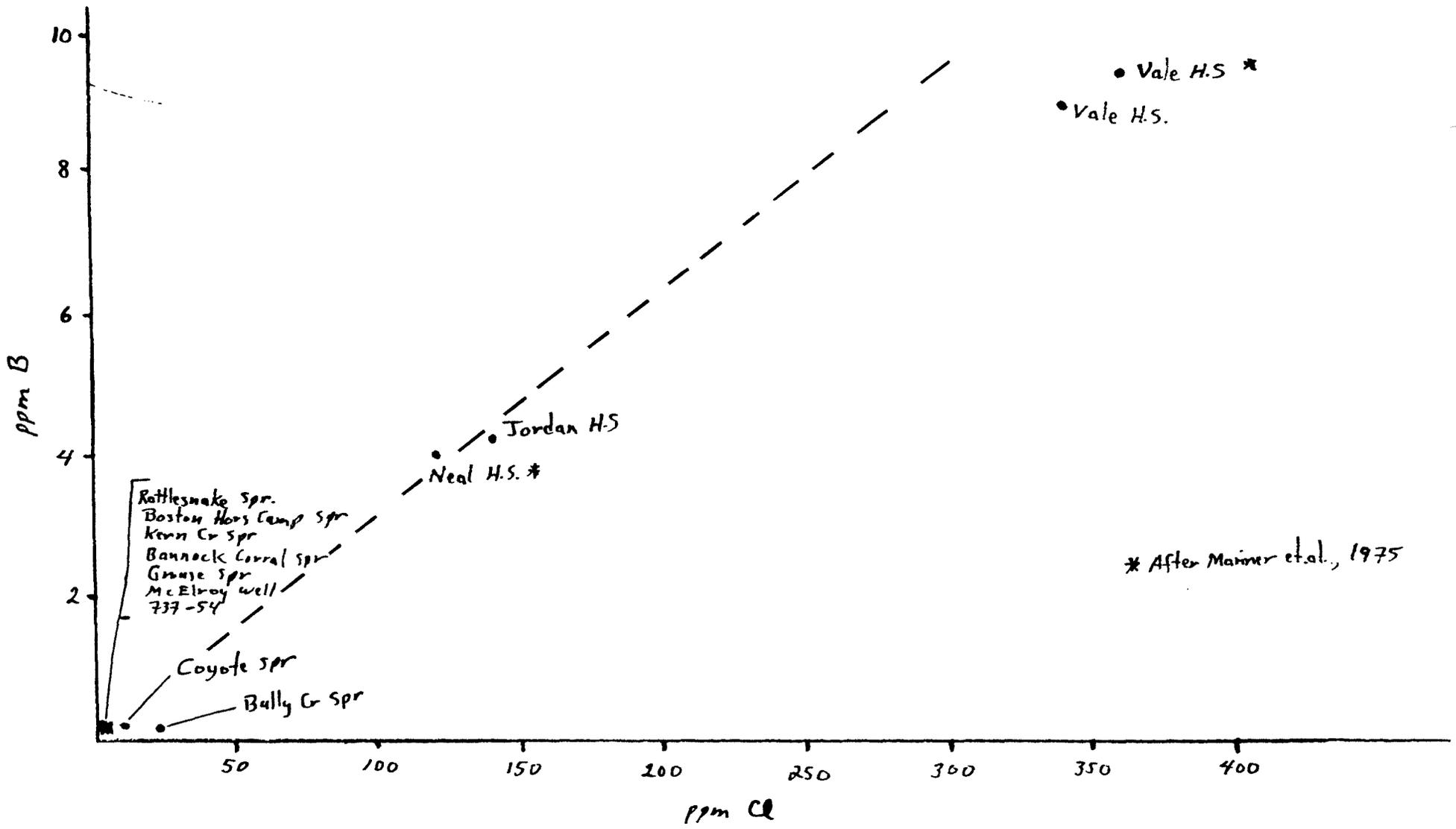Figure 4. Boron vs. Sodium plot for Bully Creek and Vale waters.

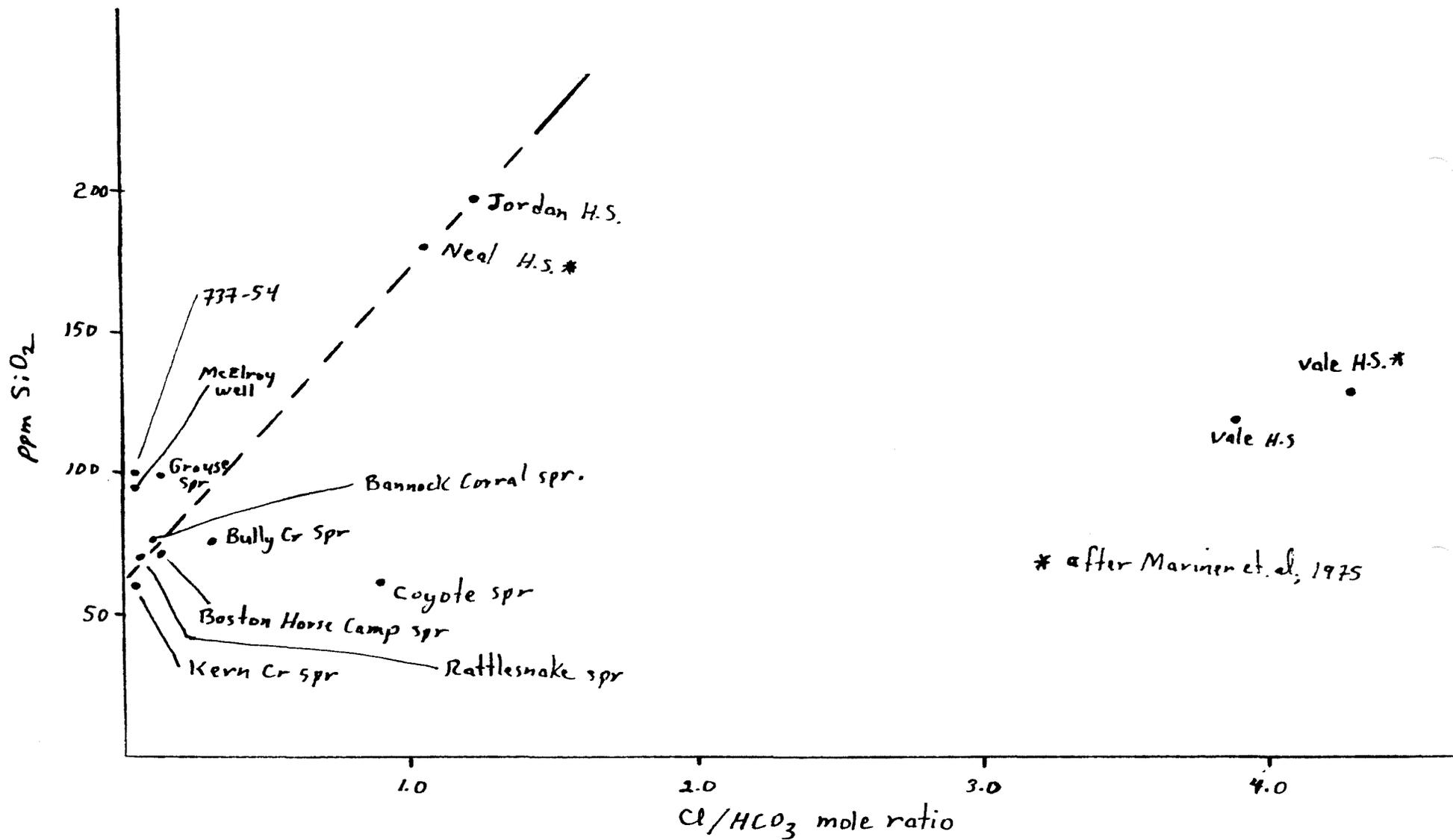Figure 5.   Boron vs. chlorine plot for Bully Creek and Vale waters.

Figure 6. Relationship between SiO2 and the δ/HCO3 mole ratios for Bully Creek and Vale waters.

Water Rock Reactions

The chemical characteristics of groundwaters are controlled by (1)
subsurface temperatures to which they are exposed, (2) mixing of thermal
and meteoric waters, (3) residence time in aquifers, and (4) the water-rock
reactions which have occurred. In order to evaluate our water chemistry to
the fullest extent we must attempt to determine how much water-rock
reactions have affected the chemical signature of the water.

When available isotopic data (Fig. 3) may help in sorting out the role
of water-rock reactions as mentioned previously. However, the broad data
base needed for such work is usually not available during geothermal
exploration work.

The graphical scatter seen on various geochemical diagrams may provide
some clue to the role of water-rock reactions play in water chemistry. For
example, on Figure 4 what is the significance the fact that the waters from
Bully Creek spring, thermal gradient well 737-54, McElroy's Warm Artesian
Well, and Coyote Spring which all plot to the right of the line drawn from
the hot springs through the average of the non-thermal springs? One thing
they all have in common is that they all issue from the Chalk Butte
Formation of Middle Pliocene age. Ground waters issuing from tuffaceous
rocks (White, 1979) tend to be enriched in Na. The enrichment is related
to time of residence; therefore, we can speculate that waters from
McElroy's Artesian Well have spent more time in contact with the tuffaceous
rocks than either the waters from thermal gradient well 737-54 or the
waters from Bully Creek spring. The very strong sodium enrichment seen at
Coyote Spring (Fig. 4) might be related to either mixing with thermal
waters or long residence time. If Coyote Spring has a significant thermal
water component then we should see a similar increase in chlorine.
However, as shown in Figure 5 the chlorine content of the water is only
slightly higher than the average for meteoric waters in the area.
Therefore, the sodium enrichment seen in the Coyote Springs waters appear
to reflect devitrification of volcanic ash in the tuffaceous rocks over a
long period of residence.

On Figure 6 those groundwaters which represent meteoric water which has

penetrated only to shallow depths plot near the ordinate. Note that the waters from Grouse Speing, McElroy warm well and well 737-54 all plot to the left and above the line connecting the hot springs with meteoric waters which suggest water-rock reactions may be responsible. The high silica values in these waters is responsible for their location on the plot. As mentioned previously, both the McElroy well and thermal gradient well 737-54 produce water from the Chalk Butte Formation. Grouse Spring issues from the contact between the basal vitrophyre and the overlying ash-flow tuff. Thus, all issue from rocks with a high content of devitrified glass which probably enriched the waters with amorphous silica gel. All the groundwaters in the Bully Creek area have a silica content of two to three times higher than average groundwater.

Silica Deposits

The Jordan Hot Springs (Neal Hot Springs) are actively depositing siliceous sinter. The silica cemented terrace gravels north and west of the hot springs suggest the hydrothermal system may have been active since Pleistocene times. Also, numerous northwest trending zones of chalcedonic quartz extend as much as 9km northwest from the present day hot springs. The chemical analysis of the silica deposits is given in Table II.

Table II. Selected Geochemical Analyses of Bully Creek Area Silica Deposits.

Sample #	Location	Au ppm	Ag ppm	Hg ppm
G100000	Jordan H.S. Sinter	0.02	0.2	35.00
G10001	Silica Veins Rd to 737-46	0.02	0.4	0.02

The chemical geothermometers (Table I) for the Jordan (Neal) Hot Springs give subsurface temperatures of 173-179°C for SiO_2, 181-183°C for Na-K-Ca and 116°C for lithium. The geochemical data suggests the only water from Jordan Hot Springs may have originated from a deep geothermal reservoir, and that the other thermal waters (McElroy Well and 737-54) represent meteoric waters which may have circulated to depths of 0.5km. At such depths they were heated and moved upward to present aquifers.

What is the nature of the parent geothermal fluids for Jordan Hot Springs? Figure 7 is a plot of silica concentration versus temperature using the average groundwater value from Table I and the AMAX analysis for Jodan Hot Springs. The silica solubility should be plotted against enthalpy; however, for temperatures up to 250°C the values are nearly equal. On Figure 7 a line drawn from the average groundwater through the Jordan Hot Springs to the silica solubility curves gives the silica concentration and temperatures of possible reservoir fluids. If the fluids have boiled on their way to the surface the reservoir fluids would have contained about 365 ppm SiO_2 at a temperature of 210°C and if the fluid cooled conductively during ascent then the reservoir fluid contain about 420 ppm SiO_2 at a temperature of 245°C.

Another method of analysis of the thermal history of geothermal reservoir fluids is to plot enthalpy against chloride concentration (Figure 8). Since Jordan Hot Spring is the only thermal spring we have to work with our analyses of potential reservoir fluids will be somewhat limited. A line connecting Jordan Hot Springs to the enthalpy of steam at 96°C provides one point of reference. Point A represents with enthalpy equal to a fluid defined the intersection with maximum steam loss line of Figure 7. With boiling the parent fluid A could give rise to the fluids issuing at Jordan Hot Springs. However, if the waters at Jordan Hot Springs are mixed, as suggested by the discrepency between the silica and alkali geothermometers; then a parent fluid B could by conduction give rise to Jordan Hot Springs fluids or by boiling

give rise to a fluid of composition C, temperature of 119°C and chlorine content of 175 ppm. Such a fluid could by mixing with local groundwater give rise to the Jordan Hot Springs fluids.

In order to better evaluate the thermal history of the fluids additional sampling should be done. As many of the individual orifices at the sinter mound as possible should be collected as well as the warm springs to the east and the seeps to the west.
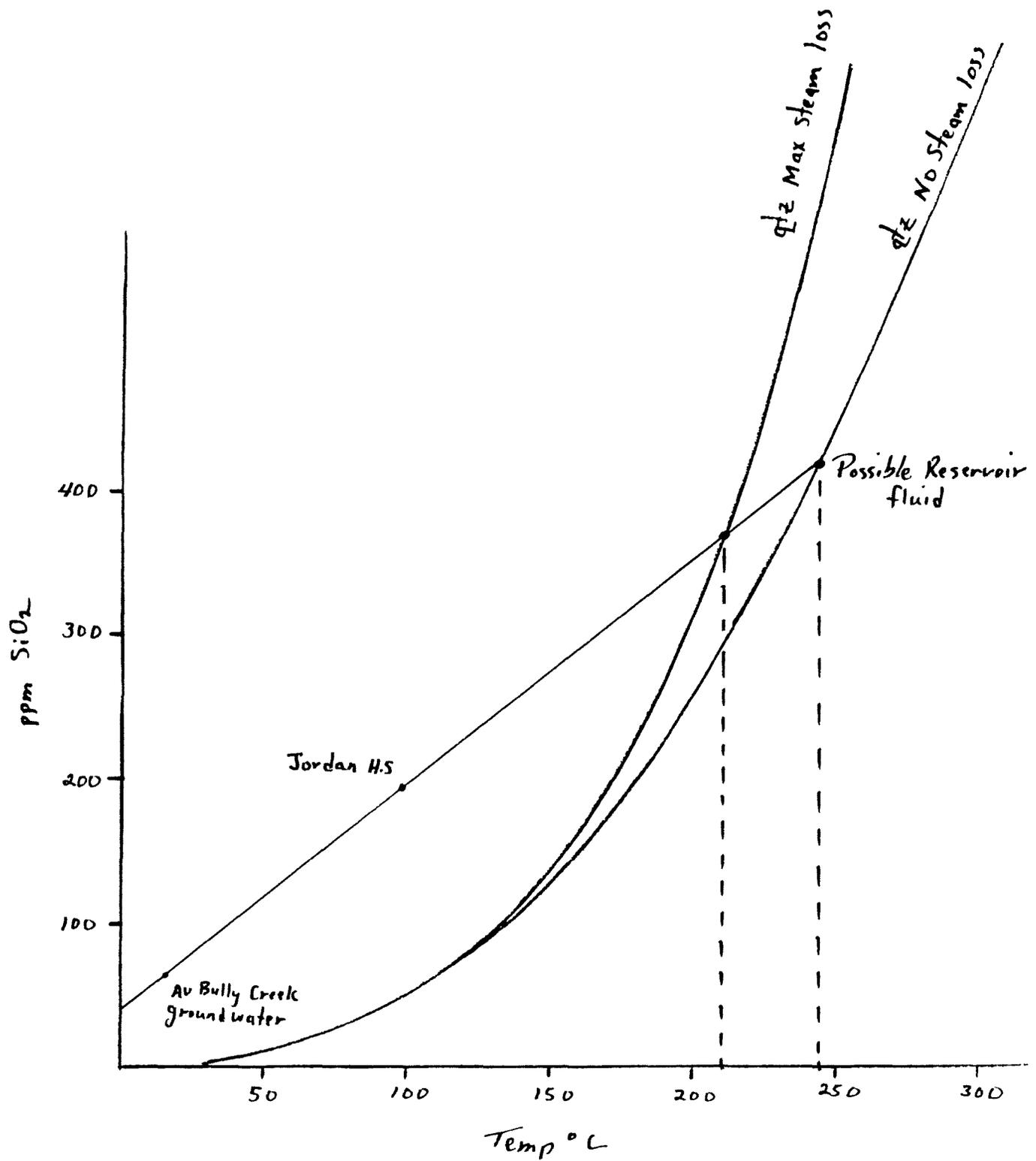
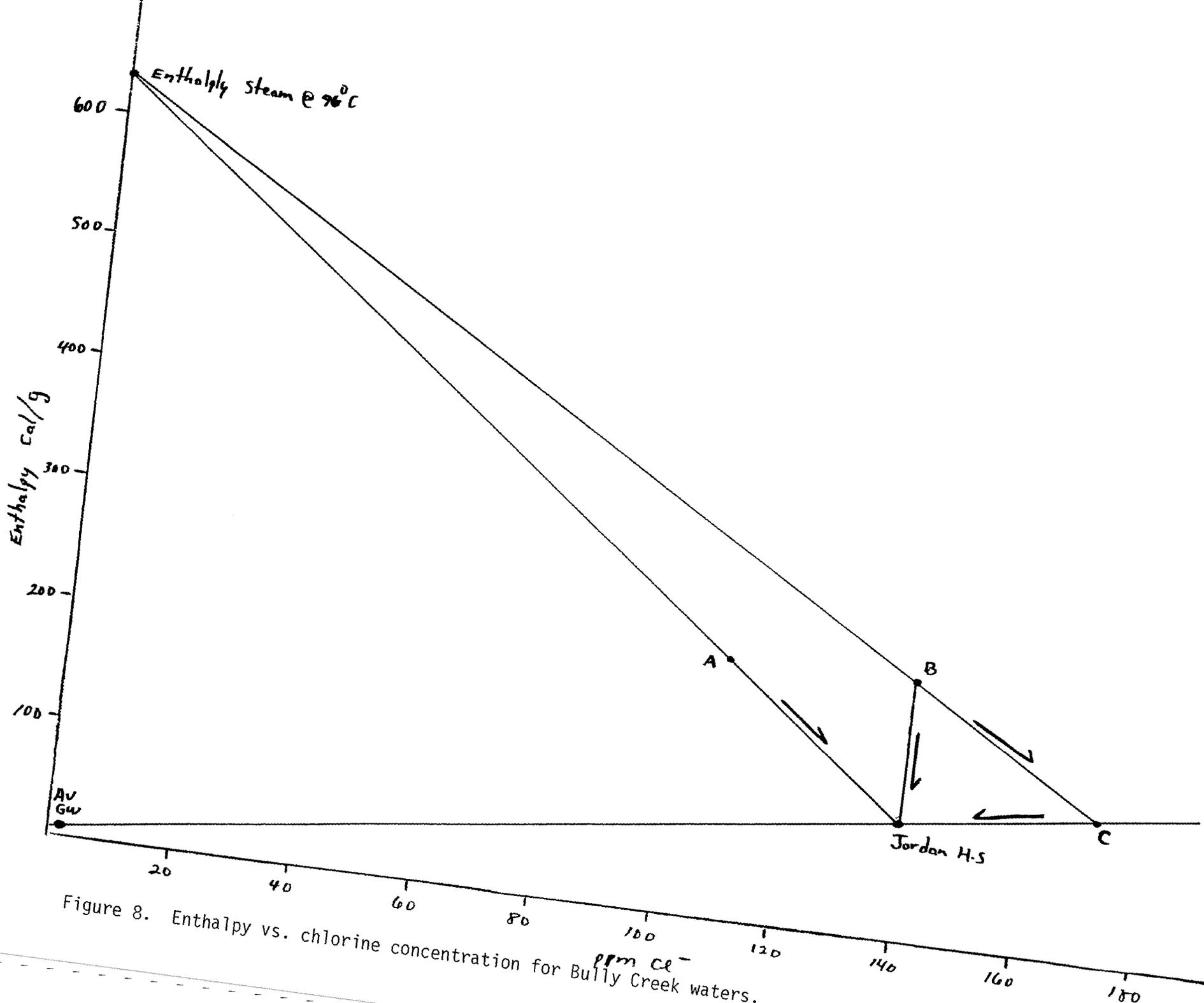Figure 7. Silica concentration vs. temperature.

Figure 8. Enthalpy vs. chlorine concentration for Bully Creek waters.

REFERENCES

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Mariner, R.H., Rapp, J.B., Willey, L.M. and Pressor, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon; U.S. Geological Survey Open-File Report, 1974.

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White, A.F., 1979, Geochemistry of groundwater associated with tuffaceous rocks, Oasis Valley, Nevada; U.S. Geological Survey Prof. Paper, 712-E.