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COLLECTION AND COLLATION OF GEOCHEMICAL AND HYDROLOGICAL PARAMETERS OF GEOTHERMAL SYSTEMS IN COLORADO AND AN EVALUATION OF GEOTHERMAL RESERVOIR TEMPERATURES--A PRELIMINARY APPRAISAL

by

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INTRODUCTION

The Colorado Geological Survey, in conjuction with the U.S. Geological Survey, initiated in May, 1975 a two year evaluation of the geothermal resource potential of Colorado as determined by the usage of hydrogeological and geochemical data, and geothermometer models. This investigation, sponsored by the U.S. Geological Survey as a part of its Geothermal Research Program, is being funded in part by Grant No. 14-08-0001-G-221. This paper presents the findings of the first field data acquisition season and a preliminary evaluation of the subsurface reservoir temperatures of 5 thermal areas using various geothermometer models.

The geothermal resource potential of Colorado is expressed in the numerous thermal springs and wells located throughout the western one-half of the state. These springs and wells, numbering in excess of 100, have been reported on by numerous authors. The first most comprehensive inventory of these thermal springs and wells was published in 1920 by R.D. George and others. Since then other summaries have been published by Lewis, (1966); Mallory and Barnett, (1972); Pearl, (1972); and Waring,(1965). A recent paper by Renner and others (1975) made a tentative appraisal of the total geothermal resource potential of Colorado.

FIELD DATA ACQUISITION TECHNIQUES AND PROCEDURES

During the past field season 135 thermal springs and wells having a temperature above 21°C were located and field measurements of such physical parameters as discharge, pH, conductivity, and temperature were made. Water samples were collected and sent to the U.S. Geological Survey, Water Resources Division's Central Lab. in Salt Lake City, Utah for analysis and to the Denver Analytical Laboratory for spectrographic analysis.

The spring or well location was determined by the use of either 7½' or 15' topographic maps, to the nearest degree, minute and second of latitude and longtitude. The land grid location was also determined if the township, range, and section had been determined and printed on the topographic map. To avoid confusion by the use of varying ambient air temperatures throughout western Colorado, an ambient air temperature of 60°F was assumed. The base thermal temperature of 70°F, or 21°C,was then used. Field pH values to the nearest .1 ~~¼~~ unit were determined using a Leeds and Northrup 7417 Specific Ion Mv pH meter supplied by theColo. Dist., Water Resources Div., U.S. Geol. Survey. Conductivity measurements were made using a Colo. Geol. Survey Lab-line Lectro Mho-Meter Model MC-1, Mark IV. Where possible the discharge of the spring or well was accurately determined by either the use of a 3" parshall flume or by determining the time to fill a 2 gallon bucket. Where it was not possible to measure the discharge by either of these two methods an estimate of the discharge was made. In several instances, for various reasons, the field pH was not determined. These values will be determined at a later date this coming spring. The water samples that were collected for analysis were collected, filtered, and acidized in accordance with standard U.S. Geol. Survey, Water Resources Division field procedures.

Evaluation of the field data shows that in Colorado there are 32 distinct thermal areas, consisting of one or more groups of springs or wells. Each spring area may consist of one or more thermal springs. Although 135 thermal springs and wells were located and field information collected, only 91 of these springs and wells were sampled for chemical and spectrographic analysis of dissolved mineral matter. If the spring site consisted of only one spring or well, it was sampled and field data collected. If however, the site consisted of multiple springs or wells, the spring having the greatest discharge and highest temperature was sampled. Table 1 is a summary of the field data collected for those 91 springs and wells where water samples were collected for chemical and spectrographic analysis. All the laboratory analytical data for the 91 sampling sites have not yet been returned. Therefore the water quality analysis for the 18 thermal springs and wells which will be used in conjunction with the various geothermometer models are presented in table 2. Plate 1, at the end of the paper is a location map showing some of the field data values for all the springs listed in table 1.

GEOTHERMOMETER MODELS

This section deals with the use of the silica, Na-K, Na-K-Ca, and the mixing model geothermometer models to estimate the reservoir temperatures of the Cottonwood, Mt. Princeton, Poncha Springs, Mineral Hot Springs, and Valley View geothermal systems. The various equations are outlined to demonstrate and clarify the steps involved for each geothermometer calculation. While the calculated reservoir temperatures are presented for all five systems the complete calculations for only one, Mt. Princeton Hot Spring A, will be presented in detail as an example.

SILICA GEOTHERMOMETER

The silica geothermometer is based on experimentally determined variations in silica solubility vs. temperature and pressure (Fournier 1970). This geothermometer assumes that the thermal water activity is not greatly diminished, the silica concentration is affected by quartz only (no other solid silica phases), and no change has resulted in silica concentration due to dilution, precipitation, or steam loss (adibatic cooling). Where the silica concentrations of the spring approach the solubility of amorphous silica at the spring temperature, the geothermometer is not applicable. The approximate solubility of amorphous silica at temperatures below 200°C can be calculated from the following equation:

$$-\log SiO_2 = \frac{731}{t_{°C} + 273} - 4.52 \qquad (1)$$

where "SiO_2" is the silica concentration in ppm or mg/l and $t_{°C}$ is the spring's surface temperature in °C.

Example Calculation

The silica content of Mt. Princeton Hot Spring A is 60 mg/l. The subsurface temperature is determined by entering the silica content value into the "Silica concentration vs temperature" curve (figure 1) and reading the temperature in °C. In this case, the temperature corresponding to a silica content of 60 mg/l is 110°C.

Figure 1 near here.

At higher silica concentrations (above approximately 115 mg/l) this curve splits into two branches: one for subsurface temperature determinations under conditions of adiabatic cooling, ("B" maximum steam loss), the other for conductive cooling conditions, ("A" minimum steam loss). Under these circumstances the silica geothermometer yields maximum and minimum subsurface temperatures.

Na-K-Ca GEOTHERMOMETER

The Na-K-Ca geothermometer is based on an empirical relationship between water composition in moles/liter (molality of Na, K, and Ca) and temperature. The equation as expressed by Fournier and Truesdell,(1974) is:

$$\log\left(\frac{Na}{K}\right) + \beta\log\left(\frac{\sqrt{Ca}}{Na}\right) = \left(\frac{1647}{273 + t_{{}^\circ C}}\right) - 2.24 \qquad (2)$$

(where $t_{{}^\circ C}$ represents the subsurface temperature in °C; the terms Na, K, Ca represent the molality of the ions).

For convenience, equation (2) can be rewritten algebraically as:

$$t_{{}^\circ C} = \frac{1647}{\log\left(\frac{Na}{K}\right) + \beta\log\left(\frac{\sqrt{Ca}}{Na}\right) + 2.24} - 273 \qquad (3)$$

β is equal to either 1/3 or 4/3 as explained in the following procedures.

If the value of the term $\log\left(\frac{\sqrt{Ca}}{Na}\right)$ is positive, use $\beta = 4/3$ in the equation, (Fournier and Truesdell, 1973). If this calculation results in temperatures below 100°C use $\beta = 4/3$, if the result is above 100°C recalculate with $\beta = 1/3$.

If the value of the term $\log\left(\frac{Ca}{Na}\right)$ is negative however, use $\beta = 1/3$ in the equation.

Caution is stressed in using the empirical relationships proposed by Fournier and Truesdell,(1972, 1973, 1974). The Na-K-Ca and N-K geothermometers are intended only for analysis of near-neutral and alkaline waters that do not deposit travertine. The model is suitable for analysis of geothermal spring waters in which the value of the term $\log\left(\frac{\sqrt{Ca}}{Na}\right)$ is less than .5 (White, 1972) or $\frac{\sqrt{\text{molal Ca}}}{\text{molal Na}} < 3.1623$.

Since most water analyses are reported in parts per million or milligrams per liter, conversion to molality (moles/liter) is required before applying equation (3). For solute concentrations below approximately 7,000 mg/l, analyses in parts per million can be considered equivalent to milligrams per liter (Hem, 1970).

Example Calculation

From the analysis of Mt. Princeton Hot Spring A:

Na concentration = 57 mg/l

(57 mg/l)(.0000435) = .0024795 moles/liter

K concentration = 2.1 mg/l

(2.1 mg/l)(.00002557) = .000053697 moles/liter

Ca concentration = 11 mg/l

(11 mg/l)(.00002495) = .0002745 moles/liter

Determine the value of β :

insert values of Ca + Na into the term $\log\left(\frac{\sqrt{Ca}}{Na}\right)$, $\log\left(\frac{\sqrt{.0002745}}{.0024795}\right) = .8249$

Try $\beta = 4/3$ in equation (3).

Thus, from equation (3):

$$t_{°C} = \frac{1647}{\log\left(\frac{.0024795}{.00053697}\right) + 4/3 \log\left(\frac{\sqrt{.0002745}}{.0024795}\right) + 2.24} - 273 = 56°C$$

Since this result is below 100°C, use $\beta = 4/3$.

The Na-K-Ca geothermometer analysis, therefore, yields an estimated temperature of 56°C.

Na-K GEOTHERMOMETER

The Na-K geothermometer is based on an empirical relationship between water composition in molality, (moles/liter) and temperature. For this geothermometer, however $\beta = 0$ and equation (2) is reduced to:

$$\log\left(\frac{Na}{K}\right) = \frac{1647}{273 + t_{°C}} - 2.24 \qquad (4)$$

To solve for t°c (subsurface temperature in °C), equation (4) can be rewritten algebraically:

$$t_{°C} = \frac{1647}{\log\left(\frac{Na}{K}\right) + 2.24} - 273 \qquad (5)$$

Example Calculation

As determined previously in the Na-K-Ca geothermometer example calculation (from analysis of Mt. Princeton Hot Spring A):

Na = .0024795 moles/liter

K = .00053697 moles/liter

Inserting these values into equation (5):

$$t_{°C} = \frac{1647}{\log\left(\frac{.0024795}{,000053697}\right) + 2.24} - 273 = 149°C$$

The Na-K geothermometer analysis, therefore, yields an estimated subsurface temperature of 149°C.

MIXING MODEL ANALYSIS

For the hot springs analyzed in this paper, mixing model number one (Fournier and Truesdell, 1974) is suitable for the estimation of the subsurface temperature and fraction of cold water in the hot spring. Mixing model number one assumes no loss of enthalpy due to the separation of steam from the geothermal fluid before mixing with colder meteoric groundwater. The mixing model analysis requires the surface temperature, and silica contents of the hot spring and surrounding cold springs in the area. Additionally, the heat content (enthalpy) of liquid water and quartz solubilities for various temperatures are needed. The enthalpy of water and quartz solubilities at various temperatures are tabulated in Table 3.

Table 3 near here.

The mixing model analysis may be performed by graphical techniques or by use of a computer program (Truesdell and others, 1973). This report utilizes the graphical techniques only. To construct the graph the following equations are used (Fournier and Truesdell, 1974):

$$x_t = \frac{(\text{Enthalpy of hot water}) - (\text{Temperature of Warm Spring})}{(\text{Enthalpy of hot water}) - (\text{Temperature of Cold Spring})} \quad (6)$$

$$x_{Si} = \frac{(\text{Silica in hot water}) - (\text{Silica in Warm Spring})}{(\text{Silica in hot water}) - (\text{Silica in Cold Spring})} \quad (7)$$

For each temperature listed in table 3, the enthalpy of hot water is entered into equation (6), and the silica content is entered into equation (7) along with the appropriate field data. Values for x_t and x_{Si} are calculated for each temperature assumed from table 3. The calculated values of x_t and x_{Si} are then plotted versus temperature; the intersection of the two curves provides the subsurface temperature and the fraction of cold water present in the thermal spring.

Example Calculation

From table 3 a hot water temperature of 125°C yields an enthalpy of 125.4 cal/g and a silica concentration of 80 mg/l. Entering these values into equations (6) and (7) yields:

$$x_t = \frac{125.4 - 54}{125.4 - 11} = .62$$

$$x_{Si} = \frac{80 - 60}{80 - 7.8} = .28$$

These calculations are performed similarly for each temperature listed in table 3; the results shown in table 4 are plotted as shown in figure 2.

Table 4 near here.

In figure 2 the intersection of the curves x_t and x_{Si} is at t = 188°C and x = .76. Therefore the estimate of the subsurface reservoir temperature is 188°C and the fraction of cold water in the spring is 76 %.

Figure 2 near here.

APPRAISAL OF SUBSURFACE RESERVOIR TEMPERATURES

This preliminary analysis is limited to five hot spring groups, Mt. Princeton, Cottonwood, Poncha Springs, Mineral Hot Springs, and Valley View Hot Springs. These five groups were selected based upon availability of preliminary data and the five serve to demonstrate the type of analysis that will be done for the remaining thermal systems in Colorado.

MT. PRINCETON HOT SPRINGS GROUPS

The Mt. Princeton and Cottonwood Hot Springs groups are located on the north and south flanks of Mt. Princeton, along the west side of the upper Arkansas Valley in Central Colorado, (see table 1 for detailed location).

The upper Arkansas Valley, a structurally complex region, can be briefly described as a narrow, downdropped, structural trough, transected and bounded by several NW and NE trending, near-vertical fault zones, (Scott, 1975; Scott et al, 1975; Van Alstine, 1974; Van Alstine et al, 1969).

Both Mt. Princeton and Cottonwood Hot Springs groups are located within intense shear zones. In these shear zones, the quartz monzonite of the Mt. Princeton batholith has been locally altered and zeolitized. Hortense Hot Spring (Mt. Princeton group) is surrounded by several hundred feet of green-gray, propylitized, fault gouge and brecciated quartz monzonite (Sharp, 1970). This zone grades abruptly into zeolitized quartz monzonite which forms the "Chalk Cliffs", a landmark in the area (Sharp, 1970).

Leonhardite, the only zeolite recognized in the shear zones, is a white or light pink, powdery coating on the weathered surfaces and in cracks of the quartz monzonite. This zeolite coating is so pervasive that a white hue is imparted to the otherwise gray quartz monzonite in both the shear zones and "Chalk Cliffs."

Cottonwood Hot Springs are also surrounded by a similar zeolitized shear zone, however, the quartz monzonite is less extensively mineralized than in the Mt. Princeton Hot Springs group. "Chalk Cliffs' occur also at the Cottonwood Hot Spring area, but, again, the zeolitization is not as widespread as that in the Mt. Princeton group. As Sharp (1970) pointed out, the "Chalk Cliffs" of both spring areas appear to be the product of a localized intense alteration and metasomatism of the quartz monzonite.

Silica geothermometer analysis of the Mt. Princeton and Cottonwood Hot Springs group yields subsurface reservoir temperatures that range from 97°C to 118°C (table 5). If adiabatic cooling is predominant in the springs systems, silica concentrations would increase due to fluid loss in the form of steam, and the geothermometer results would be high. Of the two groups, Hortense Hot Spring and Hortense Hot Water Well alone have surface temperatures near the boiling point and thus are the likeliest to cool adiabatically (table 5). Logically, the geothermometer results for these two sites should be greater than geothermometer results for the other hot springs. Yet, the subsurface temperatures predicted for the hot springs and well (118°C) are not appreciably greater than those subsurface temperatures predicted for the other springs in the group (table 5). This occurs because adiabatic cooling is minor in the two sites and the subsequent increase in silica concentration is small. Thus, it appears that the silica geothermometer does not yield excessive temperatures.

The silica geothermometer analysis is probably a low estimate of the temperature at depth. Silica loss due to reequilibration with wall rocks at temperatures below 200°C is possible. Also, dilution of the thermal fluids with shallow meteoric groundwaters can lower silica concentrations. Both reequilibration and dilution would result in minimum temperature approximations. In view of the extensive zeolitization in the area, it is also possible that some of the free silica in the geothermal fluids is lost due to reactions with aluminum and other available ions forming zeolite at depth.

Na-K geothermometer analysis of the Mt. Princeton and Cottonwood Hot Springs groups yields temperature estimates ranging from 132°C - 150°C (table 5). The Na-K-Ca geothermometer analysis yields temperatures ranging from 59°C to 97°C (table 5).

Several conditions at depth can occur which will cause the Na-K and Na-K-Ca geothermometers to give anomalous results. Concentration due to loss of steam has little or no effect on these geothermometers. Dilution of the thermal fluids by shallow meteoric groundwaters, however, may affect either geothermometer depending upon the chemical content of the groundwater. Dilute groundwaters may affect the geothermometer so that excessive temperatures result. If the calcium content of the thermal fluids is low, however, mixing with dilute groundwater will have minimal affect on the geothermometer (Fournier and Truesdell, 1972).

From table 5 it is evident that no correlation exists between high Na-K/Na-K-Ca geothermometer temperatures and the percentage of cold water in the hot springs. This implies that the calcium concentration of the undiluted thermal fluid is low; furthermore, the geothermometers are not affected by mixing with dilute groundwater.

Mixing model analysis of the Mt. Princeton and Cottonwood Hot Springs groups yields temperatures ranging from 147°C to 198°C with cold water fractions from 52% to 80% of the spring flow. In the mixing model calculations, a water analysis from Chalk Creek near Mt. Princeton Hot Springs was used to represent the average cold water in the region. When laboratory data for the cold springs in the area is made available, these calculations will be redone to include and reflect the cold spring analyses. These subsequent calculations, however, are not expected to yield results that are significantly different.

Research done by Coombs (1952) outlines the environmental conditions necessary for the formation of laumontite (hydrated leonhardite) as within the temperature range of 145°C to 220°C corresponding to depths of 450 to 6000 feet (Sharp, 1970). This correlates well with the temperature ranges suggested by the Na-K/Na-K-Ca geothermometers and mixing model analyses of the Mt. Princeton geothermal area.

With few exceptions, the Cl/B ratios are similar between the Mt. Princeton and Cottonwood Hot Spring groups. Thermal waters of both groups are probably of the same origin. The slight difference between the Cl/B ratios for the two spring systems is probably due to the difference in flow paths from the thermal source to the ground surface. Future statistical analyses of these and similar data are planned.

PONCHA HOT SPRINGS

The Poncha Hot Springs are located at the southern end of the upper Arkansas Valley near the town of Poncha Springs (Central Colorado).

These springs occur on a faulted contact between tertiary volcanics and Pre-Cambrian sedimentary rocks. This east-west trending, near-vertical fault marks the northern boundary of a complex transverse horst which separates the San Luis and upper Arkansas Valley grabens, (Grose, 1974).

Extensive mounds of travertine deposited in the vicinity of the springs suggest that historically, the total flow of the group was greater than the present flow of approximately 150 gpm (George et al, 1920).

Silica geothermometer analysis of the Poncha Springs group yields subsurface temperatures ranging from 122°C to 125°C (table 5). As explained for the Mt. Princeton geothermal area these estimations probably represent a minimum temperature at depth.

The Na-K geothermometer analysis of the Poncha Springs group yields temperature estimates ranging from 154°C to 157°C (table 5). The Na-K-Ca geothermometer analysis yields temperatures ranging from 140°C to 145°C (table 5).

As explained previously for the Mt. Princeton Hot Spring area, it does not appear that dilution of thermal waters by the addition of shallow groundwater has altered these estimates appreciably.

The mixing model analysis of the Poncha Springs group yields temperatures ranging from 183°C to 204°C with cold water fractions from 65% to 75% of the spring flow (table 5).

For these calculations an average water temperature of 10°C and silica content of 11 milligrams per liter was assumed for the meteoric groundwater in the region. When laboratory data for the cold springs in the areas is made available these calculations will be redone. These subsequent calculations, however, are not expected to yield results that are significantly different.

Both the Cl/B and $Cl/(HCO_3 + CO_3)$ ratios are similar for the springs analyzed in the Poncha Springs group (table 5). Statistical analysis of these and similar data are planned; these springs are probably from the same thermal systems.

MINERAL HOT SPRINGS

The Mineral Hot Springs are located near the center of the northern part of the San Luis Valley in south-central Colorado.

The San Luis Valley, an extension of the Rio Grande rift system, is characterized by tensional block faulting, thick graben fill, (possibly as thick as 30,000'), and many thermal wells and hot springs (Keller, 1974 and Reiter, 1975). East dipping, San Juan volcanic rocks (late Cenozoic), outcrop along the western margin of the valley and project beneath the valley fill. The eastern boundary of the valley is delineated by the Sangre de Cristo Range, a normally faulted block of intensely deformed late Paleozoic sedimentary rocks (De Voto, 1971).

Silica geothermometer analysis of the Mineral Hot Springs group yields subsurface temperatures ranging from 98°C to 100°C (table 5). As explained for the Mt. Princeton geothermal areas, these estimates represent a minimum temperature at depth.

The Na-K geothermometer analysis yields temperature estimates ranging from 197°C to 206°C (table 5). The Na-K-Ca geothermometer analysis yields temperatures ranging from 87 °C to 91 °C (table 5). Since the calcium analyses of these hot springs are high, it is likely that mixing effects of the shallow groundwaters with the thermal fluids has yielded geothermometer results which can be considered a maximum temperature estimation, (see Mt. Princeton Hot Springs group).

Mixing model analyses of the Mineral Hot Springs group yields temperatures ranging from 130°C to 133°C with cold water fractions from 59% to 61% of the spring flow (table 5). Laboratory analysis of groundwater from a nearby well (Emery et al, 1972) was used to represent the dilute meteoric waters in the mixing model. Subsequent mixing model determinations using other shallow groundwater analyses are not expected to yield significantly different results.

Both the Cl/B and $Cl/HCO_3 + CO_3$) ratios are similar for the springs analyzed in the Mineral Hot Springs. Statistical analysis of these data is planned; moreover, it is expected that the springs are of the same thermal system.

VALLEY VIEW HOT SPRINGS

The Valley View Hot Springs are located on the east side of northern San Luis Valley approximately five miles NE of Mineral Hot Springs. These springs issue from an alluvium-basement rock contact along a north-trending, near vertical fault zone at the base of the Sangre de Cristo Range (see Mineral Hot Springs), (Pearl, 1972).

Preliminary geothermometer analysis of these springs provides subsurface temperature estimates ranging from 58° to 356°C. Due to the irregular nature of these estimates (table 5) individual treatment of each geothermometer result will not be done in this report.

The excessive temperature estimates of the Na-K/Na-K-Ca geothermometers may be due to peculiarities of the mineral suite in this spring area as compared to the mineral suites used in formulating the geothermometers. Surface contamination of the spring pools from-which the samples were taken could also cause the geothermometer analysis to be in error.

These springs have been resampled recently with the intent of avoiding the effects of surface contamination. When laboratory results are returned they will be compared to the above analyses to determine the nature of the geothermometer anomalies in Valley View Hot Springs.

FUTURE PLANS

In January and April, 1976 the physical parameters of 41 of the 91 thermal springs will be remeasured and water samples collected and analyzed to determine if there are any changes in the chemical composition or physical parameters during a year's time. During the spring of 1976 an appraisal of the reservoir temperatures of all the thermal areas in the state will be made using the various geothermometers models. As shown earlier the geothermometer models do not appear to be working at the Valley View Hot Spring Area. This will be evaluated further, and if no reason can be found for this dichotomy, it may be necessary to develop a geothermometer model that will give reliable results. This will be especially true if this same condition exists when the other systems are analyzed. Starting in May, 1976 field work will commence on a hydrogeological appraisal of selected geothermal systems utilizing selected C, H, and O isotopes contained in the thermal and cold waters.

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Table 1. Thermal Springs and Wells in Colorado analyzed for dissolved mine

	Location						
Name	Latitude	Longtitude	T.	R.	Sec.	P.M.	(
Antelope Warm Spring	374436	1070214	40N	2W	1dd	N.M.	I
Canyon City Hot Spring	382557	1051546	18S	70W	31d	6th.	
Cebolla Hot Spring A	381626	1070554	46N	2W	4ab	N.M.	
Cebolla Hot Spring B	381626	1070554	46N	2W	4ab	N.M.	
Cebolla Hot Spring C	381626	1070554	46N	2W	4ab	N.M.	
Cement Creek Warm Spring	385006	1064934	14S	84W	18cd	6th.	
Clark Spring Water Well	381529	1043635	21S	65W	1aa	6th.	
Conundrum Hot Spring	390044	1065326	12S	85W	16-	6th.	
Cottonwood Hot Spring	384848	1061321	14S	79W	21dc	6th.	
Don K. Ranch Artesian Well	381020	1050032	22S	68W	5a	6th.	
Dotsero Warm Spring	393739	1070622	5S	87W	12bd	6th.	
Dunton Hot Spring	374618	1080538	41N	11W	32-	N.M.	
Eldorado Spring A	395552	1051646	1S	71W	25da	6th.	
Eldorado Spring B	395553	1051646	1S	71W	25da	6th.	
Fremont Natatorium	382738	1051146	18S	70W	26bb	6th.	
Florence Artesian Well	382453	1050243	19S	68W	7ba	6th.	
Fullinwider Warm Spring	381818	1055855	47N	9E	21dc	N.M.	
Geyser Warm Spring	374448	1080702	40N	11W	6 -	N.M.	
Glenwood Springs Area							
South Side of Colo. R.							
Spring A	393258	1071910	6S	89W	9dd	6th.	
Spring B	393302	1071904	6S	89W	10cb	6th.	
Spring D	393305	1071900	6S	89W	10cb	6th.	

Table 1 (Cont.).

	Location						
Name	Latitude	Longtitude	T.	R.	Sec.	P.M.	Count
Glenwood Springs Area							
North Side of Colo. R.							
Bath House Hot Spring	393259	1071918	6S	89W	9ad	6th.	Garfi
Drinking Spring	393259	1071919	6S	89W	9ad	6th.	Garf
Graves Hot Spring	393314	1072008	6S	89W	9bb	6th.	Gar
Vapor Caves Mens Spg.	393259	1071917	6S	89W	9ad	6th.	Garf
Haystack Butte Warm Wtr. Well	400548	1051416	2N	70W	33ba	6th.	Boul
Harstel Hot Spring A	390105	1054740	12S	75W	8da	6th.	Park
Harstel Hot Spring B	390105	1054739	12S	75W	8da	6th.	Park
Hot Sulphur Spring A	400433	1060643	1N	78W	3dc	6th.	Gran
Hot Sulphur Spring B	400433	1060644	1N	78W	3dc	6th.	Gran
Hot Sulphur Spring C	400433	1060645	1N	78W	3dc	6th.	Gran
Hot Sulphur Spring D	400433	1060645	1N	78W	3dc	6th.	Gran
Hortense Hot Spring	384359	1061026	15S	79W	24bd	6th.	Chaf
Hortense Hot Wtr. Well	384359	1061027	15S	79W	24bd	6th.	Chaf
Idaho Spring Hot Spg. A	394420	1053043	4S	73W	1ba	6th.	Cle
Idaho Spring Hot Spg. B	394421	1053043	3S	73W	36cd	6th.	Cle
Idaho Spring Hot Spg. C	394419	1053043	4S	73W	1ba	6th.	Cle
Idaho Spring Lodge Spg.	394422	1053043	3S	73W	36cd	6th.	Cle
Jump Steady Hot Spring (Cottonwood Area)	384840	1061320	14S	79W	21dd	6th.	Cha
Juniper Hot Spring	402801	1075710	6N	94W	16cd	6th.	Mof
Lemon Hot Spring	385100	1080311	44N	11W	34dd	N.M.	San
Merrifield Hot Wtr. Well (Cottonwood Area)	384840	1061321	14S	79W	21dd	6th.	Ch

Table 1 (Cont.).

	Location								
Name	Latitude	Longtitude	T.	R.	Sec.	P.M.			
Mt. Princeton Hot Spg. A	384358	1060940	15S	78W	19bc	6th.			
Mt. Princeton Hot Spg. G	384358	1060941	15S	78W	19bc	6th.			
Mineral Hot Spring A	381008	1055505	45N	9E	12ad	N.M.			
Mineral Hot Spring C	381006	1055511	45N	9E	12ad	N.M.			
Mineral Hot Spring D	381004	1055511	45N	9E	12ad	N.M.			
Ouray Pool Hot Spring	380100	1074041	44N	7W	31cb	N.M.			
Ouray-Wesbaden Vapor Cave Spring 1	380115	1074003	44N	7W	31ac	N.M.			
Vapor Cave Spg. 2	380115	1074003	44N	7W	31ac	N.M.			
Vapor Cave Spg. 3	380115	1074003	44N	7W	31ac	N.M.			
Pagosa Spring-Big Spring	371552	1070037	35N	2W	13cd	N.M.			
Pagosa Spring-Spa Hot Wtr. Well	371551	1070035	35N	2W	13cd	N.M.	Arc		
Pagosa Spring-Courthouse Spring	371555	1070037	35N	2W	13	N.M.	Archuleta		
Paradise Hot Spring	374515	1080753	-	-	-	N.M.	Dolores		
Penny Hot Spring	391333	1071328	10S	88W	4ba	6th.	Pitkin		
Pinkerton Hot Spring A	372650	1074817	37N	9W	25ab	N.M.	La Plata	3	
Pinkerton Hot Spring B	372658	1074817	37N	9W	25a	N.M.	La Plata	33	
Pinkerton-Mound Spring	372707	1074820	37N	9W	25aba	N.M.	La Plata	30	
Poncha Hot Spring A	382949	1060437	49N	8E	15cb	N.M.	Chaffee	71	8
Poncha Hot Spring B	382949	1060436	49N	8E	15cb	N.M.	Chaffee	66	N/D
Poncha Hot Spring C	382950	1060431	49N	8E	15	N.M.	Chaffee	63	8.0
Rainbow Hot Spring	373034	1065652	38N	1W	-	N.M.	Archuleta	40	N/D

75
18/75
6/18/75
6/18/75
9/19/75

Table 1 (Cont.).

	Location						
Name	Latitude	Longtitude	T.	R.	Sec.	P.M.	Co
Ranger Warm Spring	384857	1065228	14S	85W	22dc.	6th.	Gu
Rhodes Warm Spring	300949	1060353	10S	78W	24cb	6th.	Pa
Rico Big Geyser Wm. Spg.	374115	1080144	40N	11W	-	N.M.	Do
Rico Geyser Warm Spring	374117	1080144	40N	11W	-	N.M.	Do
Rico Little Spring	374119	1080144	40N	11W	-	N.M.	Do
Routt Hot Spring A	403334	1065100	7N	84W	18dc	6th.	Ro
Routt Hot Spring B	403335	1065059	7N	84W	18dd	6th.	Ro
Sand Dunes Swimming Pool Hot Water Well	374642	1055120	41N	10E	27aa	N.M.	Sa
Shaws Warm Spring	374501	1061901	41N	6E	33dd	N.M.	Ri
South Canyon Hot Spring A	393316	1072353	6S	90W	2cd	6th.	Ga
South Canyon Hot Spring B	393315	1072353	6S	90W	2cd	6th.	Ga
Splashland Hot Water Well	372919	1055127	38N	10E	34dd	N.M.	Al
Steamboat Springs	402829	1064936	6N	84W	17bd	6th.	Ro
Stinking Springs	370205	1064825	33N	1E	2dd	N.M.	Ar
Trimble Hot Spring	372328	1075052	36N	9W	15bb	N.M.	La
Tripp Hot Spring	372330	1075052	36N	9W	10cc	N.M.	La
Valley View Hot Spring A	381132	1054849	46N	10E	36db	N.M.	Sa
Valley View Hot Spring B	381131	1054835	46N	10E	36db	N.M.	Sa
Valley View Hot Spring D	381123	1054835	46N	10E	36	N.M.	Sa
Wagon Wheel Gap 4UR Spg.	374106	1064947	41N	1E	35dd	N.M.	Mi
Wagon Wheel Gap CFI Spg.	374102	1064947	40N	1E	2ab	N.M.	Mi

Location

Name	Latitude	Longtitude	T.	R.	Sec.	P.M.
Waunita Hot Spring,						
Upper Spring C	383050	1063027	49N	4E	11cc	N.M.
Upper Spring D	383050	1063028	49N	4E	11cc	N.M.
Lower Spring B	383100	1063055	49N	4E	10dc	N.M.
Lower Spring D	383101	1063100	49N	4E	10dc	N.M.
Wright Water Well, East	384400	1061000	15S	79W	24ad	6th.
Wright Water Well, West	384358	1061025	15S	79W	24ac	6th.
Woolmington Hot Water Well	384324	1061038	15S	79W	24db	6th.
Young Life Hot Water Well	384357	1061027	15S	79W	24bd	6th.

Table 2. Water Quality Analysis

Name	Alkalinity (As Ca CO3) mg/1	Arsenic ug/1	Bicarbonate mg/1	Boron ug/1	Cadium ug/1	Ca
Cottonwood Hot Spring A	60	2	73	90	0	
Jump Steady Hot Spring	60	4	73	90	0	
Merrifield Hot Wtr. Well	62	4	71	80	0	
Mt. Princeton Hot Spg. A	58	1	71	20	0	1
Mt. Princeton Hot Spg. G	60	1	73	10	0	1
Wright Hot Wtr. Well East	56	1	68	20	0	
Wright Hot Wtr. Well West	59	1	72	30	0	
Hortense Hot Spring	68	3	83	40	1	
Hortense Hot Wtr. Well	62	2	75	30	0	
Young Life Hot Wtr. Well	59	2	72	20	0	
Mineral Hot Spring A	275	32	335	350	1	6
Mineral Hot Spring C	280	28	341	370	0	6
Mineral Hot Spring D	286	26	349	370	0	5
Poncha Hot Spring A	177	2	216	80	0	2
Poncha Hot Spring B	176	2	214	70	0	1
Poncha Hot Spring C	176	6	214	80	0	24
Valley View Hot Spg. A	98	1	120	8	0	51
Valley View Hot Spg. B	105	2	128	8	0	4

Table 2 (Cont.) Water Quality Analysis

Name	Mercury	Nitrate	Phosphate	Potassium	S
	ug/1	mg/1	mg/1	mg/1	
Cottonwood Hot Spring A	0	0.08	0.04	2.8	
Jump Steady Hot Spring	0	0.12	0	2.6	
Merrifield Hot Wtr. Well	0	0.09	0	2.5	
Mt. Princeton Hot Spg. A	0	0.14	0.05	2.1	
Mt. Princeton Hot Spg. G	0	0.24	0.04	1.9	
Wright Water Well East	0	0.15	0	2.1	
Wright Water Well West	0.2	0.09	8.8	2.5	
Hortense Hot Spring	0	0.06	0.05	3.2	
Hortense Hot Wtr. Well	0	0.02	0.01	2.8	
Young Life Hot Wtr. Well	0	0.15	0.04	2.3	
Mineral Hot Spring A	0	0.14	0.04	14.	
Mineral Hot Spring C	0	6.5	0.04	14	
Mineral Hot Spring D	0	2.0	0.03	14	
Poncha Hot Spring A	0.1	0.05	0.05	8	
Poncha Hot Spring B	0.1	0.02	0.04	7.8	
Poncha Hot Spring C	0	0.02	0.05	8.3	
Valley View Hot Spring A	0	0.57	0.01	2.5	
Valley View Hot Spring B	0	0.22	0.01	2.2	
Jump Steady Hot Spring	0	0.12	0	2.7	

Table 3 Enthalpies of liquid water and quartz solubilities at selected temperatures and pressures (Fournier and Truesdale, 1974)

Temperature (°C)	Enthalpy (cal/g)	Silica (mg/l)
50	50.0	13.5
75	75.0	26.6
100	100.1	48.0
125	125.4	80.0
150	151.0	125.0
175	177.0	185.0
200	203.6	265.0
225	230.9	365.0
250	259.2	486.0
275	289.0	614.0
300	321.0	692.0

Table 4 Calculated values of x_t and x_{si} for selected hot water temperatures (Mt. Princeton Hot Spring "A")

Hot Water mperature (°C)	x_t	x_{si}	Hot Water Temperature (°C)	x_t	x_{si}
50	--	--	200	.78	.80
75	.39	--	225	.80	.85
100	.52	--	250	.83	.89
125	.62	.28	275	.85	.91
150	.69	.55	300	.86	.92
175	.74	.71			

Table 5

Spring Name	Surface Temperature (°C)	Na-K Geothermom. Temp. (°C)	Na-K-Ca Geothermom. Temp. (°C)	SiO_2 Geothermom. Temp. (°C)	Mixing Model Temp. (°C)	Fraction of Cold Water (%)	Cl/B Ratio	$Cl/(HCO_3+CO_3)$ Ratio	F Concentration (mg/l)
Mt Princeton Springs "A"	54	149	56	110	188	76	220	.062	9.1
Mt Princeton Springs "G"	49	150	51	107	198	80	380	.052	8.3
Hortense Hot Spring	81	146	94	118	162	54	245	.118	18
Hortense Water Well	82	144	90	118	158	52	277	.277	14
Wright Hot Water Well, East	67	146	62	103	147	60	245	.072	10
Wright Hot Water Well, West	72	145	77	116	167	61	213	.088	13
Young Life Water Well	66	135	68	116	184	69	96	.054	9.2
Cottonwood Hot Springs	58	132	84	110	176	74	333	.41	14
Jump Steady Hot Springs	54	133	79	108	173	71	311	.38	14
Merrifield Hot Water Well	46	141	68	97	171	76	288	.32	12
Mineral Hot Springs "A"	60	206	90	98	130	59	108	.116	3.7
Mineral Hot Springs "C"	60	197	91	100	133	60	116	.126	4.2
Mineral Hot Springs "D"	59	202	92	98	132	61	105	.112	3.9
Valley View Hot Springs "A"	37	356	12	62	73	58	100	.007	.4
Valley View Hot Springs "B"	32	338	11	58	--	--	325	.020	.3
Poncha Hot Springs "A"	71	155	140	122	183	65	613	.23	11
Poncha Hot Springs "B"	66	154	139	124	199	71	686	.22	12
Poncha Hot Springs "C"	63	157	139	125	204	73	613	.23	11

Figure 1

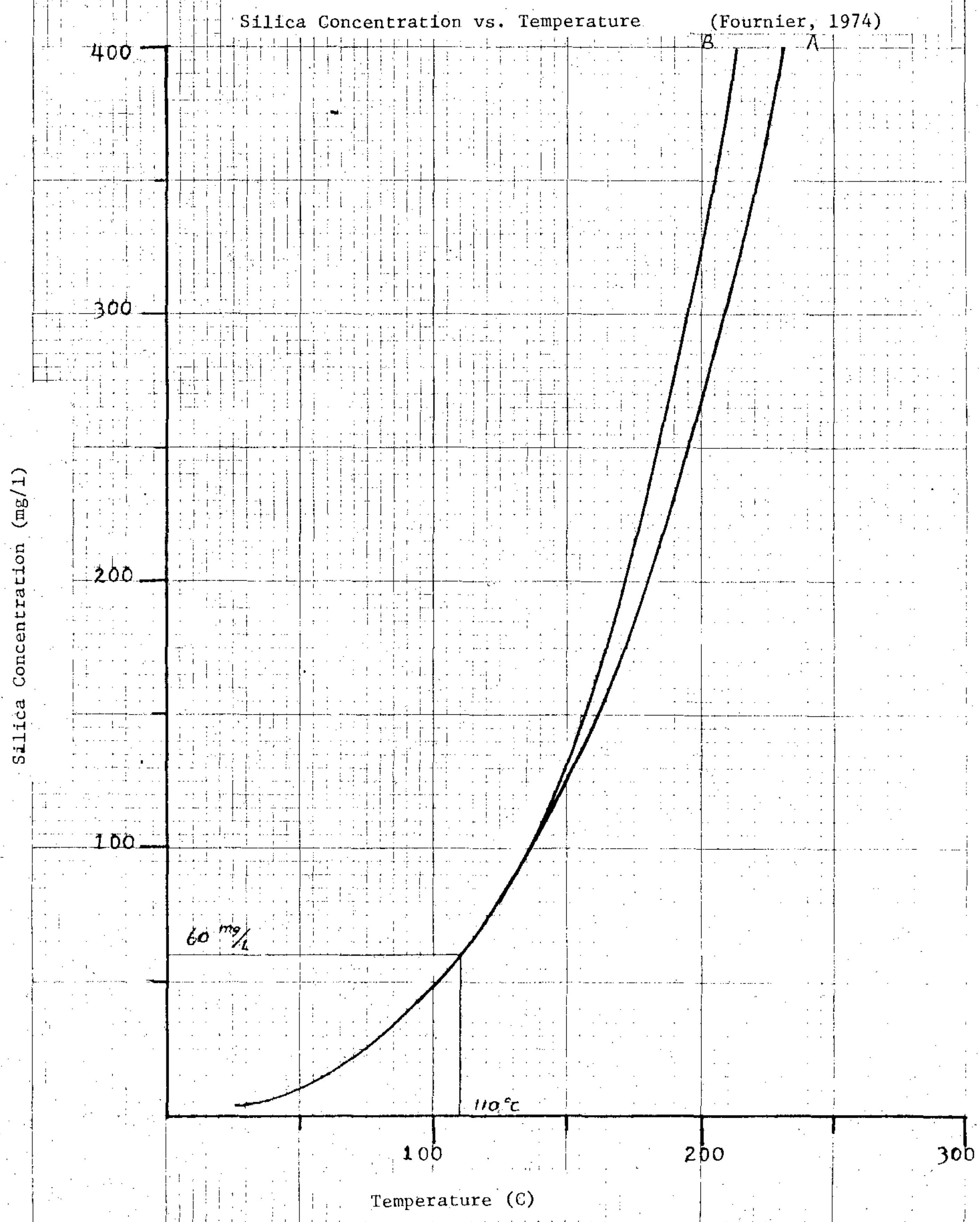
Silica Concentration vs. Temperature (Fournier, 1974)
B
A
400
300
200
100
Silica Concentration (mg/1)
60 mg/L
110°C
100
200
300
Temperature (C)

Figure 2

Mixing Model Solution Mt. Princeton Hot Spring "A" (Fournier,