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Helium and Ground Temperature Surveys at Steamboat Springs, Colorado

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Abstract

As demonstrated in Steamboat Springs, Colorado, helium and shallow temperature surveys are quick, inexpensive geothermal exploration methods that can be used together with excellent results. Steamboat Springs, in northwestern Colorado, lies primarily upon terrace gravels and alluvium with the major structure being a north-trending normal fault passing through the western portion of the city. Work by Christopherson (1979) indicates that the Steamboat warm springs are not laterally connected at shallow depth with Routt Hot Springs, 6 km to the north, although both resource areas are fault controlled. A shallow temperature survey was conducted in the city to determine the usefulness of this method in a low temperature resource area. Several extraneous factors influencing shallow temperature measurements were dealt with by field technique or subsequent analysis. A helium survey was conducted to compare with temperature results. Sixty-two soil helium samples were taken, using an interval of .1 to .2 Km, twice the density of the 18 temperature probe stations. A mobile spectrometer allowed immediate analysis of helium samples. A direct correlation of temperature to helium value at each site is not valid due to the high solubility of this gas. The contoured data from each method does correlate well and indicates that two faults control the resource in Steamboat Springs. Although these surveys should always be used to supplement other data, their utility in this study was readily apparent.

Introduction

Many effective methods have been perfected for geothermal exploration; however, some techniques cannot be used in an urban environment, and cost is often prohibitive. As demonstrated in Steamboat Springs, Colorado, helium and shallow ground temperature surveys are quick, inexpensive methods that can be used in fault controlled hydrothermal areas with excellent results, even in an urban setting. These methods may enhance results of adjacent geophysical surveys, and are best used after careful interpretation of surficial geology and groundwater hydrology.

Geology

The city of Steamboat Springs, in northwestern Colorado, lies primarily upon Quaternary terrace gravels and alluvium. The major geologic structure in the immediate vicinity is a north-trending normal fault that passes through the western portion of the study area (Fig. 1). This fault is in turn offset by at least two northeast-trending right-lateral strike-slip faults (Snyder, 1977b). The ridge of Dakota Sandstone that is exposed along the trace of the normal fault is overturned from an easterly dip to the south to a westerly dip north

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of the transverse faults (Zacharakis, et al., 1981). These transverse faults may, in fact, be wrench faults common in the region as described by Stone (1969). General geology is shown in figure 2.

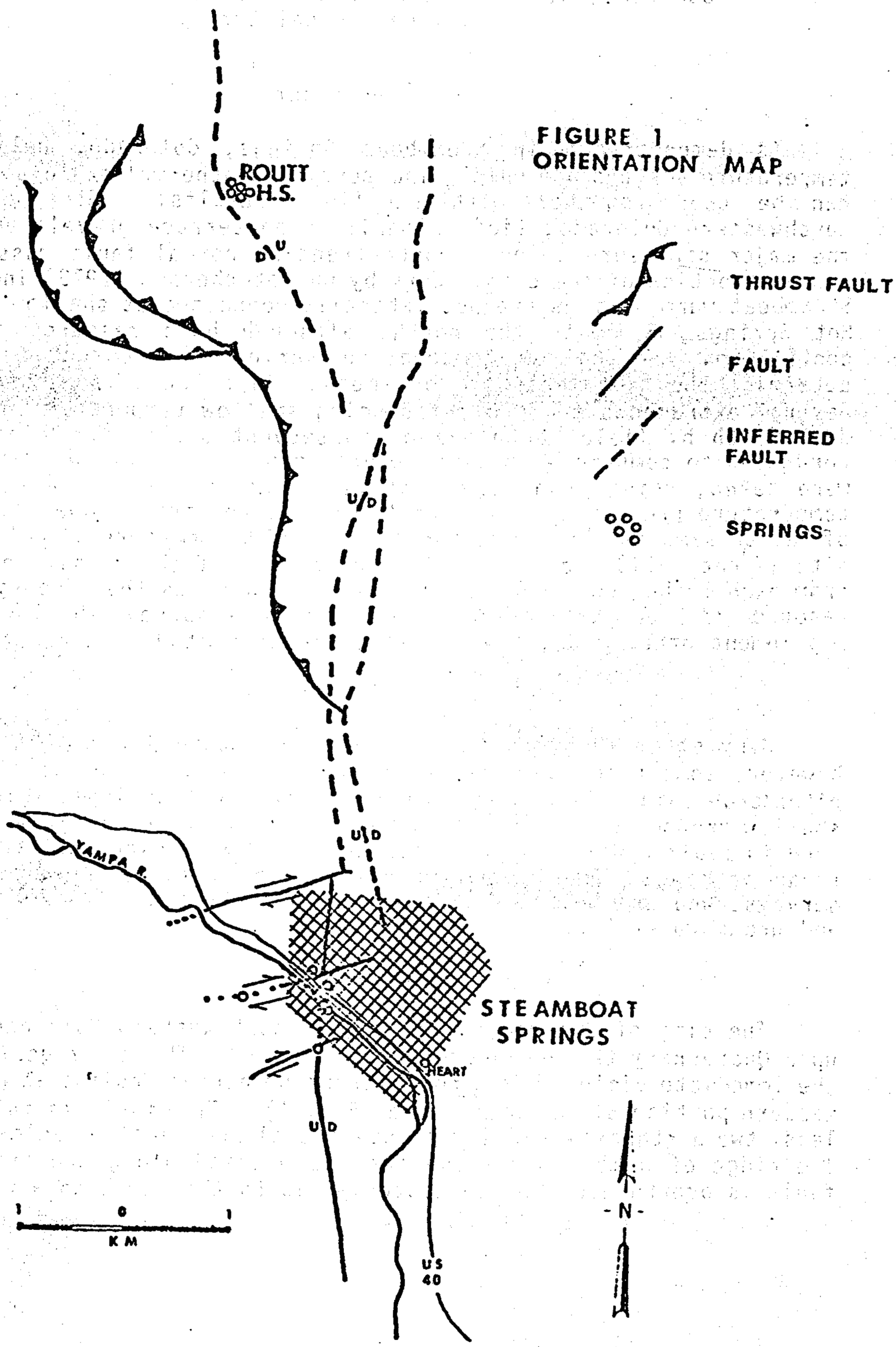
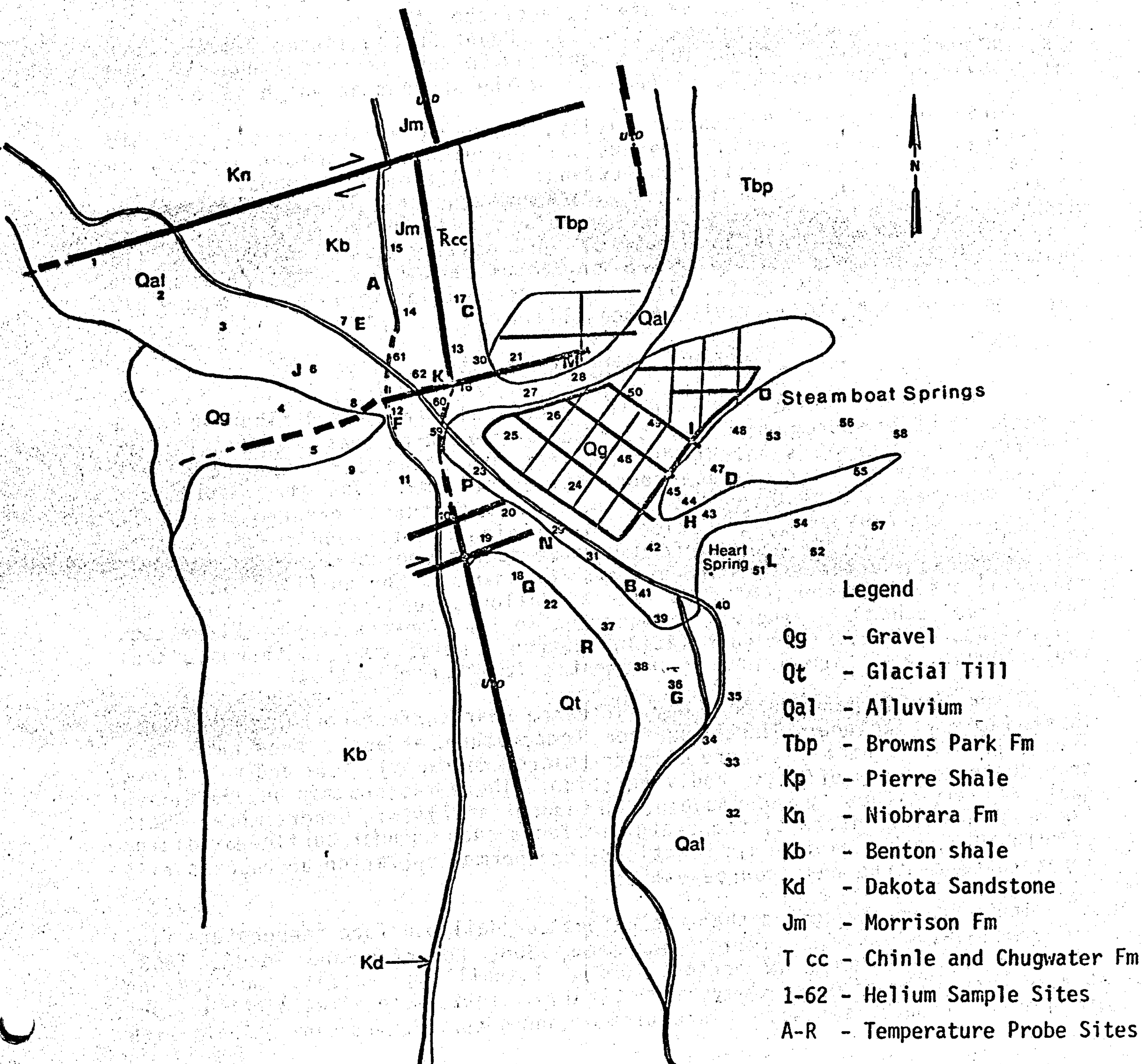


Figure 2

GEOLOGY AND SURVEY SITES AT STEAMBOAT SPRINGS



Geothermal Resource Characteristics

About five hot springs, Routt Springs, are clustered in a small area about 6 kilometers north of Steamboat Springs. Temperatures range from 51°C (124°F) to 66°C (151°F) and total discharge is about 3.2 l/s (50 gpm). The total dissolved solids content is low, about 539 mg/l (Barrett and Pearl, 1976). The springs issue from fracture zones within faulted Precambrian granitic and metamorphic rocks (Pearl, 1979).

Within the City of Steamboat Springs, several warm springs range in temperature from 20°C (68°F) to 40°C (104°F). Most of the springs are clustered along the river on the west side of the city, but Heart Spring, to the east, is a notable exception (Fig. 1). Heart Spring is the largest (8.8 l/s, 140 gpm), hottest (40°C, 104°F) spring with the best water quality (903 mg/l TDS) (Barrett and Pearl, 1976). All of the springs are high in sulphur.

Christopherson (1979), using gravity, audio-magneto tellurics, telluric profiling, and self-potential geophysical techniques in the area shown in figure 1, came to the following conclusions: (1) Although Steamboat and Routt Springs are both fault controlled, they are not connected laterally at shallow depth. (2) A low resistivity zone extends to a depth of about 1000 meters below Routt Springs. (3) The Steamboat Springs are fault controlled. (4) Subsurface flow is controlled by subhorizontal faulting at depth associated with a prominent thrust fault. (5) Frequent tremors in the area are a possible mechanism for maintaining fault permeability.

Shallow Temperature Probes

It is theoretically possible to determine spacial distribution of a subsurface heat source by near surface temperature measurements. This procedure has proven useful in delineating the extent of a secondary heat source in areas of near surface convective geothermal systems. Kintzinger (1956) reported excellent results in mapping temperatures measured at a depth of 1 meter in Lordsburg, New Mexico for defining a hot ground water system. Olmsted (1977) had good results from 1 meter deep temperature measurements in an area of near surface steam in Nevada. Friedman and Norton (1981) were able to define areas of anomalous heat flow at Yellowstone National Park by using the Pallman method of temperature determination at 2 meters depth. Flynn, et. al. (1980), reported good correlation between 2 meter deep isotherms, local fault trends, and temperature measurements from thermal wells.

Several extraneous factors may influence near surface earth temperature. These factors include diurnal surface temperature effects, seasonal flux, erratic climate anomalies, micro climate (micro geography), soil and rock type, groundwater damping effects, and vegetation. These factors may be dealt with qualitatively either by technique or subsequent analysis. Other, more subtle (in most areas of interest) temperature effects such as near surface oxidizing of sulphides, other exothermic reactions, or thermal pollution are necessarily interpreted as true heat source values.

It is generally agreed that the effects of daily surface temperature flux are negligible below 1 meter (Thompson, 1860, Lovering and Goode, 1963, Olmsted, 1977, Friedman and Norton, 1981). Installing, reading, and removing temperature probes in 1 to 3 days effectively mitigates the effects of seasonal or erratic climate variance. Micro-climate and other factors can be dealt with somewhat by recording surface temperature, slope orientation, elevation, soil type, geology, and vegetation present at each site. Correlation of each of these effects to results of the survey can be made to modify interpretation if necessary.

Probably the greatest single factor distorting shallow temperature data is is groundwater. Shallow, unconfined aquifers are generally warmer than dry soil in the winter, and cooler in the summer. Ground water considerably dampens temperature drift. Cartwright (1968) reported as much as a 2°C temperature change over shallow groundwater in a surface temperature survey. Parsons (1970) found groundwater in a permeable esker warmer than groundwater from adjacent clay and till. The usefulness of shallow temperature measurements to locate groundwater was demonstrated by Birman (1969), who concluded that increasing temperature is proportional to increasing depth to groundwater. This temperature change could be considered negligible where depth to groundwater is very consistent, or greater than 75 m (225 ft). The effect of this variable can be determined where local well data is available.

The shallow temperature survey is more an effective measure of geothermal convection, rather than conduction. Most successful results have been obtained near fault zones, and high temperature surface features. Ideally, the best area to apply this technique should have high temperature surface manifestations present, uniform soil type, geology, and vegetation, a deep or uniform groundwater table, relatively flat topography, and invariable, uniform climate. Olmsted (1977) considers near surface heat flow of at least several thousand times background to be ideal. Basin and Range-type geothermal sites in the southwestern United States are well suited to this procedure.

A shallow temperature survey was conducted at Steamboat Springs to determine the usefulness of this method in a less than ideal area. The temperature probes used consist of thermistors epoxied to tapered one inch diameter maple dowels. The two inch long dowels are fastened to five foot long, one inch diameter PVC pipe. This probe construction was advised by the Nevada Bureau of Mines and Geology (Tom Flynn, oral communcation, 1981).

Station intervals were .4 Km in a NW line, and .2 Km in a NE trend to coincide with streets (Fig. 2). Most probes were emplaced by augering a two inch diameter hole to a five foot depth with a soil auger. Some probes had to be emplaced by drilling four inch holes with a power auger. Packed dirt was used to fill hole space around the probes. Some intended sites had to be abandoned or moved due to rocky soil and a few probes were emplaced at only four foot depth. Most probes were left in the ground for 24 hours, while others were left for up to 72 hours to determine if further temperature change would occur with time.

Temperatures were recorded to an accuracy of $\pm$ .1°C with an Electrotherm IT 610 digital thermometer. For each site the following variables were recorded: Probe depth, geology, elevation, distance from nearest spring, distance from river, slope orientation, surface temperature, time emplaced, thermister reading, and other remarks. Soil type, vegetation present, and estimated soil moisture should also be recorded at each site.

Helium Survey

Helium is formed during the radioactive decay of uranium. Anomalous concentrations of helium occurring in groundwater or soil gas may indicate the presence of uranium, hydrocarbons, or geothermal energy (Reimer, 1976). As a geothermal exploration tool, helium can be detected at some distance from the source, allowing greater efficiency with fewer sample sites. The usefulness of this exploration technique has been well documented (Westcott, 1980, Denton, 1976, 1977, Hinckle, 1980, Mazor, 1974, Roberts, 1975, Roberts, et. al, 1975). Very high helium values were obtained near Idaho Hot Springs, Colorado by Roberts, et. al. (1975).

A helium survey was conducted at Steamboat Springs to compare with temperature results. Soil helium samples were taken near each temperature probe site, as well as 44 other sites, using a sampling grid twice as dense as the temperature probe survey (Fig. 2). Sample sites were .1 to .2 Km apart. Analytical equipment consisted of a mobile helium "sniffer" (Dupont Spectrometer 12055A) mounted in a crewcab pickup truck. Sensitivity in analyzing the samples is $\pm$ 10 ppb. Gas samples were collected by pounding a 3/4 meter hollow probe into the ground and extracting a 10 cc soil gas sample with a disposable plastic syringe. Samples were then analyzed by the mobile unit the same day.

Results and Discussion

Recorded temperatures ranged from 11.3°C to 18.6°C (Table I). Probes left emplaced for 72 hours showed a maximum T of + .2°C. One probe (K) left in for 48 hours showed a temperature increase of 1.6°C over 24 hours, while another (R) increased .7°C over the same period. The former change can be attributed to close proximity to a warm spring, while the latter fluctuation is unexplained. All other probes stabilized within one hour, and no other temperatures could be directly related to spring proximity. There was apparently little effect by the recorded variables, as no correlation between the results and each effect could be substantiated.

Local water conservation official Wes Signs, with the Colorado Division of Water Resources, indicated that groundwater within the alluvium in the study area is probably at a consistent, shallow depth. Although cold groundwater probably affected the near surface temperature to a minor degree, it is the opinion of the authors that the trends shown by mapped isotherms cannot be attributed to variations in groundwater proximity.

Helium results are plotted with isotherms in figure 3. Table I shows values of He and temperature for each corresponding site. A direct correlation of temperature to helium value at each site is not valid due to a slight shifting of helium concentration caused by the solubility of the gas in the warm waters. Helium anomalies tend to be down hydraulic gradient from the temperature anomalies. The most easterly helium anomaly probably reflects heat flow to the north, beyond the temperature stations. Lower helium values over the southeastern temperature high could be due to dilution near the river. The extremely low helium value at station 6 is not considered valid due to observed petroleum contamination at the site. Helium may have been purged at station 6 by evolving carbon dioxide, methane, or other gases.

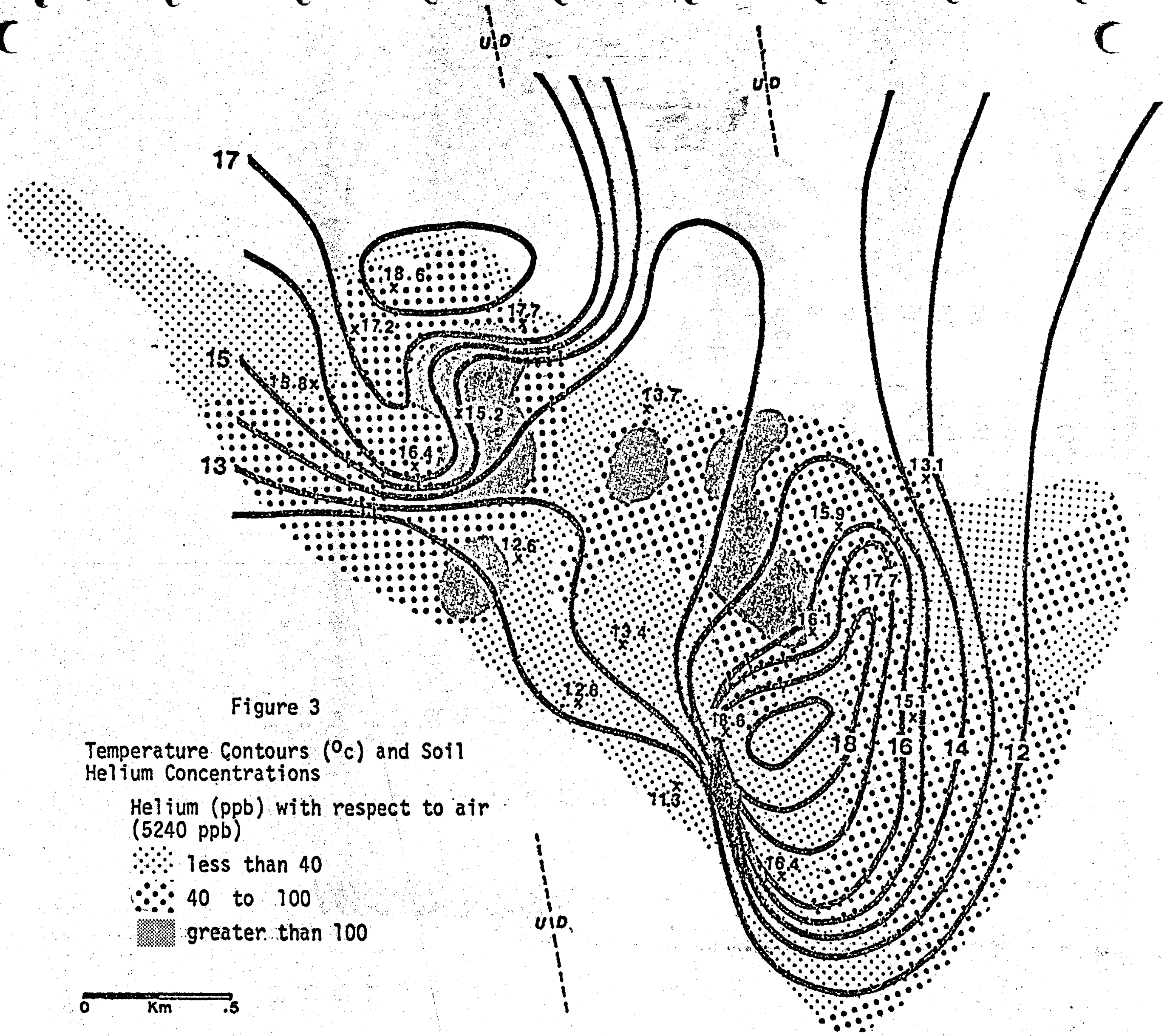


Figure 3

Temperature Contours (°c) and Soil Helium Concentrations

Helium (ppb) with respect to air (5240 ppb)

- less than 40
- 40 to 100
- greater than 100

Table 1

He values (ppb) with respect to air (5240 ppb)

1.	0	25.	29	49.	49
2.	0	26.	741	50.	3694
3.	-20	27.	39	51.	60
4.	60	28.	-78	52.	80
5.	60	29.	20	53.	20
6.	-1199 *	30.	68	54.	20
7.	68	31.	0	55.	80
8.	59	32.	50	56.	20
9.	40	33.	20	57.	20
10.	440	34.	40	58.	50
11.	60	35.	70	59.	510
12.	98	36.	0	60.	4275
13.	254	37.	-20	61.	22800
14.	59	38.	-20	62.	76950
15.	39	39.	0		
16.	107	40.	40		
17.	0	41.	40		
18.	-40	42.	90		
19.	20	43.	39		
20.	50	44.	1073		
21.	20	45.	263		
22.	0	46.	312		
23.	10	47.	59		
24.	39	48.	78		

*contaminated

Temperature values compared with interpolated helium values

	(°C)	(ppb-5240)
A.	18.6	50
B.	18.6	20
C.	17.7	10
D.	17.7	55
E.	17.2	70
F.	16.4	80
G.	16.4	5
H.	16.1	1000
I.	15.9	50
J.	15.8	-1000 *
K.	15.2	76000
L.	15.1	60
M.	13.7	0
N.	13.4	25
O.	13.1	65
P.	12.6	12
Q.	12.6	-40
R.	11.3	-15

$\bar{X} = 15.4°C$

$S = 2.2°C$

Comparing figure 3 to the geology shown in figure 2, it can be seen that the highest temperature and helium values correspond to both the westernmost normal fault, and an extension of a more easterly inferred fault. The data indicates that these faults control the geothermal resource in Steamboat Springs.

Conclusion

Although the results here only confirm what could reasonably be interpreted from surface geology, this survey proves the usefulness of these two techniques. Both methods are measures of thermal convection primarily, and correlation should be consistent. Although these surveys should always be used in conjunction with other methods where possible, their utility in tandem is beyond question here.

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