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SELF-POTENTIAL AND FLUID CHEMISTRY STUDIES OF THE MEADOW-HATTON AND ABRAHAM HOT SPRINGS, UTAH

by

Howard P. Ross (1), Robert E. Blackett (2), Michael A. Shubat (2), and Robert W. Gloyn (2)

(1) University of Utah Research Institute, Salt Lake City, UT
(2) Utah Geological Survey, Salt Lake City, UT

ABSTRACT

The Meadow-Hatton and Abraham Hot Springs are two of the largest and most active thermal spring systems in Utah. Self-potential surveys were completed to search for the source of thermal fluids and characterize self-potential expressions of these spring systems, and the fluid chemistry was studied to estimate temperatures of the near-surface reservoirs. Sharp self-potential minima occur beneath the spring mounds near Hatton Hot Spring, but no significant anomaly was observed near the Meadow thermal pools. Abraham Hot Springs is expressed as a weak dipolar anomaly, but a coherent negative anomaly was mapped west of the spring mound, suggesting fluid upflow beneath Quaternary basalts. Fluid chemistry coupled with silica-enthalpy mixing models indicate reservoir temperatures approaching 140°C for both thermal systems.

INTRODUCTION

The University of Utah Research Institute (UURI) and the Utah Geological Survey (UGS) have completed several self-potential (SP) surveys in their cooperative studies of covered, Basin and Range geothermal systems. These surveys delineated a well-defined minimum closely associated with the thermal anomaly at Newcastle (Ross et al., 1990), and negative anomalies at Wood Ranch and Thermo Hot Springs (Ross et al., 1991) which appear to be related to the thermal systems. In addition, information was compiled on the fluid chemistry of the thermal waters which provided independent data on the geothermal potential of the study area, was completed with little additional time and effort while conducting the SP surveys, and helped in interpretation of the results. This paper describes recent SP surveys and fluid chemistry results for two of Utah's largest thermal spring systems, Meadow-Hatton and Abraham (Baker) Hot Springs.

GEOLOGY AND THERMAL SPRINGS OF THE SEVIER AND BLACK ROCK DESERTS

The Sevier and Black Rock Deserts of western Utah are contiguous, complexly faulted structural basins in the eastern Basin and Range province (Figure 1). A west-dipping (10° to 12°) detachment surface, known as the Sevier Desert detachment, separates shallow (< 5 km) crustal extensional structures from deep, pre-Basin and Range structures (Anderson et al., 1983; Planke and Smith, 1991). The detachment underlies the Sevier and Black Rock Deserts as well as mountain ranges to the west such as the Cricket Mountains and Drum Mountains (Holms and Thiros, 1990). The low-lying Sevier and Black Rock Desert basins are underlain by thick sedimentary deposits that thin toward the basin margins and are bordered by mountain ranges on the east and west. Listric and planar faults divide the Sevier and Black Rock Desert basins into a number of buried, smaller basins. These faults terminate at depth at the Sevier Desert detachment and die-out upward into the basin-fill deposits (Figures 1, 2).

Black Rock Desert and Meadow-Hatton Geothermal Area

The Black Rock Desert is bounded on the east and south by the Pavant Range, on the south by the Cove Creek Dome, and on the west by the Cricket Mountains. Quaternary faults in the Black Rock Desert include the Pavant-Tabernacle-Beaver Ridge Fault Zone (PTBRFZ), the southern extension of the Clear Lake Fault Zone (CLFZ), and faults in the Cove Creek Dome area (Figures 1,3). The faults are both syn and post Lake Bonneville deposition (Oviatt, 1991).

The desert floor consists mainly of Quaternary lacustrine and fluvial deposits associated with Lake Bonneville, post-Lake Bonneville eolian deposits, and Quaternary volcanic rocks (Oviatt, 1991). Quaternary volcanic rocks (Figure 3) are mainly basalt flows ranging in age from about 1.5 Ma to less that 1,000 yrs B.P. Older

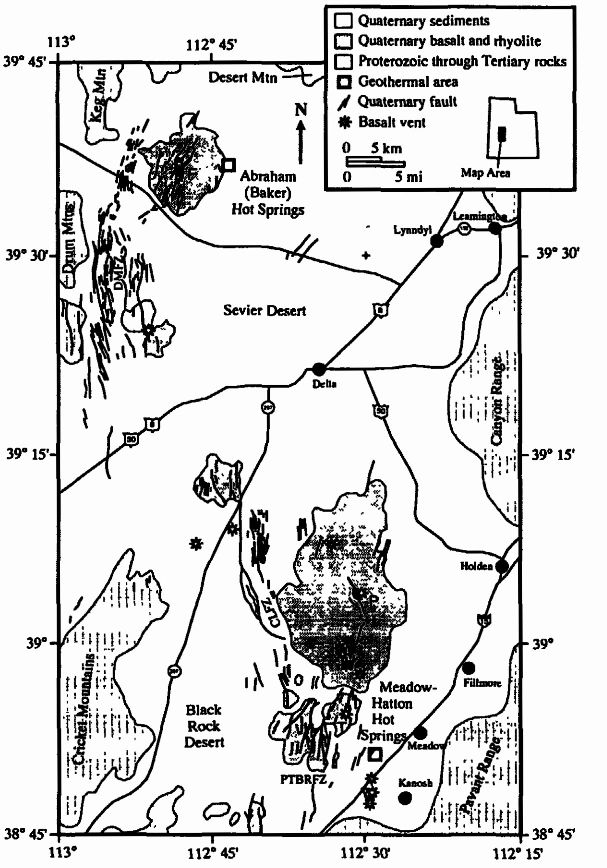

Figure 1. General geologic map and structural elements of the Sevier and Black Rock Deserts showing localities discussed in the text. F, Fumarole Butte; P, Pavant Butte; T, Tabernacle Hill; DMFZ, Drum Mountains fault zone; CLFZ, Clear Lake fault zone; PTBRFZ, Pavant Tabernacle Beaver Ridge fault zone. Modified from Oviatt (1989), Oviatt (1991), Oviatt et al. (1991).

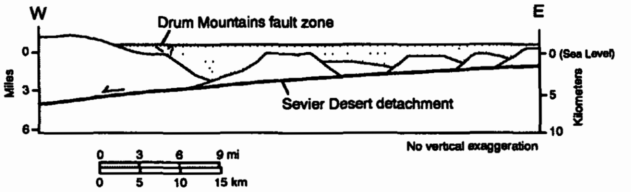

Figure 2. Schematic cross-section of the Sevier Desert basin. Faults shown are diagrammatic only and are not intended to represent actual structures (after Oviatt, 1989).

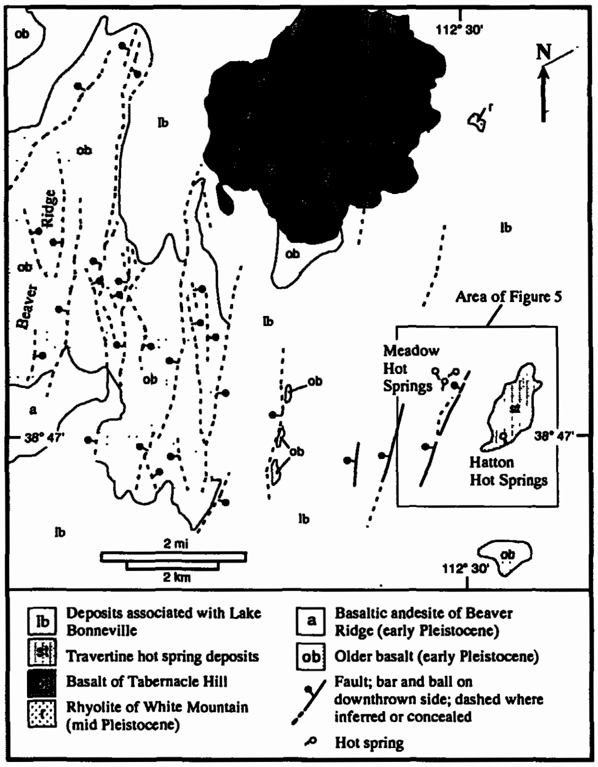

Figure 3. Geologic map of the Meadow-Hatton geothermal area showing volcanic rocks, Lake Bonneville deposits, Quaternary faults, hot springs, and travertine associated with hot spring activity.

Quaternary basaltic rocks include the basaltic andesite at Beaver Ridge (1.5 Ma), the Black Rock basalt flows (0.97 - 1.32 Ma), the Black Rock Volcano (0.6 Ma), and basalt flows at Beaver Ridge (0.5 - 0.9 Ma). A small rhyolite dome at White Mountain, dated by Nash (1986) at 0.4 Ma, may be the youngest rhyolite flow in Utah. Younger Quaternary basaltic rocks include the Pavant Ridge basalt (0.22-0.16 Ma) and ash erupted from Pavant Butte (15,000 yrs B.P.); basaltic flows, tuff, and cinders from the Tabernacle Hill vent (14,300 yrs B.P); and the Ice Springs basalt flow (660 yrs B.P) (Oviatt, 1991). The basalt of Tabernacle Hill erupted into Lake Bonneville at or near the Provo shoreline and shows features typical of basaltic eruptions into water.

The Cove Creek Dome, a doubly plunging, north-northwest-trending anticline in Tertiary basalts and lacustrine deposits 32 km (20 mi) southwest of Kanosh, is the most significant structural feature in the region. Oviatt (1991) postulated that the Cove Creek Dome has been uplifted approximately 300 to 400 m (1,000 to 1,300 ft). While most of the uplift probably took place during the late Tertiary, evidence suggests that uplift continued into the Holocene.

Meadow and Hatton Hot Springs (Figure 3) are located in the eastern part of the Black Rock Desert, about 8 km (5 mi) southwest of the community of Meadow (Figure 1). Hatton Hot Spring issues from the south end of a large, northeast-trending travertine mound at a temperature of 63°C (145°F). Nelson and Fuchs (1987) describe the mound as being about 2 km (1.25 mi) long and having long fissure ridges, terraces, sloping mounds, and raised pools (Figure 3). Meadow Hot Springs consists of several thermal springs aligned along a northeast trend and located in a marshy area about 2 km (1.25 mi) northwest of the travertine mound. Flow from Hatton Hot Springs is usually low, about 6.0 L/m (1.6 gpm). We observed variable flow from Meadow Hot Springs from no visible discharge to significant discharge. Much of the flow at Meadow is likely dispersed in the shallow subsurface.

Table 1 shows chemical analyses of waters sampled from Meadow and Hatton Hot Springs. The proximity of the springs and the similarities between analyses suggest that the fluids are from the same source. Chemical geothermometry applied to analyses from Meadow and Hatton Hot Springs yielded a wide range of equilibration temperatures (from near spring temperatures to 218°C; 424°F). M.C. Adams (verbal communication, 1993), reviewed results of the analyses and suggested that the fluid compositions probably result from complicated fluid-paths, thereby lessening the usefulness of geothermometry. By comparing fluid chemistries, he also suggested that the fluids may have been exposed to temperatures exceeding 200°C (392°F) before discharging within the shallow ground-water system. Re-equilibration is probably taking place in this shallow system.

Cleary (1978) applied a silica-enthalpy mixing model based on the method of Truesdell and Fournier (1977). He estimated that the cold water fraction made up from 86 to 90 percent of the fluid and that the unmixed temperature of the hot water component was between 190°C and 230°C (374°F and 446°F).

Holmes and Thiros (1990) summarized the groundwater hydrology of the Pavant Valley, including eastern parts of the Black Rock Desert. Ground water in the Pavant Valley is present in consolidated and unconsolidated rocks. The primary ground-water reservoir is unconsolidated lacustrine gravel, sand, and silt near the valley margins and clay with interbedded basalt in the valley center. Ground water is present within an unconfined aquifer consisting of about 15 m (50 ft) of saturated, unconsolidated fill near the valley margins and about 30 m (100 ft) of interbedded clay and fractured, vesicular basalt in the valley center. Groundwater moves generally from recharge areas near the mountains on the east and south sides of the Black Rock Desert toward discharge areas in the lower parts of the Pavant Valley and the Sevier Desert. Large withdrawals from wells locally affects groundwater movement.

Table 1: Chemical analyses of the Meadow and Hatton Hot Springs, Millard County, Utah. (values in mg/L; δD, $\delta^{18}O$ in permil)

SOURCE	Meadow HS East	Meadow HS South	Meadow HS West	Hatton HS
Reference	1	1	2	3
Temp. (°C)	41.0	34.0	31.5	63.0
pH	6.7	6.8	6.9	7.1
Na	1058.2	1054.4	1000.0	1041.0
K	148.2	149.1	130.0	137.0
Ca	468.4	467.8	480.0	438.0
Mg	92.9	92.3	94.0	86.0
Fe	0.050	0.000	0.040	0.300
SiO_2	56.7	56.8	48.0	48.0
B	5.5	5.5	5.2	3.5
Li	3.6	3.6	0.0	3.0
HCO_3	416.0	428.0	415.0	425.0
SO_4	1090.0	1090.0	1000.0	1018.0
Cl	1803.0	1795.0	1800.0	1790.0
F	9.60	9.50	3.80	3.80
TDSm	4967	4913	4770	4848
TDSc	4875	4869	4712	4723
δD	-124.0	-122.0	—	-124.0
$\delta^{18}O$	-17.2	-17.0	—	-16.6

References: 1. This paper; 2. WATSTORE (USGS); 3. Mabey and Budding, 1987.

Sevier Desert and Crater Springs Geothermal Area

Discontinuous mountain ranges bound the east, west, and north sides of the Sevier Desert (Figure 1). The north end of the Pavant Range, the Canyon Range, and Gilson Mountains form the east boundary. The Cricket Mountains, House Range, Drum Mountains, and Thomas Range form an indefinite western boundary. To the north are Keg Mountain, the Simpson Mountains, Sheeprock Mountains, and Tintic Mountains. Quaternary faults in the Sevier Desert include the Clear Lake fault zone, Drum Mountains fault zone, Cricket Mountains faults, Pavant Butte faults, Deseret faults, IPP faults, and the Old River Bed fault zone (Oviatt, 1989; Oviatt et al., 1991).

The desert floor consists mainly of Quaternary lacustrine and fluvial deposits associated with Lake Bonneville, post-Lake Bonneville eolian deposits, and Quaternary basalt (Oviatt, 1991). Quaternary basalts in the central and northern Sevier Desert, in addition to the Pavant Butte, Pavant Ridge, and Ice Springs volcanics described previously, include the Deseret basalt flows (0.4 Ma), basalt flows southeast of Smelter Knolls, and the basalt flows and scoria at Fumarole Butte and Crater Bench (0.9 Ma) (Oviatt, 1989; Oviatt et al., 1991).

The Crater Springs geothermal area is adjacent to a Quaternary eruptive center known as Fumarole Butte. Basalt flows erupted from the butte formed a broad volcanic apron known as Crater Bench. Thicknesses of the basalt may range from 150 m (500 ft) near Fumarole Butte to about 6 m (20 ft) at the flow margins. Potassium-argon ages for the flows at Crater Bench range from 0.88 Ma to 0.95 Ma, indicating an early Pleistocene age (Oviatt, 1991). The Drum Mountains

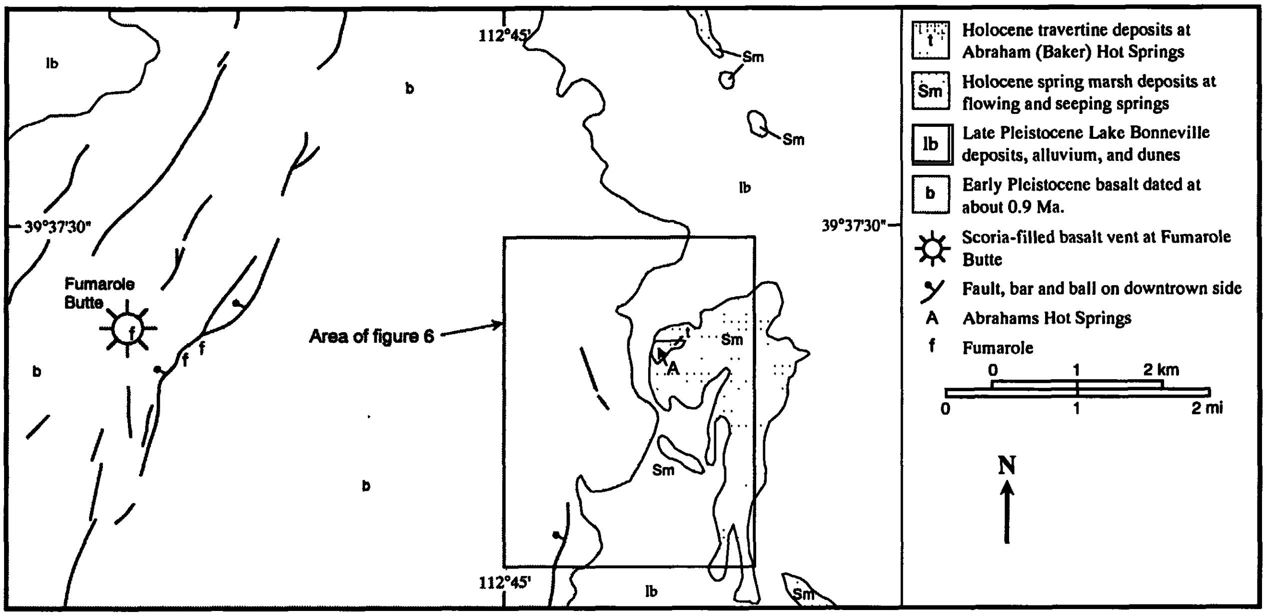

Figure 4. Geologic map of the Crater Springs geothermal area showing Quaternary basalt flows, Quaternary faults, location of Abraham Hot Springs, and fumaroles near Fumarole Butte.

fault zone, marked by obvious scarps, trends north-northeast across the western side of Crater Bench, near Fumarole Butte (Figure 4). Oviatt (1991) suggested that, following basaltic eruptions onto the valley floor and deposition of later Pleistocene lacustrine beds, more rapid erosion of the less-resistant lake beds caused Crater Bench to become an exhumed, topographic high.

Moss-lined, open fractures, documented by previous workers (Gilbert, 1890; Mabey and Budding, 1987), are conduits for water and other vapors at Fumarole Butte. Thermal springs issue from Abraham (also known as Crater or Baker) Hot Springs located on the east side of Crater Bench (Figure 4). Temperatures are as high as 87°C (189°F) and flow rates are between 90 and 140 L/s (1,427 and 2,219 gpm) (Rush, 1983). Mabey and Budding (1987) suggest that the vapors at Fumarole Butte are derived from the same fluid source as Abraham Hot Springs.

Table 2 shows chemical analyses of thermal water from Abraham Hot Springs. Rush (1983), using chemical geothermometry and a silica-enthalpy mixing model of Truesdell and Fournier (1987), suggested that the water emerging at Abraham Hot Springs may be 50 percent mixed with non-thermal water, and that the temperature of the hot water component could be as high as 140°C (284°F).

Mabey and Budding (1987) described a north-northwest trending gravity high with its axis passing directly through Abraham Hot Springs. The anomaly has an amplitude of 10 mGal and is 13 km (8 mi) long and 6 km (3.8 mi) wide. Rush (1983) suggested that the anomaly might be caused by higher-density volcanic rocks at depth, or by mineralization due to hydrothermal activity. Mabey and Budding (1987) suggested that the gravity high may reflect a buried bedrock high, possibly a horst block. They propose a geothermal model where hot fluids rise vertically along high-angle faults near Fumarole Butte, move eastward (down the hydrologic gradient) beneath or within the basalt flows,

Table 2: Chemical analyses of Abraham Hot Springs, Juab County, Utah. (values in mg/L; δD, $\delta^{18}O$ in permil)

Reference	1	2	2	3
Temp.(°C)	85.0	78.0	55.0	84.0
pH	7.4	6.3	7.8	6.5
Na	860.0	870.0	810.0	830.0
K	58.0	3.0	67.0	57.0
Ca	360.0	360.0	360.0	340.0
Mg	54.0	54.0	56.0	52.0
Fe	0.0	0.0	0.0	0.2
SiO_2	66.0	54.0	57.0	69.0
B		1.0	0.1	0.9
Li		0.0	0.0	1.0
HCO_3	150.0	146.0	150.0	156.0
SO_4	720.0	670.0	730.0	680.0
Cl	1550.0	1500.0	1500.0	1500.0
F	2.90	2.60	3.00	2.50
TDSm	3590	4060		
TDSc	3679	3531	3600	3538
δD	—	—	—	-126.0
$\delta^{18}O$	—	—	—	-16.1

References: 1. Mariner et al.,1983; 2. WATSTORE (USGS); 3. Cole, 1983 encounter the bedrock high, and surface at Abraham Hot Springs.

SELF-POTENTIAL STUDIES

The self-potential (spontaneous, or natural potential; SP) method, which measures naturally occurring voltage differences at the surface of the earth, has been used increasingly for engineering, hydrologic, environmental and geothermal applications since the early 1970's (Corwin, 1990). Self-potential surveys have often been used in exploration for high-temperature geothermal systems, but only to a limited extent for low- to intermediate-temperature systems. Although SP anomalies are often observed over geothermal systems, the expression may be positive, negative, dipolar or even more complex (Corwin and Hoover, 1979). This varied expression is confusing and reduces confidence in and use of the method in geothermal resource exploration and development.

In our study, self-potential surveys were completed using a radial or "spoke" technique so that many potential measurements, generally at 61 m (200 ft) spacings along the line, could be made directly with respect to a central electrode (Ross et al., 1990; 1991). Station spacing was reduced to 30 m (100 ft) in many of the anomalous areas. The surveys were completed using a high-impedance digital voltmeter and copper-copper sulfate porous-pot electrodes. Most stations were prewatered to reduce the variability of near-electrode soil moisture, as the surveys were conducted during a severe drought in the Great Basin.

Meadow-Hatton Hot Springs

Self-potential surveys were initiated at Meadow-Hatton in June 1992 and completed in August. A total of 29.5 line-km (18 line-mi) of data were collected. The survey covered an area of approximately 6.5 km^2 (2.5 mi^2). The completed SP contour map is shown in Figure 5.

All voltages are referenced to the initial base station, located 200 m (650 ft) west of the southern tip of the main travertine mound. This station value is about 10 to 15 mV below the regional background level, as determined from the completed survey, so the contour values are really 10-15 mV too high. Nearly 70 percent of the survey area varies between 8 and 20 mV, very close to background. This area of low SP variation includes low relief croplands to the south and east of the spring mounds, native alluvial and lakebed materials to the west and east, and wet meadows and marshlands in the northern third of the area. Low near-surface resistivities (due to wet soils containing clays and evaporite minerals) result in very low voltage differences, often less than 1 mV, for a large area north of the spring mounds and in the Meadow Hot Springs area. Three detailed profiles across the hot pools, during a period of near-zero flow, showed voltage differences of less than +/- 2 mV.

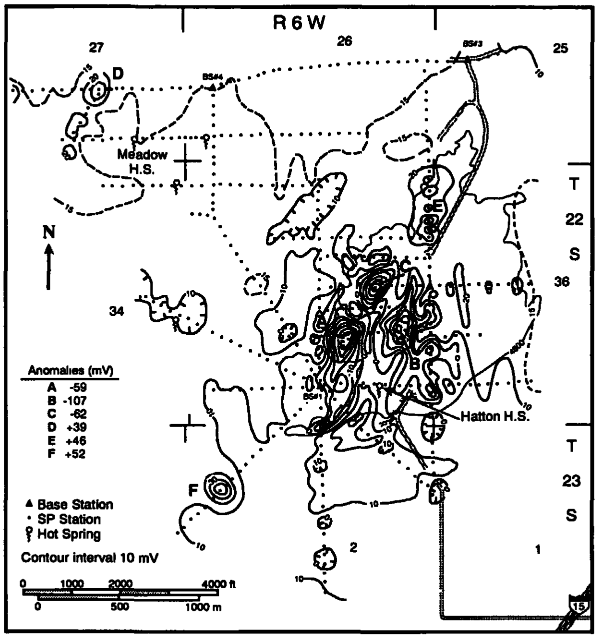

Figure 5. Self-potential contour map for the Meadow-Hatton area. The shaded area includes spring mound deposits above 4800 ft (1500 m) elevation. Contour interval is 10mV with supplemental +15mV contour (dashed).

In contrast, the SP expression for the travertine mounds, generally enclosed within the 1463 m (4800 ft) elevation contour, is quite complex. The mounds rise about 15 m (50 ft) above the surrounding flatlands, and are covered by dry soils consisting of windblown sands and travertine-rich mound debris. Vegetation is sparse, due in large part to the arid climate and active grazing. Three sharp, coherent SP lows of -59, -107, and -62 mV dominate the SP map. The largest minimum (-120 mV with respect to background) occurs 300 m (1000 ft) northeast of Hatton Hot Spring. Several local (1-5 station) maxima with amplitudes of 25 to 70 mV occur between and peripheral to the three lows. Selected profiles were repeated to verify the amplitude and position of anomalous features. The dominate expression of the Hatton spring mound area is a complex northeast trending low, perhaps 600 m (1970 ft) wide and 1000 m (3210 ft) long.

Crater Springs KGRA Area

The Crater Springs KGRA includes Abraham Hot Springs, which has perhaps the greatest flow rate of any hot spring system in Utah. Approximately 22.0 line-km (13.6 line-mi) of SP data were collected during April and June, 1991, and April 1992. Prewatering of electrode holes was necessary except in the wet meadows downgradient from the thermal springs. The survey covers an area of approximately 5.7 km^2 (2.2 mi^2). The completed SP contour map is shown in Figure 6.

All voltages are referenced to Base Station 1 located east of the outcropping basalts of Crater Bench and about 100 m (300 ft) west of the main hot spring mound. The distribution of the zero contours throughout the survey area, and simple statistics, suggest this station value is close to true background voltage levels. The generally low-amplitude, low-noise measurements east of Crater Bench permitted the addition of 5 and 15 mV contours to the standard 10 mV contour interval. With few exceptions, voltages range from -10 to +10 mV in the eastern part of the survey area. SP values in drainages and on the slopes and surface of the Crater Bench basalts vary widely, from -46 to +76 mV. Most high positive values were observed at topographic highs, or near cliffs, where there was little soil cover. The correlation was strong enough that high values could soon be predicted before the measurement was taken in the field. The high values are tentatively attributed to high resistivity and low moisture content near the roving electrode.

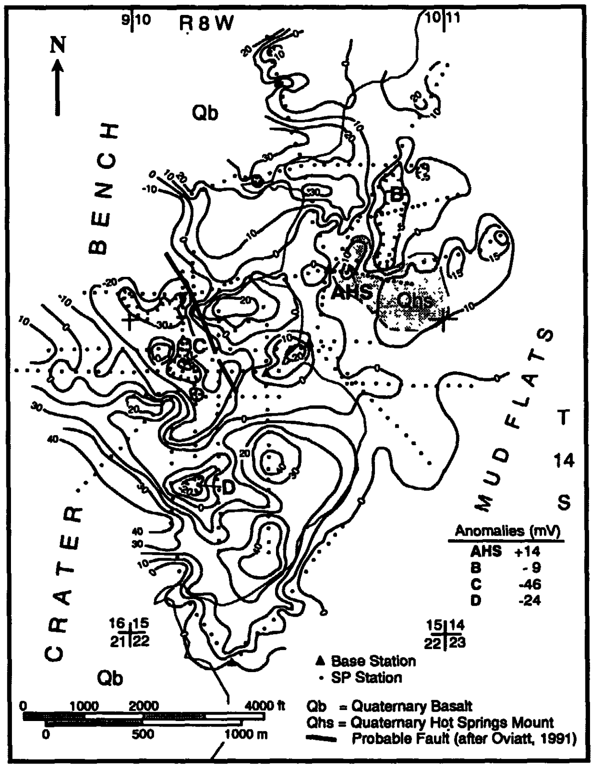

Figure 6. Self-potential contour map for the Crater Springs (Abraham Hot Spring-AHS) geothermal area. Contour interval is 10mV with supplemental -5mV and +15mV contours.

The variability of the SP values on the basalts suggested a simple statistical evaluation of the field data. Nine specific data sets were selected based on the field notes, topography, and areal distribution of coherent SP features.

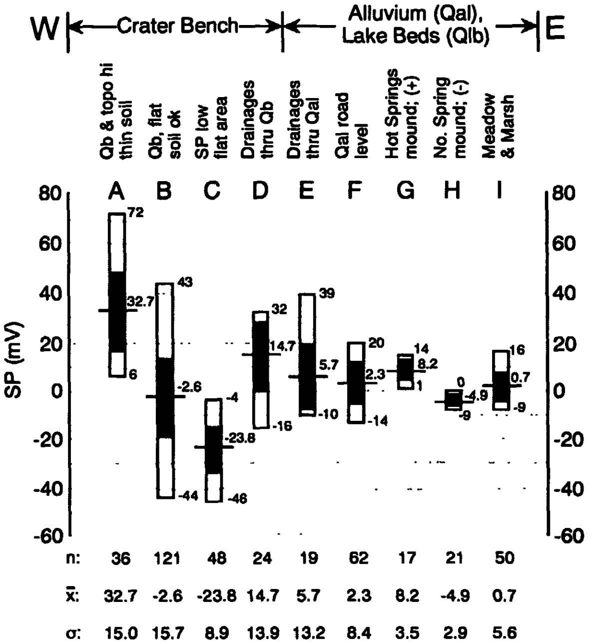

Figure 7. Statistical summary of SP data values for the Crater Springs geothermal survey. n=no. of samples, $\bar{x}$ =mean, σ = standard deviation. Filled in bar is 1σ.

The results, including number of samples, mean, range, and standard deviation are summarized in Figure 7. All sets are mutually exclusive with the exception of set B which includes 10 (of 121) samples from set C. A brief description of the sets follows.

A	Topo high on basalt (Qb), thin soil cover
B	Low-relief area with fair-good soil thickness over Qb
C	Coherent S P low, mainly confined to B (above)
D	Drainage areas cutting through Qb bench
E	Drainage areas, low relief, through slope wash and Qal
F	Qal and Qls at road level (4600 ft; 1400 m) east of bench
G	Highest part of hot spring mound, +ve S P
H	North of spring mound, -ve S P
I	Meadows and marsh, spring outflow areas.

This non-rigorous use of statistics presents a useful way to look at 388 of approximately 410 station SP values, 94 percent of the data set. Figure 7 emphasizes several points not obvious on the contoured map.

The broad, low relief area on Crater Bench (set B) shows a considerable range of S P values, but the mean, -2.6 mV, is near the regional background. Superposed on this is the effect of basalt topographic highs (set A) with little soil cover (mean 33 mV), and a significant SP minimum (set C) anomaly C, of -46 mV (mean -24 mV). Stations taken in drainages through the basalts and alluvium (sets D and E) show quite variable SP values, with means of +15 and +6 mV, respectively. Road level soils, meadows and marsh lands show mean voltages near background. The higher parts of the spring mound, travertine with obvious iron and manganese oxides, and several vents issuing 55-85°C fluids, is a definite SP high (anomaly G) of +14 mV (set G; mean 8 mV), bounded on the north by a coherent low of -9 mV (set H; -5 mV mean). These two sets describe a dipolar anomaly with a dominant high.

DISCUSSION

Earlier SP surveys by the authors (Ross et al., 1990; 1991) documented well-defined SP lows at Newcastle, Wood Ranch, and 1000 m southeast of thermal mounds at Thermo Hot Springs, in Utah. Only relatively weak (+/-25 mV) dipolar anomalies were associated with the spring mounds at Thermo. The studies reported here document: 1) no significant anomaly near three hot pools at Meadow Hot Springs; 2) three coherent minima with amplitudes of -70 to -120 mV 300 to 1000 m north of Hatton Hot Spring, within the hot spring mounds; 3) a weak (+14 mV) but coherent maxima associated with the center of Abraham Hot Spring mound, that is bounded by a weak (-9 mV) dipolar low on the north. The lack of a significant response at Meadow may be due in part to no visible flow at the time of the survey, and to low surface resistivity which shields deeper voltage differences. The complex, but substantial low, at Hatton suggests a possible upflow zone for thermal fluids, some of which vent (at low flow rates) at the springs. A broad minimum of -46 mV 1000 m west of Abraham Hot Springs may indicate fluid upflow beneath basalts along the only mapped structure in the survey area. Mabey and Budding (1987) had postulated that thermal fluids originated near Fumarole Butte, then migrated beneath or within the basalts to Abraham Hot Springs.

Fluid chemistry coupled with silica-enthalpy mixing models indicate reservoir temperatures for both the Meadow-Hatton and Abraham systems approaching 140°C. Given the regional heat-flow, this suggests a fluid-circulation depth of about 3 km.

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