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THE CODY HYDROTHERMAL SYSTEM

BY

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THE CODY HYDROTHERMAL SYSTEM

HENRY P. HEASLER¹

INTRODUCTION

The hot springs and associated travertine and sulfur deposits near Cody, Wyoming were first discovered by John Colter in 1807 or 1808 (Mattes, 1962). Because of Colter's description of the thermal areas along the Stinkingwater River (now called the Shoshone River), fur trappers called the area "Colter's Hell" (Mattes, 1962), a name which has sometimes mistakenly been applied to Yellowstone National Park.

The hot springs of Colter's Hell are the surface manifestations of a much larger hydrothermal system. That system has been studied to define its extent, maximum temperature, and mechanism of operation. The study area covers 2,700 km² (1,040 mi²) in northwest Wyoming (see Figures 1 and 2). Research and field work included locating and sampling the hot springs, geologic mapping, thermal logging of available wells, measuring thermal conductivities, analyzing over 200 oil and gas well bottom-hole temperatures, and compiling and analyzing hydrologic data. These data were used to generate a model for the hydrothermal system.

General Geologic Setting

The Cody study area covers portions of the western Bighorn Basin and eastern Absaroka Mountains. The uplifts shown in Figure 2 are Laramide in age (Fanshawe, 1952). Uplifts which are discussed include the Rattlesnake anticline and the Horse Center anticline. The Rattlesnake anticline trends northwest, has an exposed core of Precambrian granite and granitic gneiss, and is located in T.53N., R. 103W., the southwest corner of T.53N., R.102W., and the north half of T.52N., R.102W. (see Figure 2). The Horse Center anticline trends north to north-northwest, has an exposed core of Triassic Chugwater Formation, and is located in the southeast corner of T.52N., R.102W., the southwest quarter of T.52N., R.101W., and the northwest quarter of T.51N., R.101W. (see Figure 2). Both structures exert control on the areal extent and magnitude of the hydrothermal system.

Absaroka volcanoclastic material of Eocene age (Smedes and Prostka, 1972) covers the western portion of

the study area. Any heat generated by the 47-million-year-old volcanism has dissipated and no longer effects the thermal regime of the area. The volcanics are important because they cover and obscure the underlying sedimentary structure and may also influence local groundwater flow and chemistry.

Sedimentary rocks in the area represent the Cambrian through Quarternary systems, with only Silurian deposits absent. Thicknesses of the sedimentary rocks used in the thermal modeling were those of Pierce (1966, 1970, 1978), who gives a total sediment thickness of over 7 km in the eastern portion of the study area.

The thrust faults shown on Figure 2 — the Southfork thrust fault and Heart Mountain Detachment fault of Pierce (1975, 1978) — are not believed to exert significant control on the hydrothermal system.

Evidence for the Cody hydrothermal system

The most obvious evidence for the Cody hydrothermal system is the four sets of hot springs in the study area. All are located along the Shoshone River as shown in Figure 2. Chemical, temperature, and flow data for the springs are listed in Table 1.

The easternmost springs are the DeMaris Hot Springs, a group of at least seven major vents and more than ten minor vents along 220 meters of the northern shore of the Shoshone River. Measured temperatures for the vents range from 24 to 34°C, but Breckenridge and Hinckley (1978) report temperatures as high as 37°C (see Table 1). The springs occur on the southeast flank of the Rattlesnake anticline and flow from the Park City and Dinwoody Formations. A 41-meter-deep well located on a terrace 150 meters southwest of the DeMaris Hot Springs, which supplies 790 liters per minute (208gpm) of 37°C water to the Cody Health Spa, is believed to have the same source (see Table 1).

1.2 km west, along the northern shore of the Shoshone River, is a group of at least five vents called Shoshone Hot Springs (see Figure 2). Measured temperatures at three accessible vents were 28 to 34°C, with flow from the Tensleep Sandstone. Further west, the next set of hot springs is a series of 23°C seeps flowing from road fill that covers the Pilgrim Limestone. These are probably the Needle Hot Springs described but not located by Breckenridge

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Figure 1: Location of the Cody Study Area.

and Hinckley (1978). The fourth set of springs is that reported by Love and Good (1970) to have been covered in 1907 by Buffalo Bill Reservoir. Love and Good locate four possible thermal springs beneath the reservoir. Examination of pre-1907 photographs, field mapping of travertine deposits, and observation of ice-free areas on the reservoir indicate that the largest of the four springs is located beneath the reservoir as shown on figure 2. This is probably the site of John Colter's "boiling tar spring" (see Love and Good, 1970, pages B19-B21), believed to have been an active oil seep in historic times.

Additional evidence for the hydrothermal system is travertine and sulfur deposits. These deposits cover an .8-to 1.2-km-wide strip from DeMaris Hot Springs southeast 4 km along the eastern flank of Rattlesnake anticline near the contact of the Park City, Dinwoody, and Chugwater Formations (Woodruff, 1908; Wideman, 1957). Production of sulfur from these deposits was unsuccessfully attempted in 1906, 1926, and 1951 (Wideman, 1957). Travertine deposits are also located above present reservoir level near the site of the fourth set of springs (Pierce, 1970; unpublished mapping by Heasler, 1980).

Subsurface evidence for the hydrothermal system consists of reported oil well bottom-hole temperatures (BHT's) which are higher than normal. Thermal gradients were calculated as

$$\text{Thermal Gradient} = \frac{\text{BHT} - (\text{Mean Annual Air Temperature})}{\text{Depth of well}}$$

in °F/1,000 ft (which equals 1.823°C/km); these are shown in Figure 2 for each well. Most oil-well-BHT-derived gradients for wells in Figure 2 are in the range 18 to 37°C/km (10 to 20°F/1000 ft). However, along the crest of

Horse Center anticline and near the southern termination of Rattlesnake anticline, thermal gradients are high: eleven are in the range 49 to 205 °C/km (27 to 112°F/1000 ft).

Normal and high thermal gradients were verified by the precision thermal logging of available wells by the Wyoming Geothermal Resource Assessment Group, Department of Geology and Geophysics, University of Wyoming. Thermistor probes precise to $\pm 0.005^\circ\text{C}$ were lowered at 10-meter intervals to give temperature-depth plots (see Decker, 1973 for a complete description of this thermal technique). The temperature-depth plots were analyzed to define zones of hydrologic flow and of different thermal gradients through various rock types.

Table 2 summarizes all the thermally logged well data for the Cody area. The Husky and BLM wells listed in Table 2 are east of the thermal area and have normal gradients of 26 and 20°C/km (14 and 11°F/1000 ft). The measured thermal gradient values from Table 2 for the Horse Center anticline are equal to or greater than the oil well BHT gradients of 49 to 205°C/km (27 to 112°F/1000 ft). This substantiates the existence of the hydrothermal system in the area of the Horse Center anticline.

Of particular interest are thermal logs of three wells on the Horse Center anticline and five wells on the southeastern flank of Rattlesnake anticline. The location of these wells is shown in figure 3, the temperature-depth plots in Figures 4 and 5.

Figure 4 shows the temperature-depth plots of three oil exploration holes along the axis of the Horse Center anticline. Wells Letha C-4 and Gains Govt C-2, completed in the Tensleep Sandstone, show a primarily linear increase in temperature with depth. Well Rose Govt 1 was completed in Cambrian sediments with a maximum temperature of 47.54°C at 500 meters in the Madison Limestone. The Rose Govt 1 log indicates that temperatures continue to increase below the Tensleep Sandstone. The nature of this temperature increase will be discussed in the modeling section; it is believed it to be due to warm water flow in the Tensleep Sandstone and Madison Limestone. The temperature decrease and isothermal character below 500 meters in this well are not characteristic of the thermal regime of the area. Rather, they probably represent water flow down a fault system to the drill hole and then down the outside of the well casing. Note that all three of these wells have high thermal gradients (greater than 94°C/km, 52°F/1000 ft) and bottom-hole temperatures (39-48°C) higher than those of the hot springs (maximum 37°C).

Figure 5 shows temperature-depth plots down five temperature gradient holes drilled by the Wyoming Geothermal Resource Assessment Group. (A complete description of the drilling project can be found in Heasler and Decker, 1980). Well UWH-1 was completed in the

EXPLANATION

TABLE 1
Chemical Analyses¹

No.	Name	Location	Flow ³ (l/m)	Temperature (°C)	Total Dissolved Solids	pH	Cond.	Ca.	Mg	Na	K	HCO ₃	SO ₄	Cl	NO ₃
1	DeMaris Hot Springs ²	NW ¹ sec. 3, T.52N. R.102W.		24				217	173	258		681	39	17	
2				37				188	367	256		872	641	29	
3				27		7.1	1960	369	63	33	16	993	418	20	.1
4				28		6.9	1970	354	72	33	16	952	422	21	.1
5				27	1320	7.0	1880	322	66	30	18	917	402	16	0
6				27.5	1340	7.0	1790	324	70	30	17	900	418	17	0
7				27	1340	6.5	1570	300	74	28	13	880	400	17	0
8				36	1730	7.0	1800	380	86	47	20	1200	500	25	0
9				34	1740	6.7	2200	380	78	43	22	1100	470	21	0.0
10				34	1690	6.5	2260	410	82	45	21	1200	480	28	0.0
11	Cody Spa Well	NW ¹ sec. 3, T.52N., R.102W.	790	34	1700	6.6	2150	420	78	42	22	1100	470	22	0.0
12	Shoshone Hot Springs	NW ¹ sec. 4, T.52N., R.102W.	190	34	1530	6.5	2020	390	68	38	18	1100	360	18	1.0
13	Needle Hot Springs	SW ¹ Sec. 5, T.52N., R.102W.	190	28	876	6.9	1320	210	34	24	10	800	118	6	.1

No.	F	S	SiO ₂	B	Fe	CU	Mn	Zn	Ni	As	Se	Hg	Cd	Cr	Pb	Ag	Ba	Date	Reference
1		205	19															1926	Breckenridge and Hinckley, 1978
2		104	38															1926	Breckenridge and Hinckley, 1978
3	2.0		18		.2													2/15/68	Lowry and Lines, 1972
4	2.0		18		.06													2/15/68	Lowry and Lines, 1972
5	1.9		19	.55	.05													8/14/70	Lowry and Lines, 1972
6	1.9		18	.10	.08													8/14/70	Lowry and Lines, 1972
7	2.7	<.001	17	.33	0	<.01	<.05	<.02	<.1	<.05	<.001	.003	<.01	<.1	<.1	<.5	<.5	8/17/76	Breckenridge and Hinckley, 1978
8	2.9	<.001	21	.49	0	<.01	<.05	<.02	<.1	<.05	<.001	.001	<.01	<.1	<.1	<.5	<.5	8/18/76	Breckenridge and Hinckley, 1978
9	1.6	8.7	19	.6	.02	<.05	.06	<.02	<.1	<.005	<.005		<.01	<.1	<.2	<.05	<.1	10/6/79	State Lab. No. 0-1393 ⁴
10	2.8	1.3	24	.55	.2	<.04	.06	<.02	<.1	<.005	<.005	<.001	<.03	<.05	<.2	<.05	<.1	2/5/81	State Lab. No. 1-2476 ⁴
11	1.6	9.2	19	.5	.2	<.05	<.05	<.02	<.1	<.005	<.005	<.001	<.01	<.1	<.2	<.05	<.1	10/6/79	State Lab. No. 0-1386 ⁴
12	1.5	13	17	.5	.1	<.05	.06	<.02	<.1	<.005	<.005	<.001	<.01	<.1	<.2	<.05	<.1	10/6/79	State Lab. No. 0-1388 ⁴
13	1.3	.6	17	.3	.1	<.05	.09	<.02	<.1	<.005	<.005	<.001	<.01	<.1	<.2	<.05	<.1	10/6/79	State Lab. No. 0-1387 ⁴

¹ Values for major cations, anions, and trace elements are given in milligrams/liter which is nearly equivalent to parts per million by weight.

² Total flow for the DeMaris Hot Springs is approximately 6400 liters per minute.

³ Flow amounts are estimates given in liters per minute for the sampled vent. To convert to gallons per minute, multiply by .264.

⁴ Analyses by the Wyoming Department of Agriculture, Division of Laboratories, Laramie, Wyoming.

TABLE 2
Measured Thermal Gradient Data

Well Name	Location	Depth (meters)	Bottom-hole Temp. (°C)	Interval for calculation of Thermal Gradient (meters)	Thermal Gradient ¹ (°C/km)
Husky 16-69 7D	NW¼ sec. 4, T.52N., R.101W.	1916.4	60.31	26-1916	25.8
UWH-1	SW¼ sec. 2, T.52N., R.102W.	99.0	26.72	3-99	157.5
UWH-2	NW¼ sec. 11, T.52N., R.102W.	117.0	35.70	10-117	216.5
UWH-3	SW¼ Sec. 11, T.52N., R.102W.	72.0	25.72	5-70	189.9
UWH-4	NW¼ sec. 14, T.52N., R.102W.	97.0	12.38	5-97	3.6
UWH-5	SW¼ sec. 14, T.52N., R.102W.	109.0	18.14	5-105	76.9
UWH-6	NW¼ sec. 15, T.52N., R.102W.	85.1	20.43	18-85	108.1
BLM	NE¼ sec. 19, T.52N., R.101W.	61.4	12.41	7-61	20.4
Gaines Govt C-2	NE¼ sec. 31, T.52N., R.102W.	185.0	45.11	0-184	177.2
Rose Govt 1	NE¼ sec. 6, T.51N., R.102W.	740.0	45.44	20-220	101.3
Letha C-4	SE¼ sec. 6, T.51N., R.102W.	323.0	39.62	5-280	94.9

¹ Thermal gradient values were calculated using a linear least squares statistical technique for all temperature-depth values in the listed depth interval. To convert from °C/km to °F/1000ft multiply by .549.

Chugwater Formation, wells UWH-2, UWH-3, and UWH-4 in the Tensleep Formation, and well UWH-5 in the Sundance Formation. All wells except UWH-4 have high thermal gradients of 77 to 216°C/km. None of the holes encountered water except UWH-2, which found water at 85 meters, below which the temperature increases very rapidly. This confirms the Tensleep Sandstone as an aquifer containing warm water.

Hydrothermal system model

Using geological and geothermal data, a model of the Cody Hydrothermal system was devised. In the model, waters in the Tensleep Sandstone and Madison Limestone are heated at depth in a syncline, due to the regional thermal gradient. The heated waters gain access to shallower depths and the surface by moving upward along the steep western limb of the Horse Center anticline. This is shown diagrammatically in Figure 6.

The direction of water flow in such a system is important because it defines the structure through which the water flows. Pierce (in Love and Good, 1970) suggests water flow from the southeast which divides and flows around Rattlesnake Mountain. However, analysis of over 80 oil well drill stem tests and other hydrologic data show

that the primary water flow direction is from the west with a small component from the southwest around the southern edge of the Rattlesnake anticline (see Figure 7). This direction of water flow is through a syncline that occurs to the west of Rattlesnake and Horse Center anticlines. The water flow direction as shown in Figure 7 would explain the existence of the thermal springs as located on Figure 2.

Conductive thermal modeling techniques were then used as described by Heasler (1981) to estimate subsurface temperatures in the strata to the west of Rattlesnake anticline. Temperatures at a given depth in the syncline are modeled using

$$T_s = T_0 + (Q/K_1) dx_1 + (Q/K_2)dx_2 + \dots$$

where T_s is the unknown temperature in the syncline, T_0 is the mean annual surface temperature, Q is the regional heat flow from the earth, K_1 and dx_1 are the thermal conductivity and thickness of lithologic unit closest to the ground surface, K_2 and dx_2 are the thermal conductivity and thickness of the lithologic unit below unit 1, and so on. This method reflects temperature increase with depth in the earth as a function of the amount of heat flowing through the earth and the thermal conductivity of the rocks covering the earth. (Thermal conductivity differences among formations is the reason for the different linear ther-

mal gradient segments above 500 meters in the Rose Govt 1 well as plotted in Figure 4).

Results of the conductive thermal model are shown in Table 3. The range of heat flow values for the Beartooth Mountains, Absaroka Mountains, and Bighorn Basin is 54 to 75 milliwatts per square meter (Heasler et al., 1982; Buelow, 1980; Heasler, 1978; Baker, 1976; Blackwell, 1969). An upper limit of 67 milliwatts per square meter for the Cody study area was based on the work of Heasler (1978) and Heasler et al. (1982).

The data in Table 3 show Tensleep Sandstone temperatures in the syncline to the west of Rattlesnake anticline to be higher than those of the hot springs, but these data generally agree with the measured temperatures in Horse Center anticline. The model's predicted

temperatures for the top of the Tensleep Sandstone are in the range 46 to 54°C. This information, coupled with the direction of water flow, confirms the earlier suggestion by Fisher (1906) that the hot water in the Cody area is the result of normal thermal gradients within the earth. Woodruff's (1908) explanation of a slowly cooling magmatic heat source is not considered viable for many reasons. These reasons include lack of data for any recent igneous activity in the Cody area, the areal distribution of the thermal anomaly as shown in Figure 2, the low magnitude of the thermal anomaly, the flow direction of the water that is transporting heat, and the success of conductive thermal modeling in predicting the measured temperatures.

TABLE 3

Results of Conductive Thermal Modeling

Formation	Thickness ¹ (meters)	Thermal Conductivity ² (W/meter °K)	Temperature (°C) at base of formation ³	
			Using 54mW/m ²	Using 67 mW/m ²
Cody Shale	500	1.7	23	27
Frontier Fm.	137	3.1	25	30
Mowry Shale	122	1.6	29	35
Thermopolis Shale	168	2.5	33	40
Cloverly and Morrison Fms.	183	3.6	36	43
Sundance and Gypsum Spring Fms.	152	3.0	39	46
Chugwater and Dinwoody Fms.	244	2.9	44	52
Park City Fm.	21	4.0	44	52
Tensleep and Amsden Fms.	122	3.3	46	54
Madison Limestone	274	4.0	50	59
Three Forks, Jefferson Fms., and Bighorn Dolomite	180	3.2	53	63
Grove Creek, Snowy Range Fms., Pilgrim Limestone, Gros Ventre Fm., and Flathead Sandstone	396	2.1	63	76

¹Thicknesses are generalized from Pierce (1966, 1970, 1978)

²Thermal conductivities in units of watts per meter °K are from Heasler (1978) and unpublished data.

³Assuming a mean annual surface temperature of 7°C. Results are expressed to the nearest °C. Heat flow values are expressed in milliwatts per square meter.

Figure 3: Location of drilled temperature gradient holes (triangles) and three thermally logged oil wells (circles).

Conclusion and Summary

The Cody hydrothermal system covers an area 1 to 2 km in width that extends from the DeMaris Hot Springs (west of Cody) south 11 km along the Horse Center anticline. To the east of this area the important aquifers (the Tensleep Sandstone and Madison Limestone) slope into the Bighorn Basin and soon become too deep to be economically drilled for hot water use. In the north portion of this area, warm water of over 34°C in the Tensleep Sandstone can generally be reached at shallow depths of 50 to 300 meters. Higher temperatures of over 40°C are expected in the Madison Limestone at depths of 250 to 600 meters.

The heat for the hydrothermal system results from the earth's normal temperature increase with depth. Water flows through the syncline west of Rattlesnake anticline absorbing heat. This heated water then flows up over Horse Center anticline and a portion flows around the southern

Figure 4: Temperature plots for the three oil wells shown on Figure 3.

Figure 5: Temperature plots for five of the drilled temperature gradient holes shown on Figure 3.

Figure 6: Generalized model of the Cody hydrothermal system showing simplified structure and approximate temperatures and depths.

POTENTIOMETRIC SURFACE OF THE PARK CITY-TENSLEEP AQUIFER IN THE CODY AREA

— 4000 — Elevation of fluid potential in feet above mean sea level. (dashed where uncertain)

Upper contact of the Phosphoria Formation and margin of area of Paleozoic and Precambrian outcrop. (dashed where uncertain)

• Pp 4600 Drill stem test data obtained from Petroleum Information. The numbers indicate fluid levels. The formations tested are:

Rd - Dinwoody Formation
Pp - Phosphoria Formation
Pi - Tensleep Formation

• Spring Data
→ Groundwater flow direction.

SCALE
0 1 2 miles
Contour Interval = 200 feet

Figure 7: Potentiometric map showing water flow directions.

end of Rattlesnake anticline. Maximum temperatures in the hydrothermal system for the Tensleep Sandstone are predicted to be 44 to 52°C and for the Madison Limestone 46 to 59°C. These occur in the south portion of the hydrothermal area.

Although the Cody hydrothermal system is a low-temperature geothermal resource, temperatures are high enough for space heating and low-temperature industrial uses (Brown et al., 1982). Given its favorable location near Cody and nearby active subdivision areas, the Cody hydrothermal system represents a valuable energy resource.

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