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THE 1983 TEMPERATURE GRADIENT AND HEAT FLOW DRILLING PROJECT FOR THE STATE OF WASHINGTON

by

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INTRODUCTION

During the Summer of 1983, the Washington Division of Geology and Earth Resources carried out a three-hole drilling program to collect temperature gradient and heat flow information near potential geothermal resource target areas. The project was part of the state-coupled U.S. Department of Energy Geothermal Program. Richardson Well Drilling of Tacoma, Washington was subcontracted through the State to perform the work.

The general locations of the project areas are shown in figure 1. The first hole, DNR 83-1, was located within the Green River valley northwest of Mount St. Helens. This site is near the Green River Soda Springs and along the projection of the Mount St. Helens - Elk Lake seismic zone (see figure 2). The other two holes were drilled near Mount Baker. Hole DNR 83-3 was sited about 1/4 km west of the Baker Hot Springs, 10.5 km east of Mount Baker, while hole DNR 83-5 was located along Rocky Creek in the Sulphur Creek Valley. The Rocky Creek hole is about 10 km south-southwest of the peak. Two other holes, DNR 83-2 and DNR 83-4, were located on the north side of the Sulphur Creek Valley. Both holes were abandoned at early stages of drilling because of deep overburden and severe caving problems. The sites were apparently located atop old landslide deposits.

PROCEDURES

The holes were drilled towards a targeted depth of 150 meters using air rotary techniques and 6" tri-cone button bits. Casing was driven through the overburden and into a few feet of bedrock using a casing hammer and drive shoe. Holes were completed by suspending a sealed, water filled 2" iron pipe in the hole to total depth and cementing the annulus around the pipe from the bottom of the hole up.

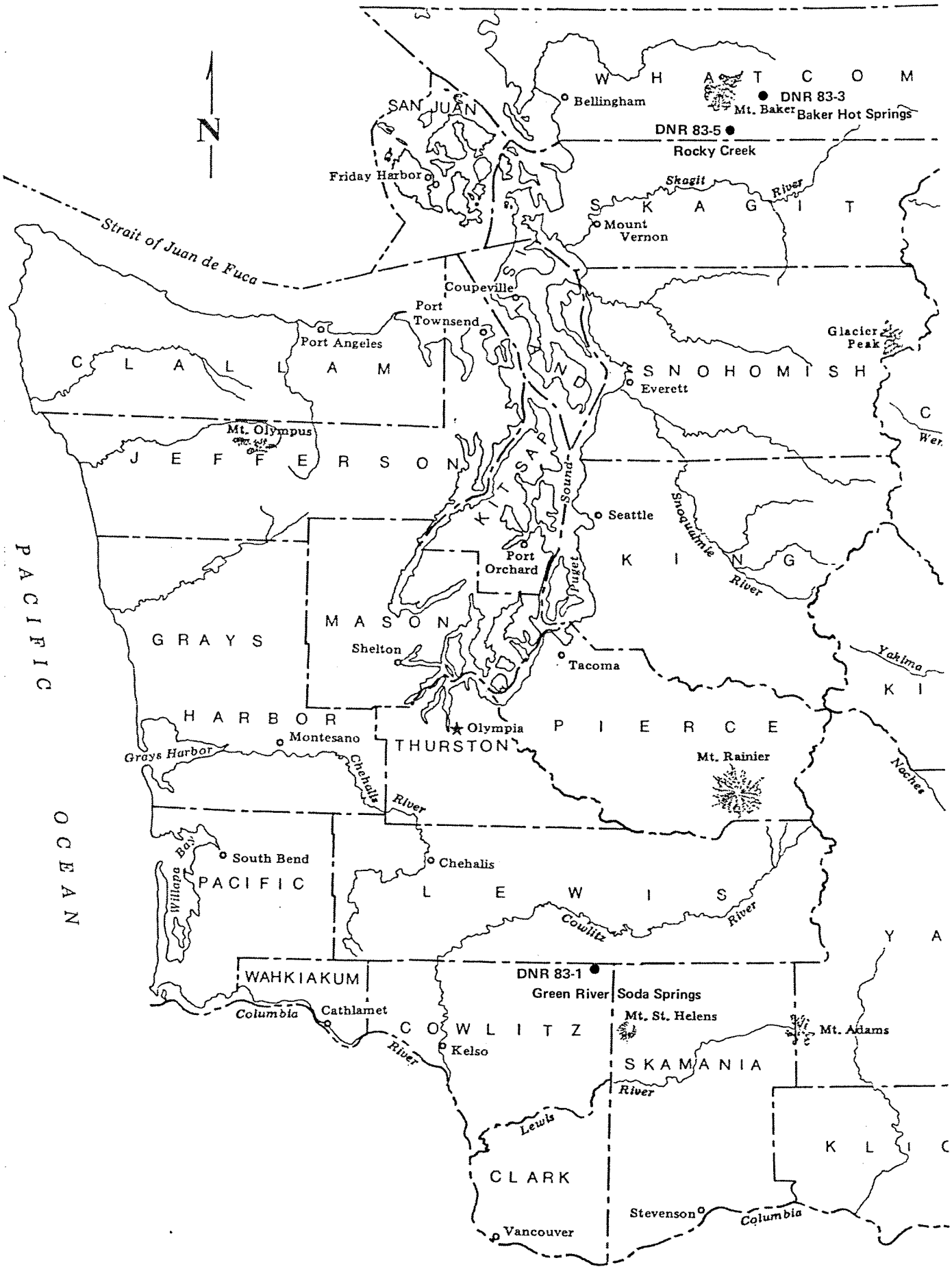

Figure 1. – Drill hole locations for 1983 temperature gradient - heat flow project.

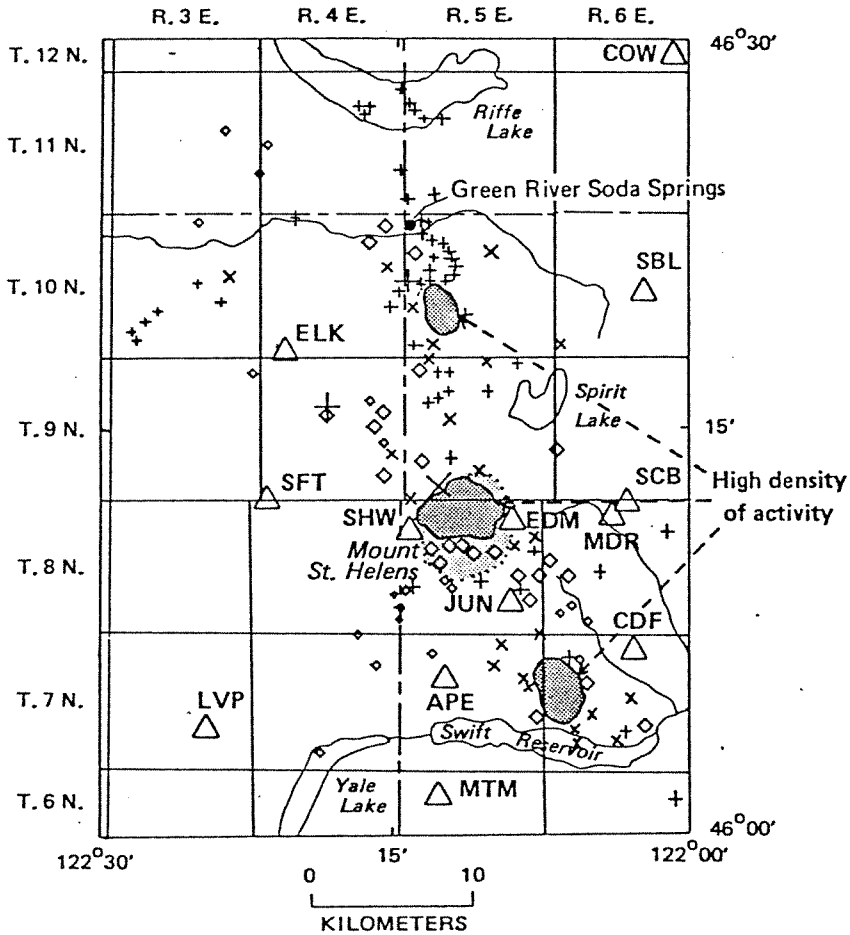

Figure 2. — Composite seismicity pattern from May 18 to August 31, 1980. Triangles, seismic stations. Symbol size indicates magnitude: small symbols, events with magnitudes less than 2.8; large symbols, events with magnitudes greater than 2.8. Depth indicated as follows: +,0-5 km; x, 5-10 km; square, 10-15 km; diamond, greater than 15 km. (from Weaver and others, 1981).

RESULTS

Green River Soda Springs (DNR 83-1) T.10 N., R.4 E., Sec. 2, NE1/4 of NW1/4 of SE1/4: This first hole was completed to a depth of 465 feet (142 meters) on July 15, 1983. It penetrated 140 feet of alluvium, and 325 feet of volcanic flows, tuffs, and breccias of the Oligocene Ohanapecosh Formation. Fracture zones which produced water were encountered at numerous depths. From early temperature logs showing cementing effects, it could be determined that the main fracture zones occurred within the intervals of 155-165 feet, 375-385 feet, and 420-430 feet. The lower aquifers were quite mineralized, producing a total artesian flow of about 50 to 60 gpm, with a temperature of 12.7°C and conductivity of 5,500 umhos/cm.

The Green River Soda Springs, located about 1/3 km west of the drill hole, consist of one main spring and numerous seeps which have built up a tufa mound on a flood plain on the north side of the river. The mound is broad and relatively flat, built up about 5 to 7 meters high and roughly 30 meters long, and covered with reeds and cattails. The flow varies with season and river level. During the drilling, the flow was only a few gpm, with a temperature of 13.9 to 14.2°C and conductivity of 3,200 umhos/cm with incessant bubbling of CO_2.

Temperature at depth data for DNR 83-1 is presented in table 1 and as a plotted gradient in figure 3. The bottom hole temperature for DNR 83-1 was 14.9°C at 141 meters. The lowest temperature measured was 8.7°C forming an inflection point at a depth of 13 meters. The calculated gradient between these points is 48.4°C/km. A straight line segment of the temperature vs. depth plot between 140 and 40 meters gives a gradient of 49.9°C/km. The area had been thought to be characterized by gradients in the 30 to 40°C/km range.

Table 1. - DNR 83-1 Green River Drill Hole
T. 10N., R. 4E., Sec. 2, NE1/4 of NW1/4 of SE1/4
(Logged 7-22-83.)

Depth (m)	Temperature (°C)	Gradient (°C/km)
5	10.67	
10	8.77	
15	8.73	36
20	8.91	48
25	9.15	54
30	9.42	62
35	9.73	54
40	10.00	48
45	10.24	34
50	10.41	38
55	10.60	48
60	10.84	48
65	11.08	56
70	11.36	62
75	11.67	76
80	12.02	106
85	12.55	42
90	12.76	14
95	12.83	34
100	13.00	52
105	13.26	42
110	13.47	54
115	13.74	46
120	13.97	42
125	14.18	58
130	14.47	58
135	14.76	32
140	14.92	
141	14.94	

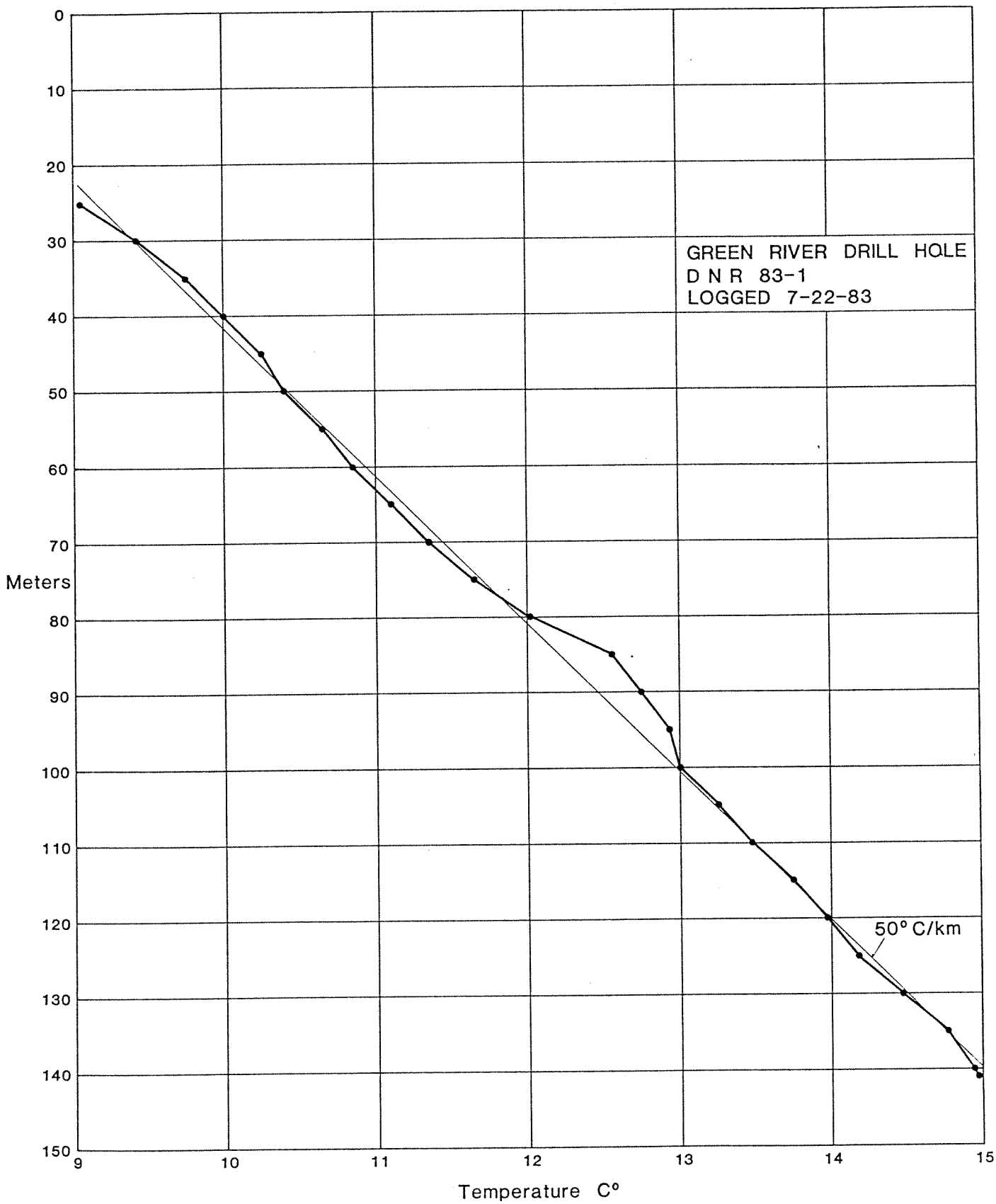

Figure 3 — Temperature vs. depth for the Green River Soda Springs Drill Hole (DNR 83-1).

Baker Hot Springs (DNR 83-3) T. 38N., R. 8E., Sec. 20, SW1/4 of NW1/4 of SW1/4: This hole, completed on August 16, 1983, was located along the road above Baker Hot Springs. It penetrated 90 feet of glacial debris, including several boulders with diameters from 1 to 3 meters, before hitting competent rock. From 90 feet, to the total drilled depth of 490 feet, the bedrock consisted of greenstone of the Chilliwack Group, of Carboniferous to Permian age.

Numerous small fracture zones were encountered throughout the hole, each producing warm to hot water. The first significant water was encountered just above the bedrock. This shallow aquifer produced 25°C water at about 10 gpm. The first artesian flow was noticed the morning after the hole had reached 200 feet. The temperature was 30.4°C, with a flow of about 3 gpm. By the time the hole reached 490 feet, the "pumped" water had a temperature of about 46°C, with a production of roughly 50 gpm. It also had an artesian flow of about 10 gpm, with temperatures varying from 43 to 46°C. Some of the most significant production zones are thought to be at 90, 195, 260-270, 280-282, 330-340, 438-442 and 460-470 feet.

Because of caving from upper zones, the hole was completed with 2-inch black pipe to a depth of only 460 feet. The temperature at depth data for DNR 83-3 are presented in table 2 and plotted in figure 4. The temperature at the bottom of the hole was also the highest temperature, at 47.9°C. Two different gradients approximate the temperature vs. depth curve. The upper gradient, from 60 to about 100 meters, averaged about 200°C/km. The gradient from 105 meters to the bottom of the hole averaged about 100°C/km. The change in gradient could be due to differences in thermal conductivity for the rocks, but since the area is conspicuously affected by the hot spring system and local convection of hot water, the change in gradient is likely due to control by lateral flow of the warm and hot aquifers.

Table 2. - DNR 83-3 Baker Hot Springs Drill Hole
T. 38N., R. 8E., Sec. 20
(Logged 9-20-83)

Depth (m)	Temperature (°C)	Gradient (°C/km)
5	13.58	
10	12.65	516
15	15.23	150
20	22.73	106
25	28.03	494
30	25.56	284
35	26.98	376
40	28.86	468
45	31.20	338
50	32.89	140
55	33.59	446
60	35.82	212
65	36.88	148
70	37.62	228
75	38.76	222
80	39.87	210
85	40.92	192
90	41.88	196
95	42.81	198
100	43.80	160
105	44.60	68
110	44.94	88
115	45.38	120
120	45.98	110
125	46.53	112
130	47.09	100
135	47.59	70
140	47.94	
(T.D.) 140.5	47.94	

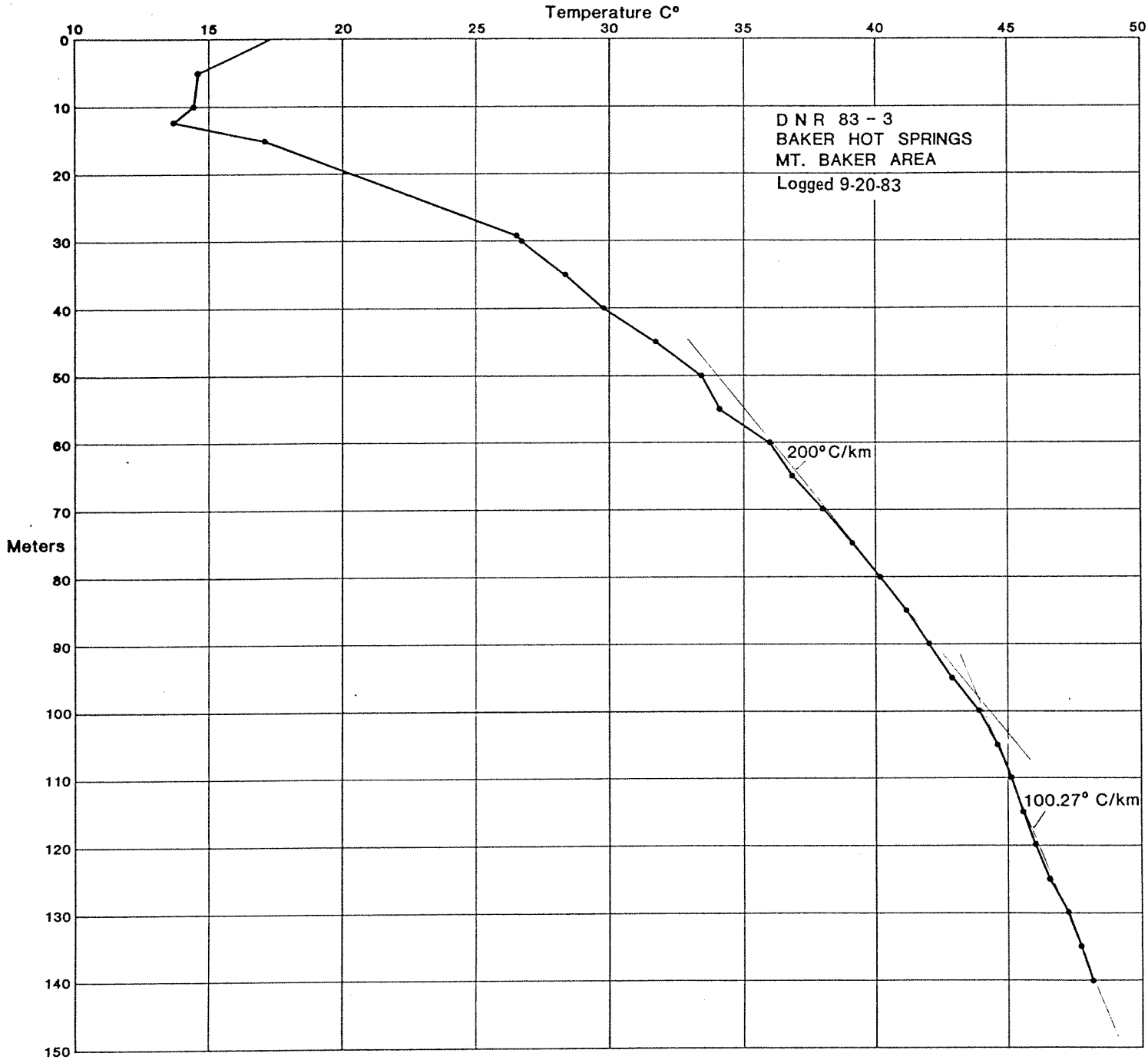

Figure 4 — Temperature vs. depth for the Baker Hot Springs Drill Hole (DNR 83-3).

The Baker Hot Springs flow at about 20 gpm from glacial deposits at an elevation roughly 200 to 300 feet below the top of DNR 83-3. The temperature of the main spring shows some seasonal variation, with a high temperature of about 45.3°C, and conductivity of 730 to 830 umhos/cm. The saltiest water flowing from the drill hole, representing a combination of all aquifers encountered, had a conductivity of 780 umhos/cm.

Rocky Creek (DNR 83-5) T. 37N., R. 8E., Sec. 20, SE1/4 of SE1/4 of NW1/4: This hole was completed to a depth of 500 feet on October 2, 1983, but no temperature at depth information has been collected to date. A blockage in the 2-inch pipe at 185 feet has prevented the passage of the temperature probe beyond this depth. Unsuccessful attempts have been made to clear the pipe, and the hole may be lost because of this blockage.

The hole is drilled into 10 feet of overburden, with Quaternary basaltic-andesite flows from 10 to 40 feet, talus and scoria from 40 to 55 feet, highly fractured bedrock from about 55 to 60 feet, and competent bedrock from 60 feet to total depth. The bedrock consists of andesite and dacite flow and highly silicious intrusive dikes. These rocks have been informally referred to as the Loomis Mountain dacite center and are considered to be part of the upper Chilliwack Group with a Permian(?)-Triassic age (Blackwell, 1983).

HEAT FLOW

The results of thermal conductivity measurements for the drill cuttings were not available as of November 1983. As a result, heat flow can only be approximated. For DNR 83-1, at Green River Soda Springs, the rock was typical Ohanapecosh Formation. In the past, this rock has been determined to have thermal conductivities ranging from 1.4 to 1.8 W/m·°K. This would produce heat flow values of 70 to 90 mW/m^2. For the Baker Hot Springs drill hole (DNR 83-3), assuming that the greenstone has a thermal conductivity between 3.0 and 3.5 W/m·°K, the upper zone heat flow would be 600 to 700 mW/m^2, while the lower zone heat flow would be 300 to 350 mW/m^2.

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