The Low Temperature Geothermal Resources of Eastern Washington

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by

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Division of Geology and Earth Resources

Department of Natural Resources

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Introduction

Relatively deep irrigation wells drilled throughout much of the Columbia Basin of Eastern Washington have often encountered warm water aquifers. As early as the turn of the century, geohydrologists were noting the anomalous temperature gradients suggested by many of these wells, especially the artesian wells in the Moxee Valley, east of Yakima (Smith, 1901). Well temperature information collected during the 1970's further suggested that large portions of the Columbia Basin could provide low temperature geothermal resources. But a closer examination of the available information by the Division of Geology and Earth Resources showed that there was a tremendous amount of variation within the basin, often over relatively short distances (Korosec, Kaler, et al, 1981 and Korosec, Schuster, et al, 1981). In addition wide discrepancies were noted for the values reported for the same well by different sources. Nonetheless, the Division produced the current Geothermal Resource Map of Washington as a preliminary compilation of information, to begin the process of identifying the areas of high potential (Korosec, Schuster, et al, 1981). Since the completion of the map, the Division has collected additional well information and has further analyzed the entire data set. This report will summarize the data collecting activities of 1980 and 1981, discuss the approaches taken toward data manipulation, and will present an updated picture of the nature and extent of geothermal resources within the Columbia Basin.

Past Work and Some Inherent Problems

The state geothermal map identifies about 330 wells with bottom hole temperatures in excess of 20°C within the Columbia Basin of eastern Washington. In addition, information on about 350 additional wells with cooler temperatures was available and used in the determination of the map's gray areas, which delineate regions potentially underlain by low temperature geothermal resources (i.e., warm aquifers at relatively shallow depths). Within the indicated potential areas, temperature gradients calculated from "bottom hole temperature" and using an average surface temperature of 12°C, were generally greater than 45°C/km. As explained in ,the map's key, "It is not implied that thermal water will be found everywhere in the gray areas. In southeastern Washington cold wells are interspersed with warm wells." In addition, "Absence of gray shading does not indicate there is no possibility of finding geothermal resources; it means only that surface and subsurface manifestations are not now known." These cautious statements alluded to the preliminary nature of the map and its designated potential resource areas. Since the compilation of the map, we have identified several causes for some of the variations and inconsistencies suggested by the map and accompanying table of well information.

Data Sources: Well information reported in Korosec, Schuster, et al (1981) and used to construct the geothermal map was compiled from several different sources, representing different degrees of quality, accuracy, and hence, reliability. High quality, reliable data includes well temperature information from Southern Methodist University (D.D. Blackwell and Staff), Washington State University (J. Crosby and Staff), and well logs collected by the Division staff. Questionable information includes unpublished U.S. Geological Survey well logs and WATSTORE data from the Water Resources Division, and information from U.S. Geological Survey water supply papers and Washington State Division of Water Resources water supply bulletins. The lower quality assigned to these sources is due to either temperature probe calibration problems (unpublished USGS well logs, reference 3) or uncertainties as to whether the temperature is a downhole reading or a well head temperature from a flowing well, possibly representing a mixture of more than one aquifer (References 4,5,6, and 7).

Bottom Hole Temperature: Most wells in eastern Washington are wholly or partially uncased irrigation, municipal, or domestic supply wells. Water flow between aquifers often produces stair-step temperature-depth plots, with large isothermal sections and high gradient "temperature recovery" sections. As a result, the actual temperature increase with depth is not manifested as a straight line gradient. By using the temperature difference between the bottom hole and the surface, an extrapolated gradient can be calculated. But during an examination of data from original driller's reports, it was found that many wells have been logged short of the true bottom of the wells. The probes were blocked by obstructions in the hole, casing step downs, caving zone, etc. If there is inter-aquifer communication extending to depths deeper than the lowest point logged, then the calculated gradient is meaningless. Upflow would produce an artificially high gradient, and vice versa for downflow. A possible example of the first case is the Moon well (7N 26E 5AB, Benton County). With a temperature of 22.1°C at a logged depth of 148 meters, a calculated gradient of 68°C/km results- The well was actually drilled to 326 meters, and upflow is' the likely cause of the relatively high temperature at the logged depth. An example of the second case might be the Phillips-11 well (16N 32E 14BB, Adams County). A temperature of 20.0°C was measured at a depth of 314 meters, producing a calculated gradient of 25°C/km. The well was actually drilled to 399 meters. Surrounding wells produce calculated gradients of 45 to 50°C/km. Downflow through the lowest zone logged probably produces the low calculated gradient at Phillips-11.

In some cases, logging to the total drilled depth does not overcome the effects of inter-aquifer water flow, specifically when the hole bottoms in an underpressured aquifer. Downflow to and into this zone will result in an artificially low bottom hole temperature. The only well in which we are sure this is happening is City of Ephrata Well #10 (21N 26E 15AD) in Grant County. This well produces 30°C water for municipal supply, and will soon be used to heat municipal buildings as part of a Federal H.U.D. funded geothermal project. But the temperature measured at total depth, about 551 meters, was only 21.3°C. The well was virtually isothermal over the lower 400 meters, suggesting strong downflow during static conditions. A gradient calculated from the temperature logged would be 17°C/km, while the actual gradient is about 35°C/km or better. (The pumped water temperature of 30°C, used as a bottom hole temperature, produces a gradient of 32°C/km, but the pumped water is most likely a mixture of a shallow aquifer at about 21°C and a much warmer lower aquifer.) Gradients from shallower wells in the surrounding area are of poor quality but range from 32 to 116°C/km.

Surface Temperature: For the published state geothermal map, an average surface temperature of 12°C was used to calculate gradients. For the Columbia Basin, reported mean annual air temperatures range from 10° to 14°C, with an average of roughly 11.5°C. Variations are controlled primarily by latitude and elevation. Mean annual surface temperatures are usually warmer than mean annual air temperatures, and show more variation, being dependent on slope angle and slope orientation as well as latitude and elevation. The size of the error introduced by using an average mean annual surface temperature for gradient calculations will be dependent on both the depth of the hole and the temperature spread between surface temperature and bottom hole temperature. The deeper and/or warmer the bottom hole temperatures, the less the percentage error. In an area where the "real" gradient is about 45°C/km, and the mean annual surface temperatures range from 10° to 13°C, calculated gradients using 12°C for holes 100 meters deep may produce errors from 45 percent too low to 25 percent too high (from 25 to 55°C/km). At 200 meters depth the errors range from 22 percent too low, to only 9 percent too high (from 35 to 50°C/km). At 300 meters, the errors are diminished to values from 16 percent too low to 7 percent too high (from 38 to 48°C/km).

New Data Collection

During 1980 and 1981, additional well temperature information was collected by three workers; John Kane, working directly for the Division, and Sherri Kelly and Walter Barker, working for D.D. Blackwell, SHU, in cooperation with the Division. A total of 180 wells were added to the data set. For many of these wells, drilling depth information was collected. The new data gives a better coverage of the Columbia Basin, especially the margins, adds detail in the Yakima area, and fills in some of the previously blank portions of the map.

As a separate project, the Division supported a W.S.U. graduate student, John Biggane, to conduct a geohydrologic examination of the warm aquifers in the Yakima area. During 1980 and 1981, Biggane examined temperature and geophysical logs for the high concentration of irrigation and municipal wells throughout the valleys surrounding Yakima. A preliminary report has already been released (Biggane, 1981), and a thesis will be completed in 1982. The results of this geohydrologic investigation will be examined in future Division publications.

In addition, the authors gathered drilling depth information for several hundred holes. The summaries of driller's reports found in several hydrologic reports were used. Eventually, the total drilled depth for most of the wells in our files will be known, but only after the original driller's reports filed with the State of Washington Department of Ecology are examined.

Data Manipulation

With the additional information collected over the past few years, new approaches to data manipulation have been found. These new approaches have enabled us to overcome many of the problems discussed earlier, and present a somewhat different picture of the extent, boundaries, and values of the temperature-gradient anomaly areas, areas representing the best locations for potential low temperature geothermal resources.

The problem of differing data quality resulting from different information sources was overcome by assigning degrees of confidence to the data sets. We have high confidence in information collected by all individuals associated with S.M.U., W.S.U., and the Division and therefore use primarily these data sets for contouring and the determination of anomalies.

The best quality gradients are straight-line plots of temperature vs. depth, observed over most of the length of the well. These gradients are designated "A". Cased holes, with no intrahole flow, will produce A gradients, but these condition:, are relatively rare in eastern Washington. Straight line gradients can be produced in uncased holes, in zones above, below, and even between aquifers, which are being affected by intrahole flow. Since one or both end points are being artificially set by the flow, the resulting gradient does not represent the true gradient. For these wells, and for any other well with known or suspected intrahole flow, calculated gradients were used.

By knowing the drilled depth at the time of well completion, the quality of the calculated temperature gradient can be roughly determined. Good gradients, designated "G", result when logged depth approximates reported drilled depth. For nearly all of these wells, interaquifer flow has little if any effect on a calculated gradient.

Gradients calculated for wells logged short of the drilled depth were designated "S". These values were assigned a low quality rating. In addition, some wells could have complete caving at depth producing a new bottom which is reached by the probe, but shallower than the reported drilled depth. Not knowing the exact nature of the blockage, especially its effect on water flow to or from lower zones, these wells were still designated S, and considered of low quality. Some of these wells may not have had water flow effects on the lowest temperature reading. Under this condition, the well would have probably produced a straight-line plotted gradient, quality A, which would be favorably used instead of a calculated gradient.

When the drilled depth was not determined, the well was designated "U". The unknown quality of these wells gave them about the same low credibility as S gradients, but overall, these wells had a higher probability of being close to a realistic calculated gradient because some of them were undoubtedly logged to the drilled depth. As such, they were often used to influence the contouring of the temperature gradient information.

For wells reported in U.S. Geological Survey water supply papers and State of Washington Division of Water Resources water supply bulletins, which have already been assigned a relatively low quality as a source, gradients calculated from their temperatures were designated "F", for flowing. It is assumed that the temperatures represent a pumped or artesian flowing water, which is either cooled as it rises through the well, warmed as it passed through the pump (if the flow is low), or represents a mixture of lower and upper aquifers. For the most part, these gradients should be minimums. As such, these gradients were only used to influence the position of contours and the designation of anomalous areas.

The problem of errors introduced by using a single mean annual surface temperature for all of eastern Washington was partially overcome by several different methods. By placing more emphasis on the deeper holes, and virtually ignoring the holes less than 120 meters in depth, high-percentage errors were reduced. For holes in the northern portions of the Columbia Basin, where the mean annual air temperature is a few degrees cooler than southern sectors, conservatively lower values were used to generate calculated gradients. For wells with sufficiently detailed near-surface temperature/depth information, where undisturbed by obvious in-hole flow, the mean annual surface temperature was determined from the upper gradient inflection point. This was usually the coolest temperature in the well, if measured during the primary field season, the warm months of May through October. Another method "used, especially for wells logged during the cooler seasons, involved determining the general temperature gradient trend of the upper portion of the temperature-depth plot and projecting this trend to the surface. These two methods were used with good success on most of the well temperature information collected during the past two years. Gradients calculated in this manner often produced values relatively close to observed gradients of quality A.

With the newly acquired information, a computerized data base was formed, allowing for quick sorting by parameters such as county, location, depth, temperature, gradient, gradient quality, and information source. For example, a high quality data subset was produced by using S.M.U., W.S.U., and Division data, and using the parameter limits of depth greater than 150 meters and gradients of quality "A" or "G". This reduced the number of wells from over 1000 to about 150 wells. Computer-run trend surface analysis and contouring programs using this data subset produced a picture of the Columbia Basin very different than previously imagined. However, the complexity suggested by the results, and the very poor percentage of variation explained by the trend surface, at all orders, discouraged our further use of computer manipulation, except for sorting. Computer contouring work continues, and will be discussed in future publications.

The complexity was not a total surprise. The geohydrologic work conducted by John Biggane in the Yakima area demonstrated that shallow to intermediate depth wells, with depths up to 200-250 meters, could show a tremendous range of high quality gradients over a relatively small area. Biggane suggests that structure and hydrologic controls play an important part in producing these temperature gradient variations.

After plotting all temperature gradients of wells deeper than 120 meters, with quality A, and G, and including several gradients with quality U and S (if their values fell within a "reasonable" range), a detailed gradient contour map was hand produced (scale 1:500,000). Without too much difficulty, a contour interval of 5°C/km was attainable. Figure 1 is a simplified and smaller-scale version of this hand contoured map, using a contour interval of 10°C/km. Several areas of above average gradients have been identified. Figure 2 shows the locations of the geothermal anomalies, and Table 1 presents a listing of some of the best wells within these anomalies.

Cascades: A large portion of the southern Cascades is characterized by gradients in the range of 45 to 55°C/km, or better. Smaller areas with gradients in excess of 80°C/km are found along the Tieton River east of Rimrock Lake (40 km west of Yakima) and along the Columbia and Wind Rivers in the Columbia Gorge (see Fig. 2). The extent of these high gradient areas, and the extent of areas with gradients between 55 and 80°C/km (as suggested by a few single-point anomalies) is not yet known. South Cascade gradients and anomalies will be discussed in future papers.

For the middle Cascades, from Mt. Rainier north to Stevens Pass, gradients suggest that this is a relatively low gradient province, but coverage is inadequate. For the northern Cascades, the average temperature gradient is still unknown. The relatively high gradient of 68°C/km at a heat flow hole near Scenic (Stevens Pass area), and the occurrence of two stratovolcanoes, Mt. Baker and Glacier Peak, suggest that there may be substantial areas with gradients better than 35°C/km within this province, and further investigations are needed to verify this.

Columbia Basin: The Columbia Basin, an area of relatively higher gradients than surrounding areas to the north, east, and south, shows substantial internal variation. Good to fair quality gradients range from 25 to 90°C/km, but the average falls between 35 and 45°C/km. Most anomalously warm wells, with gradients in excess of 45°C/km, fall within several major and minor discrete areas described below. Unlike the "gray areas" on the Geothermal Resources Map, we need not be as cautious concerning the occurrence of colder gradient wells within these areas. They may still exist, but they do not occur within our high quality data set.

Yakima and Ahtanum-Simcoe areas: The highest degree of variation and complexity occurs around Yakima. This complexity has been brought out by the high density of wells in the area. Investigations by John Biggane confirmed this complexity,

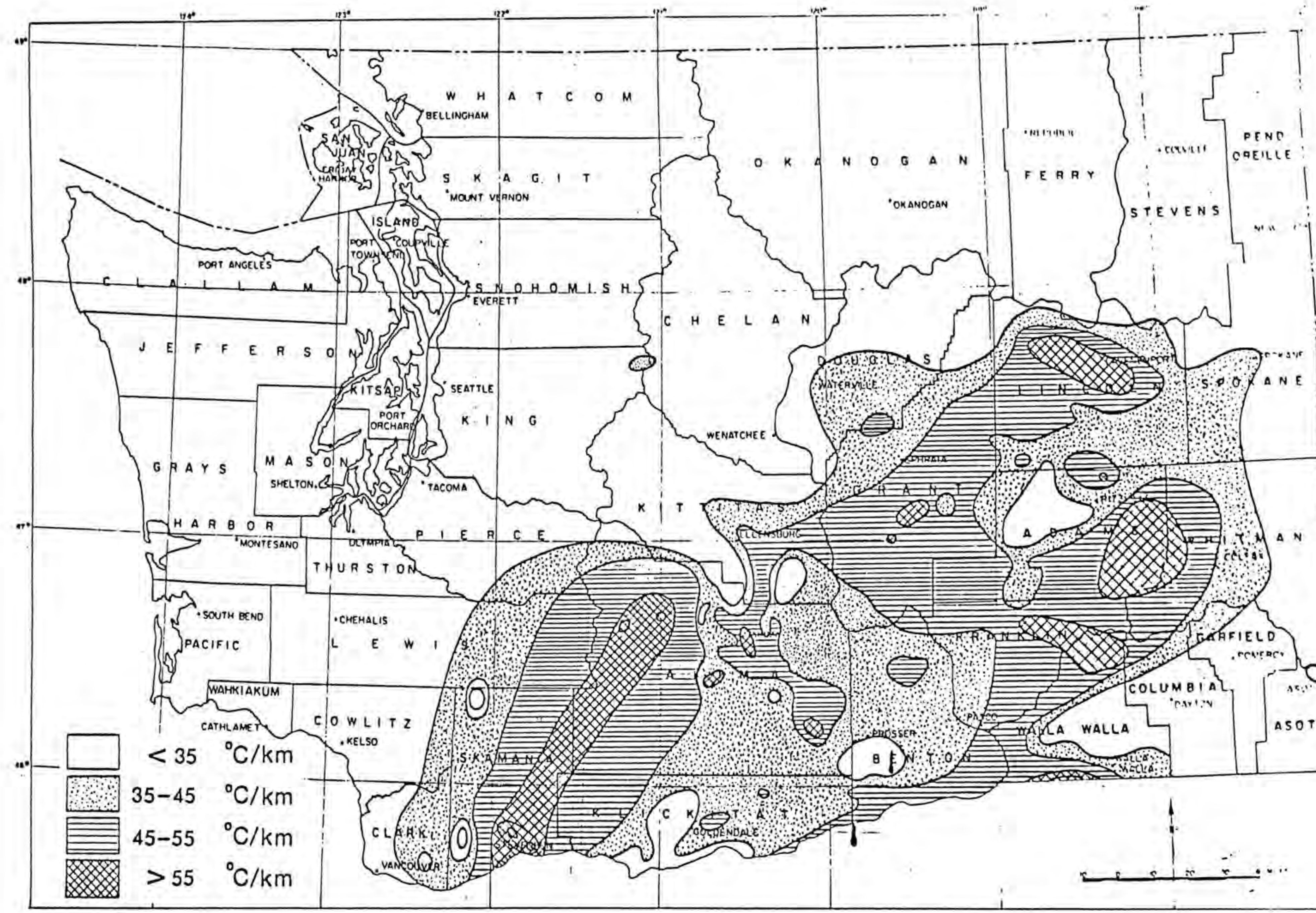

Figure 1. Temperature gradient contour map of Washington.

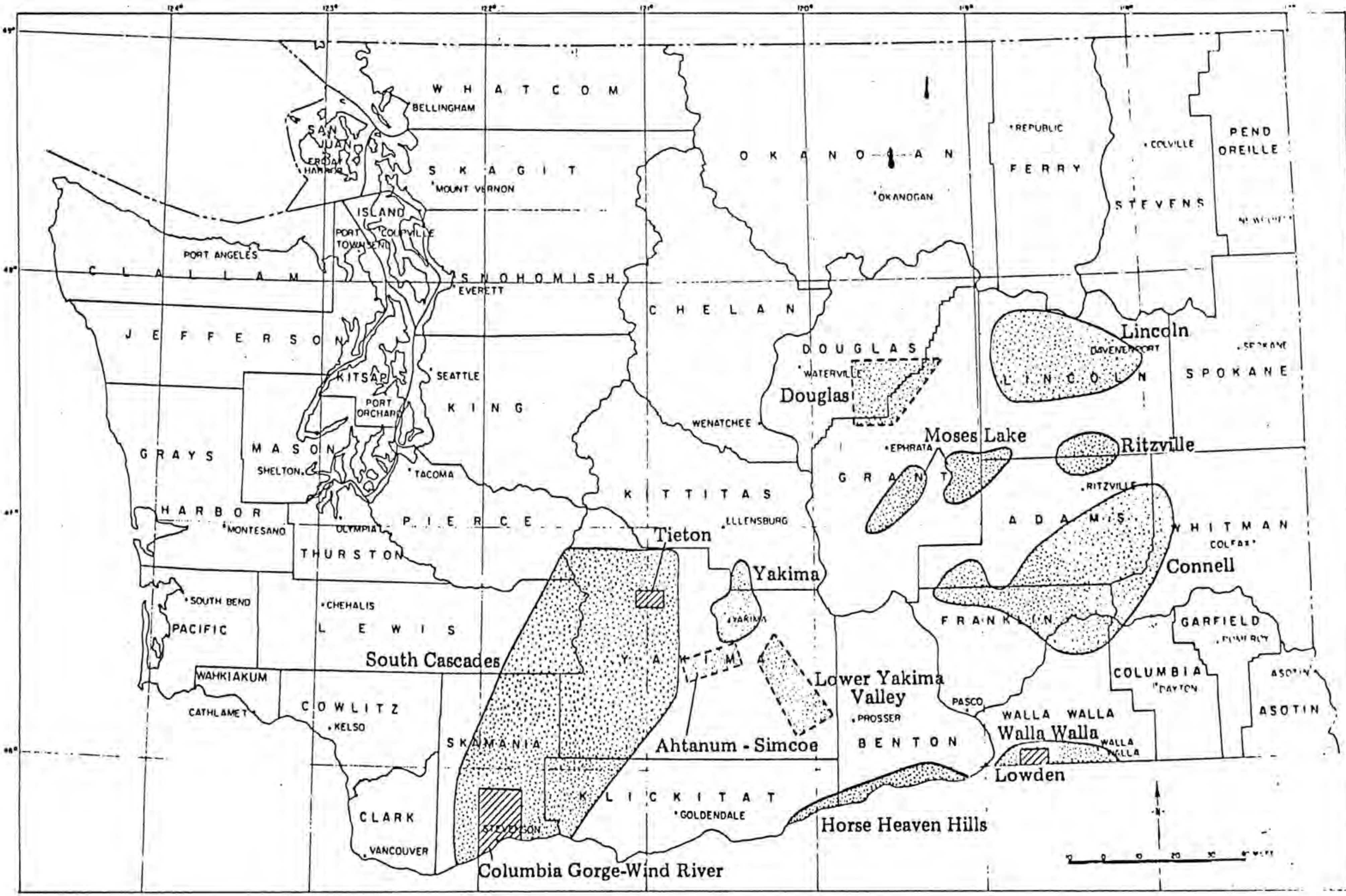

Figure 2. Low-temperature Geothermal Resource Areas in Washington.

and suggest that topographic control of hydrology is responsible for much of the variation (Biggane, personal communications). The best gradients occur along the main Yakima River valley, from Wymer south to Union Gap, and extend into the Moxee Valley (along Roza Creek). Gradients are generally 50 to 60°C/km within these areas. To the southwest of the city, within the Ahtanum and Simcoe River valleys, a few wells with high quality information, and several wells of marginal to poor quality produce relatively high gradients from 50 to 70°C/km. Some of these wells may fall within closed anomalies, with conditions controlled by valley alluvial fill and the Ahtanum Ridge anticline (which separates the two drainages), but the high gradients on the west side of this area may be representative of a broad high gradient zone associated with the southern Cascades (see the contour maps, Fig. 1).

Moses Lake-Ritzville-Connell Areas: Within the central and east portions of the Columbia Basin, several pockets of either very high gradients or very low gradients occur. The complexity is revealed through the high density of wells in the area. For the warm areas near Moses Lake, many gradients range from 45 to 60°C/km, with a few higher. North of Ritzville, anomalous gradients range from 50 to 60°C/km, with one well at 63-65°C/km (Kliphardt, 16N 30E 24BB). A very broad anomalous area extends northeast, east, and southeast from Connell, extending over 70 km to the east. Many high quality gradients define this anomaly, but the density of coverage is very uneven. They, along with many more fair quality gradients, suggest that gradients of 50 to 60°C/km might be found throughout the area. Most good quality gradients are in the 55-60°C/km range.

A large portion of the Moses Lake-Connell-Ritzville area is the target of a current geohydrologic study by Al Amos, a graduate student at W.S.U. working for the Division.

Lincoln: A broad area which extends from around Davenport west 50 km contains many wells with good quality gradients ranging from 50 to 60°C/km. Only a small gray area appears on the state resource map, immediately surrounding the town of Davenport. The acquisition of new temperature gradient information over the last two years, the lack of low gradient wells in the area, and the use of lower surface temperatures for calculating gradients has enabled us to extend the boundaries of this anomaly west and southwest. Many of the wells used for this designation are relatively shallow, with no wells over 250 meters, and are spread out over a wide region, with a resulting low density of coverage. More work needs to be done within this anomaly to further define the potential and its full extent.

Douglas: This anomaly is defined by only a few high gradient wells, most of which are of fair to poor quality. The anomaly may extend south to include the Ephrata-Quincy area. The density of coverage is very poor in this region, and further work is needed to determine the potential.

Horse Heaven Hills: Numerous wells in eastern Klickitat and southern Benton Counties (just north of the Columbia River) produce warm water from relatively shallow depths. Calculated gradients for these wells range from 45 to 55°C/km.

Lower Yakima Valley: Throughout the Yakima River valley, south of Yakima from Union Gap to Prosser, temperature gradients range from the lower to upper 40's (°C/km) but a few wells fall between 50 and 55°C/km. West of Mabton, a small area contains wells with gradients between 50 and 55°C/km. Northwest of Sunnyside and east of Zillah, a few wells produce gradients in the low 50's (°C/km). Most of the Yakima River valley was included in the Yakima geohydrology project by J. Biggane.

Walla Walla: The Walla Walla River valley, from Walla Walla west to near the Columbia River, contains some of the highest gradients observed in the Columbia Basin for relatively deep wells. Near the city of Walla Walla, especially on the west and south sides, temperature gradients range from 45 to 55°C/km, with most values between 50 and 55°C/km. In the Lowden-Touchet area further to the west, a few wells produce gradients greater than 70°C/km. The best of these wells, Gilbert-Merry (6N 34E 7CD) has a temperature of 41°C at a depth of 407 meters. An observed gradient of 77.8°C/km is supported by the calculated gradient, 71°C/km (assuming a surface temperature of 12°C.) In addition, the only warm spring in the Columbia Basin occurs close to this area, Warm Springs Canyon Warm Springs, with a temperature of 24°C.

Other Areas: In addition to the anomalous areas listed, several single point anomalies show up in the data set, individual wells with good quality information and relatively high calculated gradients. These wells are occasionally surrounded by much cooler wells (with lower gradients), but more commonly, they represent the only well in the vicinity. These isolated occurrences are either due to very local structural and/or hydrologic controls (especially when seemingly contradicted by surrounding wells), or represent additional anomalous areas of unknown extent. Some of these anomalies may be of significant size. This will be determined only when the density of information for these areas is improved.

Table 1. — High-gradient warm wells within Columbia Basin geothermal anomaly areas, from WELLTHERM (see notes at end of table).

Location			Name	Bottom Temp.	Logged Depth	Total Depth	Grad. A	Grad. B	Quality	Surf. Temp.	Source
			YAKIMA								
Yakima-Moxee Valley											
12N	19E	16BB	DNR Gangle	22.0	153	153	--	58	G	13.0	1
12N	20E	16CA	DNR Elephant	29.2	418	?	--	44	U	11.0	2
12N	20E	27CC	Logan	30.4	396	?	--	46	U	12	1
12N	20E	34CC	Estes	33.1	429	?	--	49	U	12	1
12N	21E	16CA	DNR	25.1	235	?	--	55	U	12.2	8
13N	18E	12AA	Carrell	24.8	201	200	--	59	G	13.0	3
13N	18E	24	Creamery Well	33.9	513	?	--	43	U	12.0	1
13N	19E	13DC	Terrace Heights	24.8	251	?	--	47	U	13.0	1
13N	20E	20BD	Champoux	23.3	215	214	--	52	G	12.2	8
13N	20E	33CA	Coombs	23.2	227	?	--	48	U	12	1
14N	17E	13AD	Murray-3	19.5	132	132	49	61	G	11.5	8
14N	17E	19DC	Mansperger	19.9	150	153	57	57	G	11.4	8
14N	18E	20AC	Zirkle	29.0	324	325	--	52	G	12	1
14N	19E	16CC	Roche	23.2	267	274	--	46	G	11.0	1
15N	19E	22CA	USGS Burbank	23.4		183		62	F	12.0	1
15N	19E	22CD	Larson Fruit	31.5	393	?	--	50	U	12.0	1
Ahtanum-Simcoe											
11N	16E	34DB	Gowdy	21.4	--	139	--	68	F	12	4
11N	17E	2CA	Dekker	25.5	--	255	--	51	F	12	4
11N	17E	16BC	Stephenson	31.6	302	306	--	65	G	12	3
11N	18E	9CC	Siegner	23.0	--	122	--	90	F	12	4
12N	16E	12CC	Shelton	25.2	268	?	--	53	U	11.0	1
12N	16E	13BB	Herke	14.2	70	70	--	58	G	10.2	8
12N	16E	15BC	White	21.5	179	182	--	59	G	11.0	1
12N	18E	27AD	Hansen Fruit	29.6	311	311	--	57	F	12	4
			WALLA WALLA								
6N	33E	10B	Fulgham	31.8	305	312	69.6	67	G	11.5	2
6N	34E	2AB	Miller	25.1	175	?	-	75	U	12	1
6N	34E	6AB	Chuatal	34.4	470	?	-	48	U	12	1
6N	34E	7CD	Gilbert-Merry	40.7	407	408	77.8	71	G	12	2
6N	35E	18AA	Dept. Ecology	36.1	396	399	-	61	G	12	1
7N	33E	31DB	Touchet-3	27.7	268	268	-	58	G	12	1

Location			Name	Bottom Temp.	Logged Depth	Total Depth	Grad. A	Grad. B	Quality	Surf. Temp.	Source

MOSES LAKE - RITZVILLE - CONNELL

Moses Lake

18N	29E	6DC	Am.Pot.Co.	21.5	205	213	--	47	G	12	1
19N	27E	2BD	Edwards	19.5	80	82	--	91	G	12	1
19N	27E	31BB	Lauzier	25.0	233	?	--	56	U	12	1
19N	29E	4AD	Shinn-2	25.0	280	283	--	46	G	12	1
19N	29E	16CC	Carnation	28.8	191	200	--	88	G	12	1
19N	31E	24AC	Kagele	20.1	165	191	--	49	S	12	1
20N	30E	23BC	Franz	34.8	337	340	--	68	G	12	3
20N	30E	28DD	Jantz	28.5	181	181	--	91	G	12	3
21N	30E	26AC	Schell	20.7	171	172	--	51	G	12	2
21N	31E	25AB	Sahible	28.3	195	195	--	84	G	12	1

Ritzville

20N	34E	2DC	Weber	20.9	197	200	--	50	G	11.0	1
20N	35E	24BB	Ahern	20.5	157	159	--	61	G	11.0	1
21N	34E	33BA	Hardung	24.9	253	271	--	55	G	11.0	1

Connell

13N	34E	30CB	Cockrans	32.2	355	358	56	57	G	12	1
14N	32E	2CD	Hart	27.2	242	289	50	63	S	12	1
14N	32E	13BC	Hart	25.6	187	?	--	73	U	12	1
14N	32E	31BB	Connell-6	29.4	303	304	--	57	G	12	1
15N	28E	35CD	ECBID	24.4	253	256	--	49	G	12	1
15N	29E	3CD	Othello 5	29.0	298	307	--	57	G	12	1
15N	32E	35BC	Hart	27.6	310	318	--	50	G	12	1
15N	32E	2AA	Tomkin	25.0	252	253	--	52	G	12	1
15N	36E	34BD	Blauert	25.4	211.5	?	--	63	U	12	1
16N	30E	24BB	Kliphardt	25.9	217	220	65	63	G	12	1
16N	30E	27DA	Andrews-2	25.2	207	?	--	64	U	12	3
16N	30E	36DB	Damon	25.8	241	243	--	57	G	12	1
16N	31E	15BB	Wholman	26.2	230	?	57	57	U	13	9
16N	32E	15BB	Phillips-17	33.4	437	438	--	49	G	12	1
16N	32E	25CC	Phillips-16	31.0	380	380	--	50	G	12	1
17N	32E	14CB	DNR	23.2	189	?	--	54	U	13.0	9

Location			Name	Bottom Temp.	Logged Depth	Total Depth	Grad. A	Grad. B	Quality	Surf. Temp.	Source
					LINCOLN						
23N	32E	4DA	Weishaar	28.7	212	212	--	83	G	11.0	1
23N	32E	17AC	Weishaar	21.2	206	209	--	49	G	11.0	1
24N	31E	16BC	D.O.E.	21.8	227	229	48	48	G	11.0	10
24N	33E	23CD	Schmierer	25.9	309	312	--	48	G	11.0	1
24N	36E	16AA	USGS Davenport	21.3	221	227	55	51	G	10.0	3
24N	36E	16AA	D.O.E.	21.9	225	229	76	55	G	9.5	10
25N	37E	21CA	Davenport-5	20.0	149	152	--	60	G	11.0	1
25N	37E	21CA	Davenport	24.0	227	297	--	57	S	11.0	1
26N	33E	18AC	Wilber City	14.7	129	137	56	--	--	10.0	10
26N	39E	10CA	Creston	17.7	205	234	56	45	S	8.5	10
					DOUGLAS						
22N	27E	19CC	Soap Lake	27.0	--	142	--	106	F	12.0	4
23N	25E	31CC	Schell-5	18.5	147	152	--	51	G	11.0	1
23N	26E	20BB	Pixlee	29.3	363	401	--	50	S	11.0	1
23N	28E	27BC	Schaffer	22.8	196	?	--	60	U	11.0	1
25N	28E	25AB	Dormaier	23.0	177	177	--	67	G	11.0	3
					HORSE HEAVEN HILLS						
3N	21E	19BA	RB-1	19.0	71	?	54	57	U	12	2
5N	22E	27AA	Matsen	28.1	317	?	--	50	U	12	1
5N	23E	13DA	Powers	26.2	330	?	--	43	U	12	1
5N	23E	29BB	McBride	25.5	266	267	--	51	G	12	1
6N	23E	15AD	Andrews	25.2	275	290	--	48	G	12	1
4N	24E	3AB	Sperry	20.6	-	121	--	71	F	12	5
5N	26E	5BB	Paterson	26.3	305	305	--	47	G	12	1
5N	28E	6DD	Engineers	21.5	-	170	--	56	F	12	4
6N	24E	22AD	Columbia R.	22.5	195	201	--	54	G	12	3
6N	26E	15CB	Craig	24.2	210	?	--	58	U	12	1
7N	25E	36CC	DOE Paterson	30.3	222	230	--	83	G	12	1
					LOWER YAKIMA VALLEY						
8N	22E	11DA	Flower	22.0	162	169	--	62	G	12	1
9N	21E	25CB	Shinn	28.5	295	293	--	56	G	12	3
9N	23E	7BC	Mandrell	17.8	89	89	53	54	G	13.0	10
10N	24E	36BD	DNR-Anderson	29.8	273	460	--	65	S	12	9
10N	25E	25BC	Nakamura	20.6	184	184	--	47	G	12	3
11N	17E	16BC	Stephenson	31.6	302	306	--	65	G	12	3
11N	20E	6AA	Peters	20.2	166	?	--	49	U	12	1
11N	20E	13DD	Soost	29.2	328	366	--	52	S	12	1
11N	21E	6CA	Dahl	29.2	364	?	--	47	U	12	1
11N	21E	20CB	Hanrahan	22.2	191	207	--	54	S	12	1
11N	21E	21AB	Ambrose Farms	27.0	279	283	--	53	G	12	1
11N	32E	29CC	Rowe Farms	29.6	333	337	--	53	G	12	1

TABLE 1, (continued)

WELLTHERM is a computerized summary of all well temperature information available to the Washington State Department of Natural Resources, Division of Geology and Earth Resources.

LOCATION: The first 4 columns indicate location, by township, range, section, and partial section. In the two letter partial section code the quarter section is listed first and the quarter-quarter section second, where A = NE, B = NW, C = SW, and D = SE. For example, 23 AB is the northwest ¼ of the northeast ¼ of section 23.

NAME: The well name refers to the name of the owner at the time of drilling, the owner at time of temperature logging, or the project name and number.

BOTTOM TEMP: The temperature (°C) at the lowest point of logging. This may or may not be the bottom-hole temperature.

LOGGED DEPTH: The deepest depth (meters) logged.

TOTAL DEPTH: Depth (meters) at the time of completion, as reported by the drilling logs.

GRAD. A: A relatively straight-line increase of temperature vs. depth (°C/km) observed over a major portion of the temperature log.

GRAD. B: A calculated temperature gradient (°C/km), using the difference between SURFACE TEMP and BOTTOM TEMP, divided by LOGGED DEPTH.

QUALITY: Refers to the quality of Grad B. "G" (good) indicates that the LOGGED DEPTH is approximately equal to TOTAL DEPTH; "S" (short) indicates that LOGGED DEPTH is significantly less than TOTAL DEPTH: "U" (unknown) indicates that the TOTAL DEPTH is not known; "F" (flowing) indicates that the BOTTOM TEMP is probably a flowing temperature, representing the temperature of a single aquifer, or a mixed aquifer, and not necessarily the bottom hole temperature.

SURFACE TEMP: Estimated from mean annual air temperature (usually reported as a whole number) or near-surface inflection points observed in temperature logs. For wells in the Columbia Basin without a listed SURFACE TEMP, GRAD. B was calculated using 12°C, an average surface temperature for southeastern Washington.

SOURCES:

1. Washington State University; James Crosby & Staff, 1972-1981.
2. Southern Methodist University (SMU); David D. Blackwell, & Washington Division of Geology and Earth Resources (DGER), 1971-1979.
3. U.S. Geological Survey (USGS) Tacoma, Washington, Unpublished logs from 1972-1976.
4. USGS WATSTORE computer file.
5. USGS Water Supply Paper 1999-N.
6. Washington State Division of Water Resources Water Supply Bulletin 21.
7. Washington State Division of Water Resources Water Supply Bulletin 24.

TABLE 1, (continued)

8. Sherri Kelly, SMU and DGER, 1980.
9. John Kane, DGER, 1980.
10. Walter Barker, SMU and DGER, 1981.
11. Washington Division of Geology and Earth Resources Staff, 1981.

Conclusion

Despite the lack of fully cased wells and resulting stair-step temperature gradient plots observed for these wells, good quality information can be derived from numerous wells in the Columbia Basin. Gradients calculated from wells logged as deep as they were drilled have enabled us to designate several areas within the Basin which hold high potential for low temperature geothermal resources.

Thus far, the emphasis has been on temperature gradients, with anomalies being determined by the wells with gradients above average (greater than 45°C/km), and commonly between 50 and 60°C/km. The next work in these areas should concentrate on characterizing the actual resource, by gathering information on aquifer temperature, depth, extent, chemistry, and productivity. In light of the relatively low costs associated with accumulation of temperature-depth information, our well logging efforts will continue, with the hope of discovering new anomalies and to place better boundaries on the known anomalies.

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