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GEOTHERMAL DIRECT HEAT PROGRAM

GLENWOOD SPRINGS TECHNICAL CONFERENCE PROCEEDINGS
VOLUME I
PAPERS PRESENTED
STATE COUPLED GEOTHERMAL RESOURCE ASSESSMENT PROGRAM

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GEOTHERMAL RESOURCES IN MONTANA

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Abstract --A list of persons and groups doing geothermal research in Montana is presented. A revised list of springs and wells with their flow and temperature values is shown with the heat value, in billions of British Thermal Units (Btu's) per year, for reference temperatures related to low temperature uses. The Boulder and Hunters springs are the foremost hot spring resources, while the Madison Limestone related springs around the Little Rocky Mountains, and Brooks spring north of Lewistown provide the major low temperature resources capable of large development utilizing heat pump technology. The water chemistry of almost all springs is suitable for direct application. A discussion of drilling activities around spring sites and the relative success (or lack thereof) provides some factors to consider. In an attempt to delineate areas with ground-water temperatures suitable for heat pump use, a 10°C (50°F) temperature cutoff was used. Urban area data is suspect; inadequate pumping time may yield spuriously warm temperatures.

The purpose of this paper is to summarize the work done to date, and to report on some recent results relating to Montana's geothermal resources.

Interest in surface occurrences of thermal water as something other than scientific or "medical" curiosity did not become prominent until the early 1970's when predictions of energy shortfalls began appearing. In Montana, previous work consisted of cataloguing by G. A. Waring (23), and "while passing through" studies by S. L. Groff (results summarized in 3); also, Balster (2) compiled a map using bottom-hole temperatures in the Madison Group.

Recent research was initiated by the U.S. Geological Survey in the early seventies from their Menlo park regional office. The formation of first the U.S. Energy Research and Development Agency (ERDA) and then the U.S. Department of Energy (DOE) broadened the federal research base and provided funding for state and private research projects. The following list includes most of the Montana-based groups performing geothermal research (either in resource assessment or in engineering applications):

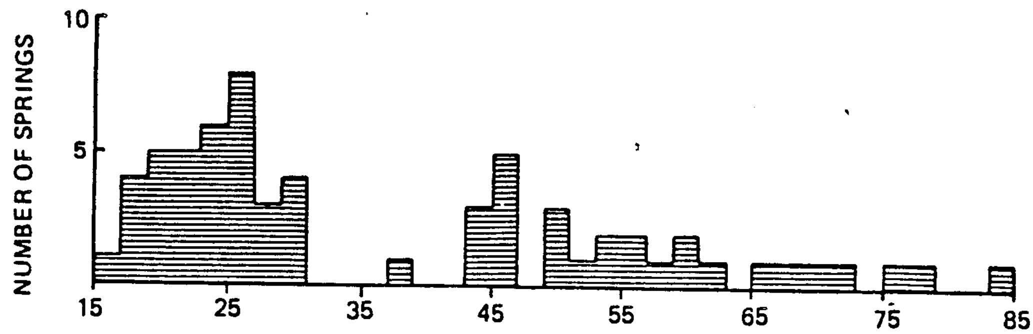
1. U.S. Geological Survey, Montana WRD Office, Helena, Montana: Robert Leonard--resource evaluation.
2. Department of Natural Resources and Conservation, Division of Renewable Energy, Helena, Montana: Michael Chapman--user assistance and grants.

3. Montana University System
   a. University of Montana, Missoula: Tony Quamar--resource evaluation
   b. Montana State University, Bozeman: Robert Chadwick--resource evaluation
   c. Montana College of Mineral Science and Technology, Butte: John Sonderegger and Charles Wideman--resource evaluation
4. Fort Peck Tribal Research Program, Poplar, Montana: Carl Fourstar--resource definition and application (near Poplar)
5. Montana Energy Research and Development Institute, Butte, Montana: Karen Barclay--resource definition and application (Warm Springs State Hospital)

THERMAL SPRINGS

Because warm and hot springs represent an expression of a geothermal system at depth, an inventory of such springs has traditionally been the first step in evaluating the resource potential. One of the problems recognized in the mid 1970's was that adequate measurements of spring discharge and temperature were not always available (at a given temperature, the energy available is directly proportional to the spring discharge) normally because of poor discharge numbers which often varied by as much as 400 percent. In the fall of 1975, Robert Leonard was assigned to the USGS Montana district; after reviewing the Montana Bureau of Mines and Geology (MBMG) spring data files, Leonard decided to restrict his work to occurrences of waters hotter than 100°F in the southwestern portion of the state. Later, the MBMG instituted a statewide study of low temperature occurrences partially funded by ERDA and DOE.

Figure 1 is a histogram of thermal spring temperatures in Montana. The large block of springs representing temperatures of 30°C or less is, in the majority of cases, related to springs issuing from the Madison Group. Most geologic parameters tend toward normal or lognormal distribution. Ground-water temperatures appear to have a lognormal distribution; in Montana, the average ground-water temperature is between 7 and 9°C depending upon the area of the state under discussion. Figure 2 is an approximation of the type of distribution one would expect for thermal spring temperatures; from Figure 2 we infer that the data presented in Figure 1 are grossly biased, i.e., that we have only included those springs with temperatures of less than 25°C which have high discharges. If the temperature of a spring is greater than 25°C, it is usually safe to assume (in western Montana) that even in the summer a body of ponded spring water loses more heat than it gains. At temperatures less than 25°C and low spring discharge quantities (less than 50 gpm), it is possible for solar and biological factors to increase the measured temperature enough to cause a spuriously anomalous spring temperature.



TEMPERATURE OF SPRINGS IN 2°C INCREMENTS; FIRST BLOCK IS 15-16°C.

FIGURE 1. HISTOGRAM DEPICTING THE FREQUENCY OF THERMAL SPRING TEMPERATURES.

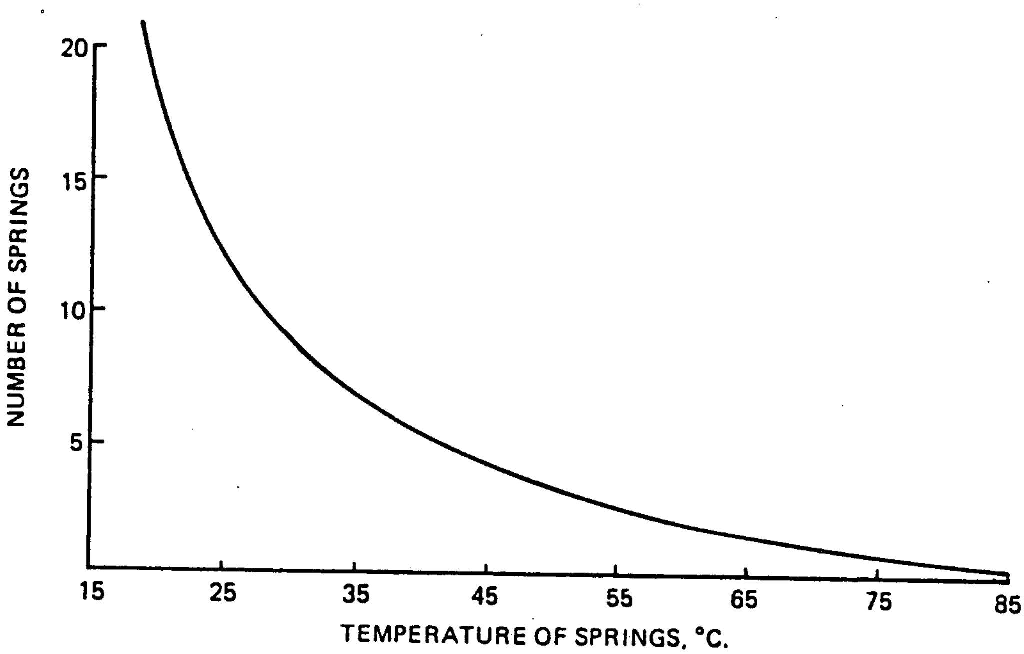


FIGURE 2. EXPECTED LOG-NORMAL DISTRIBUTION OF SPRING TEMPERATURES.

Also, our investigations into mine-water drainage, which is usually of fairly shallow origin, showed that the smaller the discharge value the greater the annual variation in water temperature (14). The smallest discharge reported in the MBMG spring data list for springs in the 15 to 20°C range is 130 gallons per minute, and only two of the springs have discharges of less than 1000 gpm (4). By comparison, only two of the seven springs with temperatures of 65°C or greater heave discharges greater than 100 gpm (Hunters Hot Springs and Boulder Hot Springs).

Obviously, we have erred on the side of being conservative in our past work. However, Table 1 (condensed and updated from references 4 and 21; the former includes location information and some water quality data) shows that when available heat energy is calculated to bottom-use temperatures of 25, 18, and 10°C, only the high discharge/low temperature springs constitute a significant resource. An alternate way of viewing these data is with respect to heat pump usage. For a domestic dwelling of 2500 square feet, the generally available heat pumps now being produced would require 10 to 15 gpm of 15°C water for typical Montana winter weather conditions. Thus, a 15°C spring with a proven 150 gpm yield could only heat ten domestic dwellings. By comparison, even without the use of a heat pump, 150 gpm of 60°C water will heat 60 to 75 domestic dwellings using modern design practices. It is for these practical reasons that only large volume springs were initially emphasized in our studies.

Figure 3 depicts the locations of the springs listed in Table 1. Most of these springs are in western Montana, with the largest concentration in southwestern Montana. At present, there are no known instances of magmatic heating of these thermal waters (6). Dates on the age of igneous rocks in Montana range from very ancient to 0.11 million years before present (9). Known rocks younger than 2.0 million years are very few, extrusive, and of very limited extent in western Montana; consequently, they are not believed to represent a significant thermal resource. The known geothermal systems in eastern Montana are believed to result solely from deep circulation of meteoric ground water with fracture control of spring locations (21).

The best summary to date of all available water chemistry is by Leonard *et al* (15) from 24 springs and 3 wells, which is essentially for the southwestern portion of the state. By the time this article appears, the MBMG will have published a preliminary map of the geothermal resources of Montana, which will include the most representative chemical data for at least 70 springs and wells. Also, an annotated bibliography of geothermal studies in Montana, current through January of 1980, has just been published (20), and NOAA has published a thermal spring list for the United States (5).

Geophysical studies at hot spring sites have been conducted by the U.S. Geological Survey and the three units of the University System listed previously. All of these results have emphasized the importance of faults and fractures controlling the

Table 1. Heat value of water from selected springs and flowing wells.

Name	Temp. (°C)	Flow (gpm)	H_1 (25°C) (10^9 Btu/yr)	H_2 (18°C) (10^9 Btu/yr)	H_3 (10°C) (10^9 Btu/yr)
SPRINGS					
Alhambra	56.5	100	24.9	30.4	36.7
Anaconda	21.7	3.2		0.09	0.30
Andersons	25	75		4.15	8.89
Andersons Pasture	26	900	7.11	56.9	114
Apex	25	750		41.5	88.9
Avon	25.5	24	0.09	1.42	2.94
Bear Creek	24	10		0.47	1.11
Bearmouth	20	1100		17.4	86.9
Beaverhead Rock	27	100	1.58	7.11	13.4
Bedford	23.6	1500		66.4	161
Blue Joint	29	200	6.32	17.4	30.0
Boulder	76	590	238	270	308
Bozeman	54.6	75	17.5	21.7	26.4
Bridger Canyon	20.2	150		2.61	12.1
Broadwater	62	12	3.51	4.17	4.93
Brooks	19.9	72000		1080	5630
Browns	23.7	1100		49.5	119
Camas	45	24	3.79	5.12	6.64
Carter Bridge[1]	26.5	1500	17.8	101	196
Chico	45	320	50.6	68.3	88.5
Deer Lodge Prison	26	100	0.79	6.32	12.6
Durfee Creek	21.1	2300		56.3	202
Elkhorn	48.5	30	5.57	7.23	9.12
Ennis	83.2	15	6.90	7.73	8.67
Gallogly (Lost Trail)	38	100(?)	10.3	15.8	22.1
Garrison	25	54		2.99	6.40
Granite	51	100	20.5	26.1	32.4
Green	26	80+	0.63	5.06	10.1
Gregson (Fairmont)	70	40	14.2	16.4	19.0
Greyson	17.9	900			56.2
Hunsaker[2]	24.5	110		5.65	12.6
Hunters	59	1300	349	421	503
Jackson	58	260	67.8	82.2	98.6
Kimpton[2]	18	300			19.0
La Duke	65	130	41.1	48.3	56.5
Landusky	21	3100		73.5	269
Landusky Plunge	24	2900		137	321
Little Warm	22	5000		160	474
Lodgepole	30	2700	107	256	427
Lolo	44	180	27.0	37.0	48.3
Lovells	19.4	3500		38.7	260
McMenomey Ranch	19	7300		57.7	519
Medicine	46	100	16.6	22.1	28.4
New Biltmore	53	26	5.75	7.19	8.83

Name	Temp. (C)	Flow (gpm)	H_1 (25°C) (10^9 Btu/yr)	H_2 (18°C) (10^9 Btu/yr)	H_3 (10°C) (10^9 Btu/yr)
Nimrod	20.5	3200		63.2	265
Norris	52.5	106	23.0	28.9	35.6
Paradise	43.4	17	2.47	3.41	4.49
Pipestone	57	250	63.2	77.0	92.8
Plunkets	16.5	4000			205
Potosi,3	38	17	1.75	2.69	3.76
Pullers	44.4	50	7.66	10.4	13.6
Renova	50	40	7.90	10.1	12.6
Silver Star	71.5	40	14.7	16.9	19.4
Sleeping Child	45	530(?)	83.7	113	147
Sloan Cow Camp	29.5	350	12.4	31.8	53.9
Staudenmeyer	28	1800	42.7	142	256
Sun River	30.4	710	30.3	69.5	114
Targhee Sulfur[2]	18	55			3.46
Toston	15.2	20000			822
Trudau	22.7	175		6.50	17.6
Vigilante	23.5	2200		95.6	235
W.S. State Hosp.	77	60	24.6	28.0	31.6
Warner	18	130			8.22
West Fork S.H.	26	500	3.95	31.6	63.2
White Sulphur[3]	46	400+	66.4	88.5	114
Wolf Creek	68	53	18.0	20.9	24.3
WELLS					
Camp Aqua	50	330+	65.2	83.4	104
Colstrip[4]	96	230	129	142	156
Lucas	42.2	100	13.6	19.1	25.4
Ringling	48	800	145	190	240
Symes	40	100	11.8	17.4	23.7
White Sulphur-dug	58	350	91.2	111	133

[1]Average temperature with mixing factors deleted.

[2]Added after Figure 1 was drafted.

[3]Replaced by well.

[4]Cemented and abandoned.

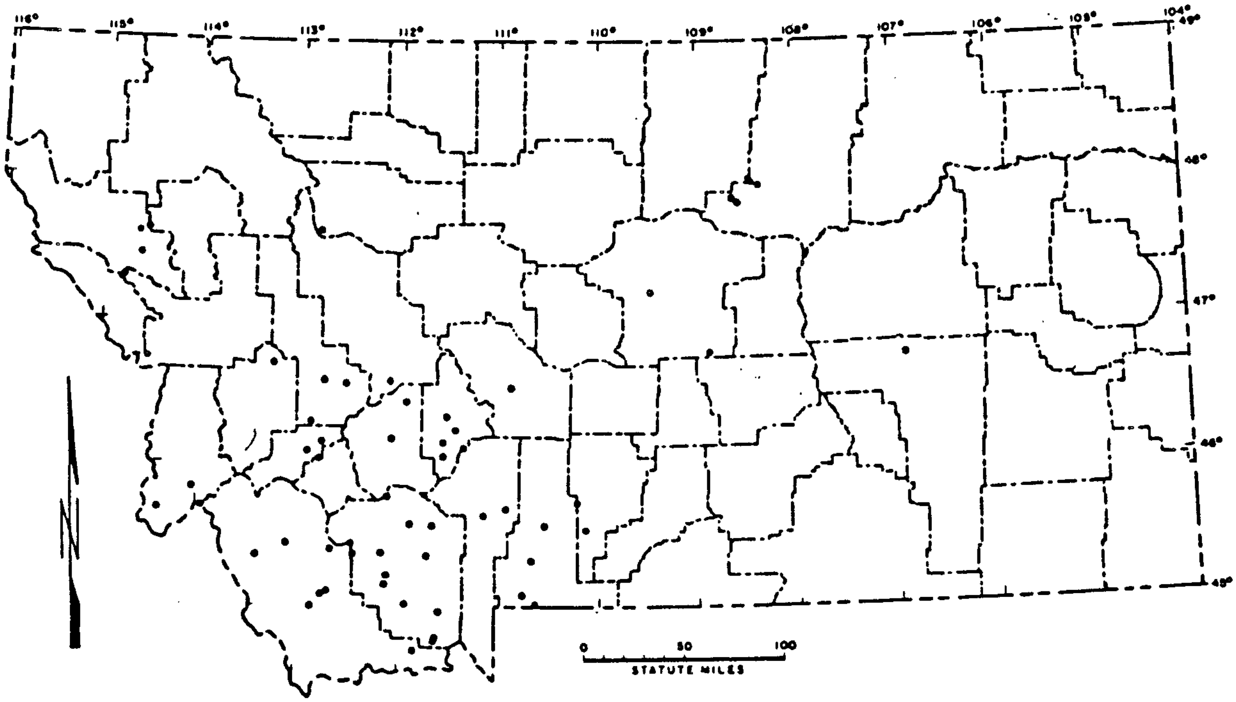


FIGURE 3. LOCATION OF THERMAL SPRINGS IN MONTANA.

occurrence of the hot spring systems that have been studied. The Ennis hot spring has the highest surface temperature (83°C) of all springs in the state, and has been the object of detailed study by the USGS and the Montana Tech Geophysics Department. At the Ennis (Thexton) hot spring, gravity, seismic, telluric, and audio-magnetotelluric investigations have shown that block faults parallel and nearly normal to the valley trend have controlled the discharge point of the thermal system (8, 17, 18). Studies at other sites such as: (1) Warm Springs State Hospital (12); (2) Silver Star (1, 16); (3) Norris and Hunters hot springs (7); and the Little Bitterroot Valley (Camas area, work in progress, 10, 13) show structural factors as having a significant effect on the location of the thermal system discharge point(s).

WARM AND HOT WELLS

Thermal wells can be divided into two basic categories: (1) those wells drilled with the express intention of obtaining hot water or hot dry rock; and (2) wells drilled for hydrocarbons or water which incidentally encountered hot water. The boundary between these two classes is sometimes vague, representing water wells drilled near a hot spring with the hope that hot water might be encountered.

Wells have been drilled expressly for geothermal purposes at the Bozeman, Broadwater, Ennis, Fairmont, Warm Spring State

Hospital, and White Sulphur Springs hot spring areas and at the Marysville heat flow anomaly. Results to date have not been highly encouraging. The best results have occurred at the Broadwater hot spring where Frank Gruber is reported to have obtained about 350 gpm of water at approximately the spring temperature, 62°C or 144°F (R. B. Leonard, pers. comm.). The results and duration of pump testing at Broadwater have not been made public, so we have no way of evaluating whether this system will provide a sustained yield at the tested discharge rate and temperature.

At White Sulphur Springs, Dave Grove has promoted the development and utilization of geothermal energy. The first attempt was to drill a deep well to heat the new bank building. The well was drilled in 1978 to a depth of 875 feet. Temperature logging of this well showed that the hottest zone encountered was between depths of 100 to 200 feet; the pump test data provided a calculated transmissibility of 103,000 gallons per day per foot of drawdown (gpd/ft) and an estimated safe yield of 50 gpm of 118°F (48°C) on a continuous use basis (D. E. Dunn, pers. comm.). The second project was to improve the spring area by cleaning it out and installing a cement culvert (equivalent to the procedure used for dug and bored wells). This system is reported to be producing 350 gpm of 136°F (58°C) water (Lloyd Donovan, pers. comm.). The latter approach is an excellent example of successful inexpensive development; previously reported temperatures for the spring range from 95 to 125°F, with the "best" value being 115°F. It appears that in the process of improving the spring, shallow ground water mixing was reduced, producing the higher temperature.

Other spring operators have not been as fortunate. At Fairmont (Gregson) hot springs, several wells were drilled in an attempt to increase the amount of hot water available. All of these wells produced cold water. Experience at the Bozeman hot spring has been mixed. The present "spring" is actually a shallow well adjacent to the spring discharge point. A recent attempt to obtain more hot water resulted in a well which could not be held open and which did not produce enough water to warrant installing a pump; reworking of this well has improved its yield.

The Marysville "hot dry rock" well was drilled because of very high heat flow values in that area. Unfortunately, the 6790 foot deep well encountered water bearing zones with a maximum temperature of 204°F (96°C) (19).

By comparison, the 540 foot well drilled last summer at Ennis, while originally scheduled as a test well, had smaller diameter pipe used for heat flow testing. The well hit bedrock at approximately 540 feet and had a bottom hole temperature of 95°C (203°F). With the bottom open it was flowing 2.5 gpm with a surface temperature of 93°C (199°F) (R. B. Leonard, pers. comm.). At present there is an obstruction in the well and attempts to fish it out have so far been unsuccessful.

At Warm Springs State Hospital, a 1498 foot production/ test well was drilled in the fall of 1979. The driller's pump broke down during development, so no pump testing was conducted. At the time the pump failed, it was reported that the discharge was about 140 gpm, with 975+ feet of drawdown, which yields a maximum transmissibility coefficient (T) of 200 gpd/ft. A flange, pressure gauge, and additional valve were recently installed by the shopmen at the hospital. We conducted a short, 65 minute, shut-in test on 9 April 1980 which proved interconnection between the well and spring, and provided T values of 34 gpd/ft before the spring responded and 70 gpd/ft after spring flow started increasing. The shut-in pressure at the end of the test was 138 pounds per square inch (psi). Based upon the data available, we estimate that the well has a maximum safe yield of 70 gpm of 78 to 80°C water. The difference in T values between the development work following drilling and the shut-in test may be because slotted casing was used instead of well screen and there may be some very large well losses. The Montana Energy Research and Development Institute has scheduled additional development and testing for this well and it is hoped that the well performance can be improved.

In the category of wells which incidentally encountered hot water, the best documented case is the Western Energy well at Colstrip. The well was drilled to a depth of 9200 feet; the majority of the hot water is believed to have come from the Mission Canyon Limestone at a depth of 7700 feet. Well tests by Van Voast yielded a transmissibility of 650 gpd/ft, and a storage coefficient of 2×10^{-4}; under test conditions, the well flowed 230 gpm of 207°F (97°C) water with a 16 psi confining pressure. A petroleum laboratory analysis of the water yielded a total dissolved solids content of about 1500 milligrams per liter. The pH value reported was 6.3, which is not very acidic; but, the water was sufficiently corrosive to cause casing leaks in a period of about five years. The well has since been cemented and abandoned.

Old petroleum test wells that produce warm or hot water frequently produce this water from the Madison Group. The Ringling and Lucas wells near White Sulphur Springs produce 800 and 100 gpm of 48°C (118°F) and 42°C (108°F) water from Mississippian age rocks (15). The Saco well, now used by the Sleeping Buffalo Resort produces a reported 290 gpm of 49°C (106°F) water from this same strata.

A recent study by P.R.C. Toups, Inc. for the Fort Peck Indian Reservation has proven a valuable resource is available in the water separated from the crude oil produced on the Poplar Dome. Also, they suspect that hot water may be available at relatively shallow depths north and east of Poplar along the trace of the Brockton-Froid fault zone (22).

HEAT PUMP APPLICATION

The present heat pump technology calls for "heavy duty" pumps and compressors in order to utilize typical Montana ground water in the temperature range of 42 to 47°F (6 to 8°C). Figure 4 shows six areas which appear to have ground-water temperatures above 10°C, and many be suitable for use with normal heat pump systems. A word of caution is needed with respect to these data. Temperature is one of the most easily altered characteristics of ground water due to failure to pump a well long enough for all aspects of the delivery system to come to thermal equilibrium, either due to the problem of disposing of the water or low well yield. Most inventory work is done during the summer months, which commonly means that any error in the temperature measurements validity will be biased towards a higher temperature.

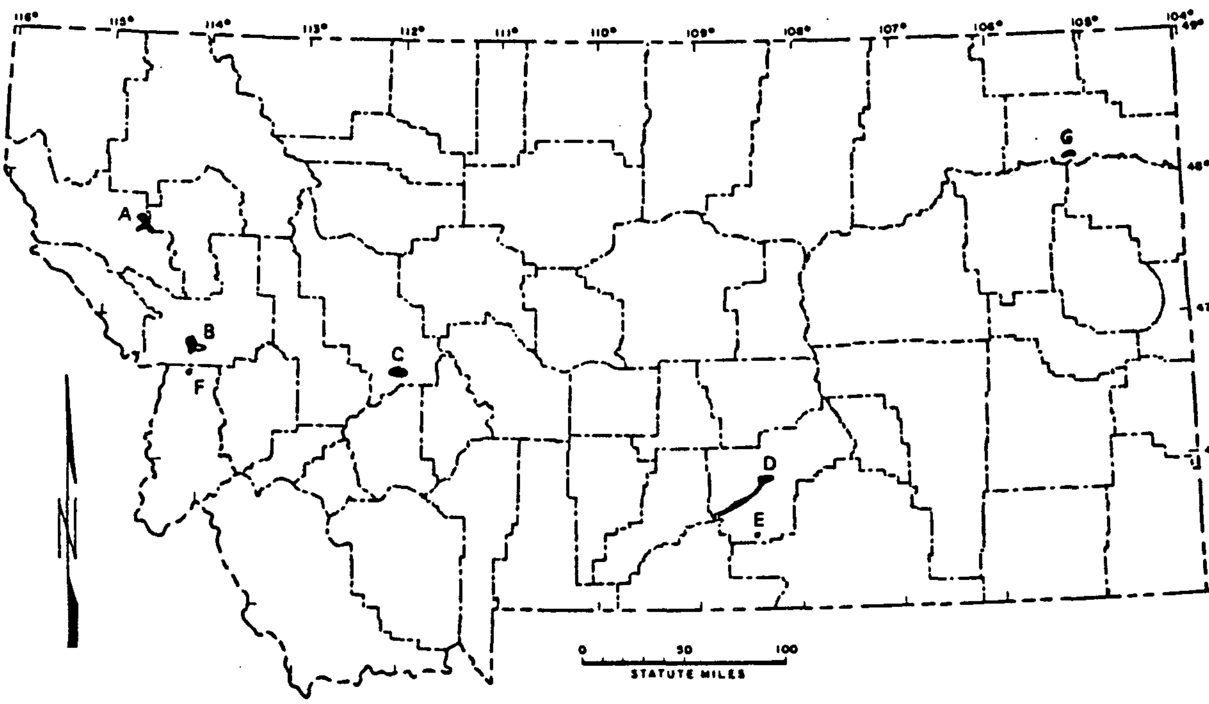


FIGURE 4. LOCATION OF AREAS FAVORABLE FOR HEAT PUMP USAGE. SEE TEXT CONCERNING SPECIFIC AREAS.

Favorable areas B, C and D are in suburban areas of Missoula, Helena, and Billings, where problems of water disposal are greater. The reported "warm" temperatures for these areas contribute a smaller percentage of the total number of temperatures in these areas, and may be related to failure to achieve thermal equilibrium. The water is almost entirely from shallow (< 300 feet deep) wells and may show considerable seasonal variation. In these three areas, it is recommended that the water temperature be measured during the winter season after the well has been pumped steadily for at least two hours. If the temperature and yield are satisfactory under these conditions, the well should be permitted to recover and a three-day continuous pumping recording the water level in the well should be conducted to ensure an adequate yield. Most people in the field believe that a sustained yield of 20 gpm is required (11).

Other areas depicted on Figure 4 have greater certainty of the temperature data. The Little Bitterroot Valley (area A) has an extensive gravel aquifer in the valley fill sediments. Temperatures of well water produced from this zone generally range from 10 to 51°C. The area is still under investigation by Joe Donovan and a final report will be issued by MBMG in 1981.

Area E, northeast of Pryor, is tentative at this time. A drilling report for one water well indicates that wells drilled into the Kootenai Formation should be abnormally warm in this area.

Area F is provisional at present, being based upon the temperature from one well. The Bureau recently drilled a 400 foot municipal test well outside of Florence. Flow testing of this well was brief (120 minutes at 10 gallons per minute); however, the well produced water at a temperature of 64°F (17.3°C). Even if increased preduction from this zone lowered the temperature because of pumping-induced vertical movement of cooler water from above, the production temperatures should still be adequate for heat pump use.

Area G, just off the Poplar Dome, is the site of ground temperature surveys conducted by Joe Birman of Geothermal Surveys Inc. Temperatures were measured at a depth of ten feet below land surface and temperatures greater than 10°C (50 F) were encountered along several linear trends (22). Bedrock is the Bearpaw Shale in this area and it may be necessary to drill fairly deep to obtain sufficient water for heat pump use. The investigators hope to find a secondary zone of hot water at a depth of roughly 500 feet, just below the Bearpaw Shale.

SUMMARY

Good data are available for most of the thermal springs in Montana. The quality of data for thermal wells varies greatly and part of our current effort is to improve this data base. Data presented show heat content for various reference temperatures related to low temperature use. Drilling results are variable in the vicinity of hot springs; development of the springs is recommended prior to drilling. Heat pump utilization will increase, with the greatest potential being in the Little Bitterroot Valley.

ACKNOWLEDGMENTS

This paper utilizes data collected by many workers. The authors thank their colleagues at the Montana Bureau of Mines and Geology, R. N. Bergantino, J. J. Donovan, S. M. Kovacich, D. C. Lawson, J. J. McDermott, M. R. Miller, T. W. Patton, K. S. Thompson, and W. A. Van Voast, their associates at Montana Tech, J. W. Halvorson and C. W. Wideman, and Glenn Wyatt from the Earth Sciences Department at Montana State University. Data from the U.S. Geological Survey, and the cooperation of R. B. Leonard, is greatly appreciated.

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Addendum

The first issue of Geothermics for 1981 (v. 10, no. 1) arrived after submission of this manuscript. This issue includes an article entitled "Sodium/Lithium Ratio in Water Applied to Geothermometry of Geothermal Reservoirs" by Christian Fouillac and Gil Michard (p. 55-70). They present the following two empirical equations for reservoir temperature calculation:

(1) $\log_{10}(m_{Na}/m_{Li}) = 1000/T - 0.38$, for $Cl^- < 0.2M$, and

(2) $\log_{10}(m_{Li}) = -2258/T + 1.44$, for $Cl^- < 0.2M$;

the reader is referred to Fouillac and Michard for details on the deviation of the equations.

Using these equations with the Camp Aqua well data results in the highest calculated reservoir temperatures. Equation (1) yields a reservoir temperature of 49°C, slightly below the observed temperature at the wellhead. Equation (2) yields a reservoir temperature of 83°C, slightly greater than our source temperature using the chalcedony curve on the SiO_2 - Enthalpy plot (figure 6). While these calculations are subject to the concerns about dilution and ion-exchange processes, these data provide additional support for use of the chalcedony curve on SiO_2 - Enthalpy plots for low-temperature geothermal systems.