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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):

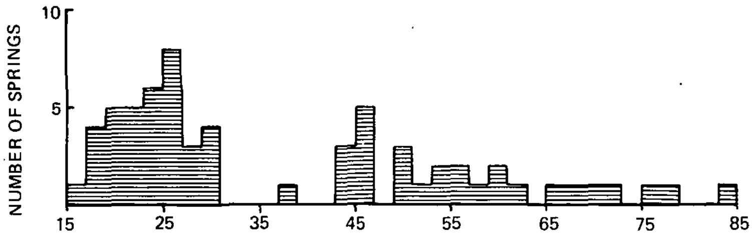
1. U.S. Geological Survey, Montana WRD Office, Helena, Montana: Robert Leonard--resource evaluation.
2. Department of Natural Resources and Conservation, Division of Renewable Energy, Helena, Montana: Michael Chapman--user assistance and grants.

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.

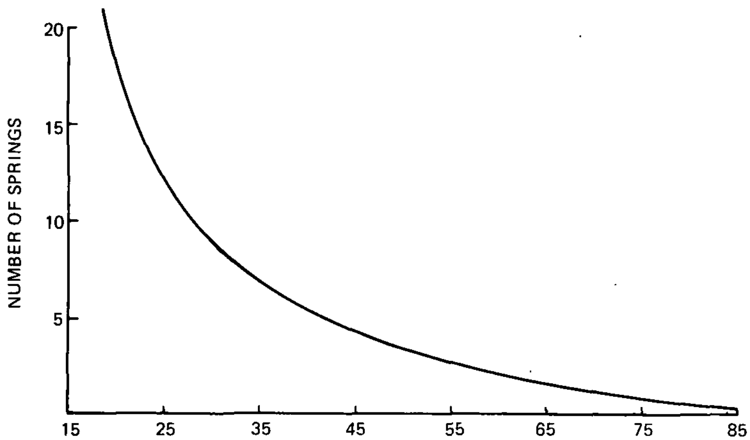


FIGURE 2. EXPECTED LOG-NORMAL DISTRIBUTION OF SPRING TEMPERATURES.

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[1]	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.

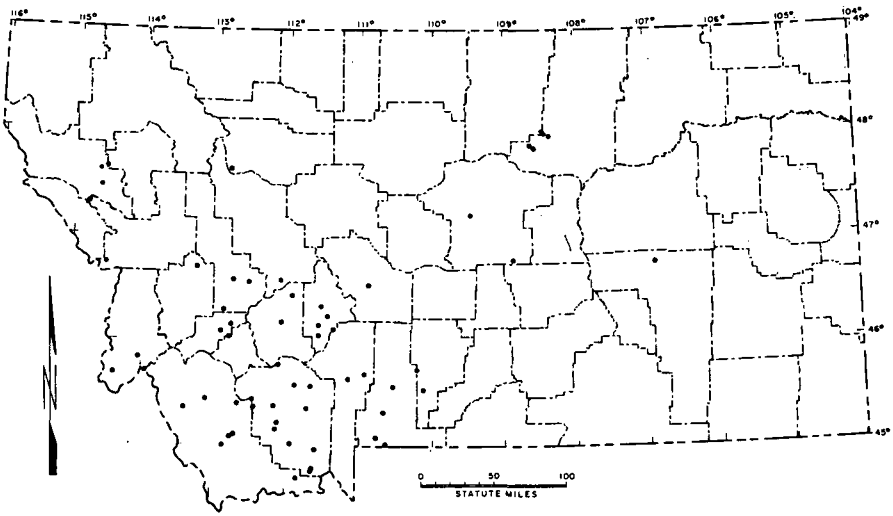


FIGURE 3. LOCATION OF THERMAL SPRINGS IN MONTANA.

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.

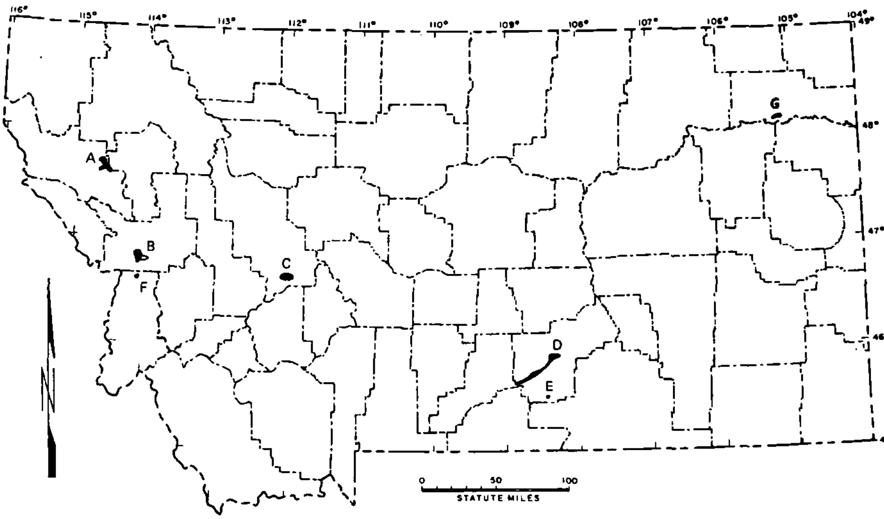


FIGURE 4. LOCATION OF AREAS FAVORABLE FOR HEAT PUMP USAGE. SEE TEXT CONCERNING SPECIFIC AREAS.

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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1 Enclosure

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EXPANDED GEOTHERMAL STUDIES IN MONTANA

John Sonderegger and Charles Wideman
Principal Investigators

Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Montana 59701

IRS No. 81-600-1254
Congressional District No. 1

Period of Performance: February 15, 1980 - August 31, 1981

Total Cost: $479,659

* *

John Sonderegger,
Principal Investigator
Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Montana 59701
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S.S.# 389-40-2023

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S. L. Groff, Director
Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology

Date submitted: 11/6/79

Copies to: Endorsers, John Dunstan and Bureau file.

PROJECT PROPOSAL

Title: Expanded Geothermal Studies in Montana

Preliminary Statement:

The Montana Bureau of Mines and Geology (MBMG) a department of the Montana College of Mineral Science and Technology, seeks to expand the geothermal research program by providing a full-time geophysical assessment program to aid in evaluating geothermal potential in high energy demand areas which are either bounded by known resource areas or adjacent to known resource areas. This work will be done in addition to the statewide resource evaluation program and the areal resource evaluation studies.

This proposal is for the period February 15, 1980 through August 31, 1981, a period of 18.5 months. Dr. Charles Wideman, an Associate Professor with the Geophysics Department and Chief of the Bureau's Geophysics Division will take a sabbatical from teaching duties and work full time on geothermal research program for the project period rather than two months per year as in the current project. Our research goals for the project period include:

(1) To complete areal investigations in: (a) West Yellowstone area, which includes drilling of one or two heat flow test holes; (b) the Radersburg basin area; (c) the Little Bitterroot Valley, which will include some test drilling.

(2) To initiate the expanded geophysical program with studies in: (a) the Helena area; (b) the southern Deer Lodge Valley; and (c) either the Boulder, Bozeman or another area to be chosen once the background evaluations are completed.

(3) To meet D.G.E. goals and deadlines for data compilation and presentation.

(4) To continue the transfer of ground-water data to the U.S. Geological Survey, Water Resources Division, data banks.

(5) To complete the interpretation of the usefulness of airborn heat-sensing imagery to detect the discharge of thermal waters to major streams.

(6) To continue the assessment of geothermal resources in eastern Montana using oil field data and on-site studies of springs and water wells.

(7) To initiate additional areal studies irrespective of current application potential in areas such as Hunters Hot Springs.

Discussion of Objectives:

Items (1) and (5) constitute the completion of authorized studies and presentation of the research results. This work will constitute roughly 30 percent of the geological effort.

Item (2) represents the expansion of the geophysical program to provide geologic, hydrochemical and geophysical information in established resource potential areas flagged by the state and Operations Research personnel as very favorable for energy transfer operations to occur in the resource potential can be proved. Roughly $110,000 of the drilling money will be spent testing the conclusions reached in these study areas, mainly in the form of heat flow holes.

Item (3) is included as a statement relating to D.G.E. needs from the state-coupled program, such as providing a public use oriented state resource map as scheduled during the current project period.

Item (4) is a continuation of an established method of feeding data for the Geotherm file.

Item (6) reflects insufficient manpower during the past year; consequently, this work is listed separately and an additional man has been authorized by the Bureau Director for work on items (2) and (6). This increase is also reflected in the budget.

Item (7) is the continuation of the areal studies aspect of the research program, with studies based soley upon resource criteria (available geologic, geophysical and geochemical data) in selecting the study areas.

Under the expanded geophysical program, $17,000 of the money for capitol equipment will be used to modify existing equipment to permit deep resistivity surveys to be conducted.

Geothermal Project Budget - Montana State-Coupled Program

February 15, 1980 - August 31, 1981 (18.5 months)

I Salaries and Wages	DOE	State	Montana Tech
Sonderegger (4,0,5)	8,426	--	10,112
Wideman (18.5,0,0)	44,797	--	--
Editor (1,0,0)	--	--	2,160
Hydrologists (30,0,3.5)	45,934	--	5,195*
Geophysical Students (30,0,0)	20,200	--	--
Bureau Students (20,0,0)	10,000	--	--
Technician (5,0,0)	6,667	--	--
	136,024	0	17,467
Benefits (15.5% of Salaries and Wages)	21,084	0	2,707
Total Salaries Wages and Benefits	157,108	0	20,174

II Operations			
Expendable Equipment	2,000	--	5,000*
Capitol Equipment	19,000	--	--
Travel and Per Diem	23,000	--	--
Drilling-logging	113,200	30,000	--
Water Analyses	19,000	--	--
Computer Processing	2,500	--	--
Publication costs	5,000	--	--
Total Operations	183,700	30,000	~~25,174~~ 5,000
III Indirect Costs (47.2% of Salaries, wages, and benefits as established by HEW)	74,155	0	9,522
IV Total Costs	414,963	30,000	34,696
	86.5%	6.3%	7.2%

*Monies provided by Montana Department of Natural Resources and Conservation, Alternative Renewable Energy Sources Program

Total Cost of Project $479,659

RESUME

Name: John L. Sonderegger II

Personal:
- Born January 14, 1942, Madison, Wisconsin
- Married, three children

Education:
- B.S.I., Geology, University of Wisconsin (Madison), 1962-1966
- M.S., Geology, University of Alabama, 1967-1969
- Ph.D., Geochemistry, New Mexico Tech, 1970-1973

Academic Honors:
- University of Wisconsin, In-State Tuition Scholarship, 1963-1966
- Northwestern University, N.D.E.A. Fellowship, 1969-1970.

Work Experience:
- Montana Bureau of Mines and Geology, Research Associate Professor and Hydrogeologist, 1978 to present; Research Assistant Professor and Hydrogeologist, 1974-1978
- Georgia Earth and Water Division, Geologist II, 1973-1974; Geologist III, 1974
- Geological Survey of Alabama, Geologist I (¾ time), 1967-1969

Organizations:
- Geochemical Society
- Geothermal Resources Council
- American Association of Professional Geologists

M.S. Thesis: A photogeologic and structural study of a limestone terrane with emphasis on fractures affecting ground-water occurrence.

Ph.D. Dissertation: A preliminary investigation of the dissolution kinetics of strontianite and witherite.

Publications:

Sonderegger, J. L., 1968, Geology of the Athens quadrangle, Alabama [abs.]: Journal of the Alabama Academy of Science, v. 39, no. 3, p. 211.

______1969, Calculation of carbon dioxide partial pressure from chemical analyses of limestone ground water: Journal of the Alabama Academy of Science, v. 40, no. 4, p. 227-231.

______1970, Hydrology of limestone terranes-photogeologic investigations: Geological Survey of Alabama Bulletin 94-C, 27 p.

______1974, Effect of Chattanooga shale facies distribution on the in situ formation of negative structures by ground-water solution [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 4, p. 399.

______1974, A preliminary investigation of strontianite dissolution kinetics [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 961.

______1976, Hydrologic and geochemical controls on tailings pond drainage affecting Soda Butte Creek, Cooke City, Montana [abs.]: Geological Society of America Abstracts with Programs, v. 8, no. 5, p. 634.

______1978, Carbonate mineral profiles in soils, till, and bedrock related to ground-water chemistry and mineralogy in saline-seep areas of Montana [abs.]: Proceedings, Montana Academy of Science (in press).

Sonderegger, J. L., Bergantino, R. N., Donovan, J. J., and Miller, M. R., 1978, Geothermal studies in Montana—Quarterly report: Montana Bureau of Mines and Geology Open-File Report 28, 88 p.

Sonderegger, J. L., Bergantino, R. N., and Miller, M. R., 1977, Geothermal potential of the Madison Group at shallow depth in eastern Montana—Final report: Montana Bureau of Mines and Geology Open-File Report 25, Part I, 27 p.

Sonderegger, J. L., and Billings, G. K., 1971, The geochemical cycle of molybdenum [abs.]: Geological Society of America Abstracts with Programs, v. 3, no. 7, p. 712-713.

Sonderegger, J. L., Brower, K. R., and LeFebre, V. G., 1976, A preliminary investigation of strontianite dissolution kinetics: American Journal of Science, v. 276, no. 8, p. 997-1022.

Sonderegger, J. L., Donovan, J. J., Miller, M. R., and Schmidt, F. A., 1978, Progress Report—Saline Seep: Investigations of soluble salt loads, controlling mineralogy, and some factors affecting the rates and amounts of leached salts: Montana Bureau of Mines and Geology Open-File Report 30, 31 p.

Sonderegger, J. L., and Kelly, J. C., 1970, Hydrology of limestone terranes—geologic investigations: Geological Survey of Alabama Bulletin 94-B, 146 p.

Sonderegger, J. L., and Miller, M. R., 1977, Preliminary results of investigations on leachable salt loads in saline-seep areas of Montana [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 6, p. 764-765.

Sonderegger, J. L., Pollard, L. D., and Cressler, C. W., 1978, Quality and availability of ground water in Georgia: Georgia Department of Natural Resources, Geologic and Water Resources Division, Information Circular 48, 25 p.

Sonderegger, J. L., and Schofield, J. D., 1979, Factors controlling the occurrence of warm springs in the Upper Centennial Valley, southwestern Montana [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 6, p. 302-303.

Sonderegger, J. L., Wallace, J. J., Jr., and Higgins, G. L., Jr., 1976, Acid mine drainage control—feasibility study, Cooke City, Montana: Montana Bureau of Mines and Geology Open-File Report 23, 197 p.

Bermel, W. M., Sonderegger, J. L., and Glasser, D. T., 1977, A reconnaissance study of geothermal poten tial in the upper parts of Red Rock Creek and Madison River Valleys, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 25, Part II.

Bergantino, R. N., and Sonderegger, J. L., 1978, Preliminary list of thermal springs in Montana: Montana Bureau of Mines and Geology in-house report, 6 p. (Available upon request)

Billings, G. K., and Sonderegger, J. L., 1971, The geochemical cycle of molybdenum in our environment [abs.]: American Chemical Society, Division of Water, Air, and Waste Chemicals, Annual Meeting, Washington, D.C.

Billings, G. K., Beane, R. E., Sonderegger, J. L., and Hayslip, D. L., 1972, Phase I: Qualitative mineralogical analysis and quantitative chemical analysis of selected shale samples from the Lyons, Kansas, nuclear-waste burial site: Oak Ridge National Laboratory Contract Research Report for Subcontract No. 3673, 22 p.

Lawson, D. C., and Sonderegger, J. L., 1978, Geothermal data-base study: Mine-water temperatures: Montana Bureau of Mines and Geology Special Publication 79, 38 p.

Miller, M. R., Bermel, W. M., Bergantino, R. N., Sonderegger, J. L., Norbeck, P. M., and Schmidt, F. A., 1977, Compilation of hydrogeological data for southeastern Montana: Montana Bureau of Mines and Geology Special Report to the Yellowstone-Tongue A.P.O., 295 p.

Norbeck, P. M., and Sonderegger, J. L., 1976, Ground-water investigation of Columbia Gardens II site: Montana Bureau of Mines and Geology Open-File Report 22, 16 p., 15 fig.

Wallace, J. J., Jr., Sonderegger, J. L., and Higgins, G. L., Jr., 1975, Annual report: Acid mine drainage control—feasibility study, Cooke City, Montana: Report to Montana Department of Natural Resources, for E.P.A. Grant No. S-802671, 39 p.

Work in Progress:

Determination of soluble salt loads in glacial deposits and weathered Cretaceous formations, and interpretation of hydrochemical factors relating to saline seep in Montana.

A reconnaissance study of the geothermal potential of the upper Centennial Valley, Montana.

Research Interests:

Field and laboratory studies of mineral-aqueous interactions which affect ground-water composition.

The use of ground-water chemistry in the evaluation of geothermal and uranium resource potential.

9/79

RESUME

Name: Charles J. Wideman

Personal:
- Born February 7, 1936
- Married

Education:
- B.S., Geophysical Engineer, Colorado School of Mines, 1954
- M.S., Geophysical Engineer, Colorado School of Mines, 1967
- Ph.D., Geophysics, Colorado School of Mines, 1975

Work Experience:
- Montana College of Mineral Science and Technology, Associate Professor, Physics and Geophysics Department, 1974 to present
- Montana College of Mineral Science and Technology, Assistant Professor of Geophysics, 1972-1974
- Colorado School of Mines, Graduate student, 1970-1972
- Montana College of Mineral Science and Technology, Assistant Professor of Geophysics, 1968-1970
- Westinghouse Electric Corp., GeoResearch Lab, Senior Geophysicist, 1967-1968

Societies and Memberships:
- Seismological Society of America
- Sigma Xi
- Registered Geophysicist, State of California

Ph.D. Thesis: Earth strain: Amchitka and Adak Islands, Alaska

Publications:
- Major, M. W., Wideman, C. J. and Butler, D. B., 1972, Episodic strain in the Central Aleutians: in "Earthquake Research in NOAA 1970-1971", NOAA Technical Report ERL 236-ESL 21, James Taggart, Ed.
- Wideman, C. J. and Van Wormer, J. D., 1970, Residual strain from Benham, Milrow and Jorum: in "Earthquake Research in ESSA 1969-1970", ESSA Technical Report ERL 182-ESL 11, L. R. Alldredge, Ed.
- Romig, P. R., Major, M. W., Wideman, C. J. and Tocher, D. M., 1969, Residual strains associated with a nuclear explosion: Bull. Seis. Soc. Am., v. 59, n. 6, p. 2167-2176.
- Wideman, C. J. and Major, M. W., 1967, Strain steps associated with earthquakes: Bull. Seis. Soc. Am., v. 57, n. 6, p. 1429-1444.

Research Interest:
- Earthquake seismology in general; and in particular, Montana earthquakes from a historical and seismic risk viewpoint.
- Geophysical studies of geothermal resource areas.

Past Projects of Special Interest:
- Geophysical investigation of the Warm Springs State Hospital area to aid in test well siting for space heating geothermal waters.
- Geophysical investigations at Ennis, Montana in support of the U. S. Geological Survey geothermal resource evaluation.
- Geophysical investigations (on-going) in the Camas, Radersburg and West Yellowstone areas as part of the DOE/DGE state-coupled program.
- Participation in the Aleutian Seismic project for the monitoring of long term crustal deformations.
- Participation in the monitoring of the long term deformations associated with nuclear detonations in Nevada and Alaska. Helped design the instruments used and the deployment of the instruments.
- Participation in the development program for near surface earth-strain seismometers of the fuzed quartz type with thermal compensation.
- Participation in the initial deployment of a short period seismic network near Denver, Colorado during the period of earthquake swarm activity. Evaluation of data and determination of velocity structure for the area were also included in this work.
- Participation in the evaluation of the suitability of a site for a nuclear power generation facility.

Montana College of Mineral Science and Technology
Montana Bureau of Mines and Geology
Project Proposal

SUMMARY PAGE

Submitted To:

Mr. David Crockett
Geothermal Energy Branch
U.S. Department of Energy
Idaho Falls, Idaho 83401

Submitted By:

Marvin R. Miller, Chief, Hydrology Division
John L. Sonderegger, Hydrogeologist
Montana Bureau of Mines and Geology
Butte, Montana 59701

Project Title:

Supplementary geothermal studies in Montana.

Project Director:

John L. Sonderegger

Investigators:

John L. Sonderegger
Robert N. Bergantino
Wesley M. Bermel

Project Duration:

May 1, 1978, to September 30, 1980

Financial Agency for Grant:

Grant and Contracts Office
Montana College of Mineral Science and Technology
Butte, Montana 59701

Total Grant Requested:

$263,599

Project Proposal

Title: Supplementary geothermal studies in Montana.

Preliminary Statement:

This application for research funding is designed to provide needed information for federal, state, and local government agencies; emphasis has been placed upon "areas of omission" where either basic investigations or data aquisition, processing, and presentation have been omitted by federal and state geothermal resource evaluation programs. Tasks to be accomplished include: (1) the evaluation of geothermal potential in the vicinity of West Yellowstone, Montana; (2) study of hot springs with calculated subsurface temperatures ≥ 140°C, with reports and recommendations on the location of test drilling sites; (3) processing and entering of approximately 2,500 chemical analyses from wells and springs to the U.S. Geological Survey W.R.D. computer files (these data will then be accessible for inclusion in the Geotherm data file); and (4) field investigations to upgrade the quality of data available on hot and warm springs in Montana, and to evaluate geothermal gradients where possible.

The proposed tasks will augment the work being conducted by others: (1) the geologic investigation of controls on hot-spring occurrences by Dr. R. A. Chadwick and students (Montana State University); (2) the study of mine-water temperatures and geothermal potential of the Upper Centennial Valley (MBMG); and (3) the evaluation of geothermal potential in western Montana by Robert Leonard (U.S. Geological Survey).

Need for Study and Objectives:

State and federal agencies are attempting to develop an adequate resource information base to evaluate the quality and quantity of geothermal resources, with the goal of producing geothermal resource potential maps and providing site-specific reports to the appropriate local government groups. The proposed tasks would provide the following types of information:

(1) A detailed report on the West Yellowstone KGRA. This is Montanas oldest KGRA, yet state and federal organizations have not attempted to define the geothermal resource in this area adjacent to Yellowstone National Park. West Yellowstone has a fairly large permanent population and is a winter resort area. We believe that this area has the best potential for geothermal energy development, for space heating purposes, in Montana. The area to be investigated is shown in Figure 1.

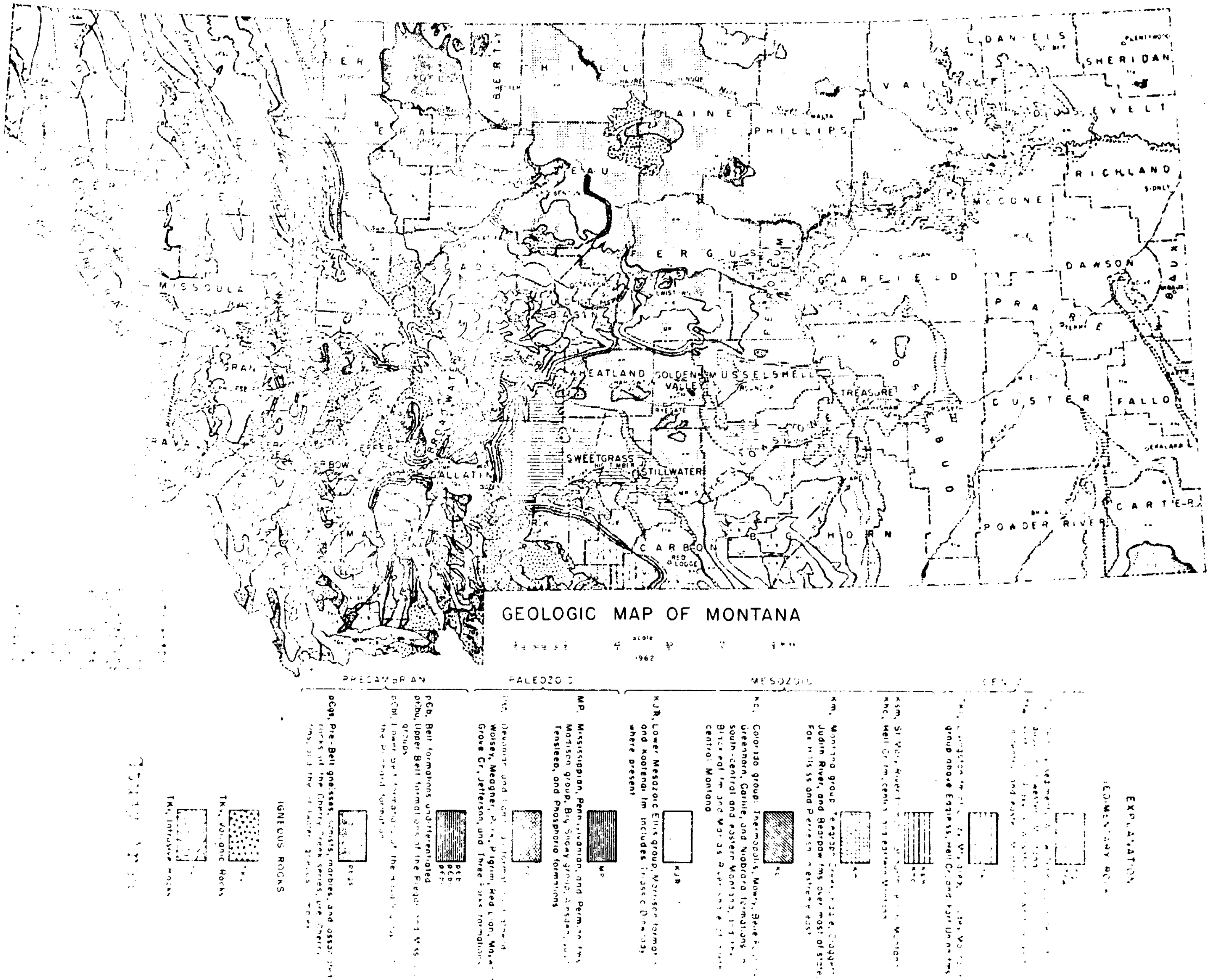

Figure 1. Location map

(2) Several communities have geothermal resources which may warrent development. State support is available through Montana's Renewable Energy Resources Program. We propose to compile all existing data and to provide additional geological and geophysical information in order to produce reports for these communities evaluating the geothermal potential and recommending test drilling sites for defining the resource and its development feasibility. A tentative list of study site areas includes: Warm Springs State Hospital, Broadwater, White Sulphur Springs, Boulder, Silver Star, and Norris.

(3) Ground-water analyses collected by the U.S. Geological Survey and MBMG have not been entered in state or federal data files. We propose to start with current analytical data and work back to older data, checking all information about source, location, etc., and getting this data base entered in the state and federal (ie. U.S.G.S. W.R.D.) data banks. This will provide a minimum of 2,500 new entries which can be evaluated for the Geotherm data file and the Montana geothermal resource map (to be prepared by N.O.A.A.).

(4) The enclosed table of thermal springs has 78 entries at present. For some of these springs, adequate discharge information is lacking, while others need both temperature and discharge measurements. We propose to measure (or remeasure) temperature, discharge, specific conductance, and pH at all thermal springs not studied by the U.S.G.S. investigators, to check for thermal springs at additional locations, and to inventory shallow (< 1,000 ft.) warm water wells and Bendix's uranium exploration holes, thereby improving the resource data base.

Methods of Investigation:

I. West Yellowstone Area

A. Field Procedures:

1. Locate springs and wells within the study area.

2. Determine in the field: temperature, flow (springs) or yield (wells), specific conductance, pH, and silica content for wells and springs.

3. Measure stream flows and estimate the thermal and non-thermal contribution to base flow.

4. Study in detail the geology of areas suspected to contain geothermal cells.

5. Collect samples for standard chemical analysis.

6. Collect special samples for detailed chemical analysis.

B. Office and Laboratory Procedures:

1. Examine maps and aerial photographs to locate all identifiable wells and springs.

2. Determine the chemical quality of spring and well waters.

a. Standard analyses include the determination of: Ca, Mg, Na, K, Fe, Mn, SiO_2, Al, HCO_3, CO_3, Cl, SO_4, F, pH, and specific conductance.

b. Special analyses include all determinations in the standard analyses plus: NH_3, Sb, B, Li, Sr, As, Hg, U, Se, Br, I, and H_2S.

3. Plot well and spring locations on base maps. Contour overlay maps based upon water chemistry and geochemical calculations of equilibrium (at depth) water temperatures using silica and K-Na-Ca geothermometery models.

4. Code all data for input to state and federal data systems.

5. Compile and integrate data with related ongoing research projects.

6. Calculate the volume of thermal waters within each identified geothermal cell.

7. Develop initial models to describe the physical, thermal, chemical, and hydrologic conditions in the study area.

8. Test drilling to test hypotheses and evaluate geothermal potential.

9. Write a final report on the study, which will include the following: the quantities of energy in each of the cells, the annual rate of natural dissipation of this energy, and a ranked list of high-potential sites within the study area, should the results indicate significant geothermal energy reserves.

II. Other Areas

A. Field Procedures:

1. Provide detailed geologic mapping in the vicinity of hot spring areas, augmented with geophysical data where feasible.

2. Measure temperature and specific conductance with a Yellowsprings model 33 Salinity-Conductivity-Temperature meter, measure discharge (flow) with a flow meter, and measure pH with a Digi-Sense model 5985-40 or equivalent pH meter. Collect selected spring samples for standard analysis.

3. Check thermal spring and well locations and elevations.

B. Office and Laboratory Procedures:

1. Collection and synthesis of existing geological and geophysical data.

2. Determine the chemical quality (standard analysis) of previously unsampled thermal springs and wells.

3. Checking for errors and coding ground-water chemical analysis information on proper format for entry into state and federal data systems.

Update thermal well and spring data base, draft maps, figures, etc., and write reports to the appropriate local, state, and federal agencies.

4. Obtain heat flow measurements if feasible from the uranium test holes to be drilled in the Missoula and Bitterroot valleys.

Note on Personnel, Funding, Laboratory Facilities, and Work Schedule:

Professional resumes are presented in Appendix I. The Bureau is currently accepting applications for a hydrologist position to work on the West Yellowstone study. Experience and interest in geothermal research will be the major criteria in hiring this man.

Dr. Sonderegger is currently matching 3½ months salary over the next 2½ years as principal investigator on a geothermal research project entitled "A reconnaissance study of geothermal potential in the upper parts of Red Rock Creek and Madison River valleys, southwestern Montana", which is scheduled to terminate September 30, 1979, and in the process of completing a final report on "A study of mine water temperatures in hardrock mining districts of Montana", a project scheduled to terminate May 15, 1978. Both of these projects are funded under contract EY-76-S-06-2426. No conflict with time available or duties is foreseen.

Budget requirements for the proposed tasks are presented in Appendix II. Graduate students will be utilized to assist Bermel (task no. 1) and Bergantino (tasks 2-4) where possible; however, such students will be closely supervised by permanent staff members. Travel and per diem were calculated assuming 480 man days in the field ($30,000), plus the travel expenses to meetings to present research results. Matching funds represent two man months per fiscal year for Sonderegger and one man month per fiscal year for Bergantino.

Laboratory instrumentation includes:

- 1 Model AA-4, Varian Techtion Atomic Absorption Spectrophotometer
- 1 Model 403, Perkin Elmer Atomic Absorption Spectrophotometer with background correction and auto-sample changer
- 1 Model 503, Perkin Elmer Atomic Absorption Spectrophotometer with background correction and graphite furnace
- 1 Model S/N243, Spectrometrics Co. Plasma Source Echelle Spectrometer with qualitative comparator attachment

The laboratory has consistently done well on USGS interlaboratory standards for the last five years, and analyzes all ground-water samples collected in Montana by the USGS Water Resources Division.

The project work plan and scheduling may be briefly summarized as follows: (a) spring of 1978, organize base maps, photos, etc., locate key points for stream flow gauging, review existing maps and data; (b) summer-fall 1978, reconnaissance field work and basic data collection in West Yellowstone, initiation of measurement studies at known thermal springs and wells, study of two or three of the community hot spring sites, and initiation of the computer processing of ground-water data; (c) winter-spring 1978-79, compilation of data, report writing, laboratory analyses, data coding, etc.; (d) summer-fall 1[illegible], completion of basic field work and drilling in West Yellowstone, geothermal gradient work in Missoula and Bitterroot valleys, one or two community resource studies, continue thermal spring measurements, ground-water data coding, etc.; winter-spring 1979-80, compile field results, write first draft of Yellowstone report, laboratory analyses, data coding, drafting, etc.; summer-fall 1980, final field work in West Yellowstone (stream gauging checks on interpretations in first draft) and writing final draft; completion of thermal spring inventory, data processing and community studies, submission of all reports.

A schedule of projected expenditures of federal funds is presented to facilitate understanding of the total program of geothermal research being conducted by the Montana Bureau of Mines and Geology with support from the Geothermal Branch of the U.S. Department of Energy.

STUDY	FY 78	FY 79	FY 80
Hard Rock Study	committed 77		
Red Rock Area	52,000	34,400	
Supplementary Studies	48,000	80,600	135,000*

*50,000 drilling costs expected to be paid in October, 1979.

APPENDIX I

Professional Resumes

APPENDIX II

Project Budget
May 1, 1978-September 30, 1980

		Federal	State
A.	Salaries, Wages, and Benefits		
	P.I. (Sonderegger; 2,2,4)	$ 4,386	$11,452
	Hydrologist (Bergantino; 4,7,7)	24,919	4,920
	Hydrologist (Bermel?; 5,6,8)	24,128	
	Technicians and students	15,000	
	Total Salaries	68,433	16,372
	Benefits*	10,265	2,456
	Salaries plus Benefits	$ 78,698	$18,828
B.	Travel and Per Diem (480 days at $62.50--assuming 150 miles/day at $.25/mile)	32,400	
C.	Field Equipment, Supplies, and Research Materials	2,750	
D.	Drilling Costs (2,000 ft. @$25/Ft.)	50,000	
E.	Computer Applications (includes 2,500 back analyses @$16)	41,500	
F.	Report Costs	5,050	
G.	Laboratory Water Analyses	12,000	
H.	Contingencies	5,000	
I.	Indirect Costs (46% of A)	36,201	8,661
J.	Total Costs	$263,599	$27,48[illegible]

*Currently 13.5% of salaries but expected to rise with new social security legislation. The cost was calculated assuming an average cost of 15%; however, only the actual costs will be charged against the project.

Method of Payment

Payment in full will be $263,599, which may be made according to standard ERDA accounting procedures.

Approval Signatures

Submitted by:

Mr. Marvin R. Miller
Chief, Hydrology Division
Montana Bureau of Mines and Geology

Dr. John L. Sonderegger
Hydrogeologist
Montana Bureau of Mines and Geology

Approved by:

Dr. S. L. Groff
Director and State Geologist
Montana Bureau of Mines and Geology

Dr. Vernon Griffiths
Director of Research
Montana College of Mineral Science and Technology

Mr. David Crockett
Geothermal Energy Branch
U.S. Department of Energy

Montana College of Mineral Science and Technology
Montana Bureau of Mines and Geology
Project Proposal

SUMMARY PAGE

Submitted To:

Dr. Clayton R. Nichols
Division of Geothermal Energy
U.S. Energy Research and Development Administration
Washington, D.C. 20545

Submitted By:

Marvin R. Miller, Chief, Hydrology Division
John L. Sonderegger, Hydrogeologist
Montana Bureau of Mines and Geology
Butte, Montana 59701

Project Title:

A reconnaissance study of geothermal potential in the upper parts of Red Rock Creek and Madison River valleys, southwestern Montana.

Project Director:

John L. Sonderegger

Investigators:

John L. Sonderegger
Wesley M. Bermel
Laurence A. Wegelin

Project Duration:

April 1, 1977, to March 31, 1979

Financial Agency for Grant:

Grants and Contracts Office
Montana College of Mineral Science and Technology
Butte, Montana 59701

Total Grant Requested:

$56,632

PROJECT PROPOSAL

Title: A reconnaissance study of geothermal potential in the upper parts of Red Rock Creek and Madison River valleys, southwestern Montana.

Preliminary Statement:

This application for a research project is intended to augment several related geothermal resource investigations in western Montana. Most Known Geothermal Resource Areas (KGRA's) were first identified by regional investigations of ground-water and surface-water resources or were previously known as hot-spring areas. The regional inventory of springs and wells as an initial field study method for the assessment of geothermal energy resource potential is a widely accepted approach (Coombs and Muffler, 1973, p. 99-101). The proposed investigation will augment studies concerning: (1) the geologic investigation of hot-spring occurrences by Professor R. A. Chadwick and students (M.S.U.); (2) the study of mine-water temperatures in hardrock mining districts (MBMG); (3) the evaluation of geothermal potential in western Montana by Robert Leonard (U.S. Geological Survey); and (4) the investigation of microseismic activity in the vicinity of Yellowstone National Park being conducted by Professor R. B. Smith and students (Univ. of Utah). The investigation will not, to the best of our knowledge, duplicate any work being performed by other investigators.

The Centennial (Red Rock Creek) Valley is west of Yellowstone National Park. The orientation of the valley is controlled by major deep-seated faults. Volcanic rocks are exposed on both sides of the valley and are believed to constitute a significant thickness of the fill within the valley. These rocks are of Pliocene age (Don Coffin, oral commun.), suggesting that considerable heat may still be retained within these rocks should they occur within the valley fill.

Investigation of the geothermal potential of this area has been almost nonexistent, and no additional research is known to be planned in this area, despite its classification as a prospectively valuable geothermal area (Bob Leonard, oral commun.).

Exhibit one shows the areas classified as a Known Geothermal Resource Area (KGRA) as of April 1, 1976, by the U.S. Geological Survey. Exhibit two, from the U.S. Geological Survey's Circular 647 (published in 1971), shows the areas then classified as KGRA's (black areas) and also shows the Potential Geothermal Resource

Areas (outline only). The proposed study area constitutes a logical area for extension of known geothermal energy related to the Yellowstone Park volcanic rocks.

Exhibit three is a geologic map of Montana. The proposed study area (red outline) occurs in the same geologic setting as the West Yellowstone KGRA (blue outline). This proposal is to conduct a reconnaissance study of the geothermal potential of this offset area along a recognized structural trend, where geologic conditions are similar. The geologic assumptions in support of this study are similar to the assumptions behind wildcat drilling along structural trends from known gas and oil producing fields.

Need for Study:

The State of Montana is currently attempting to formulate energy strategies and to project the rate of energy resource development within the state. Similarly, the federal government is attempting to evaluate the nations's energy resources in order to plan for the future. Of particular interest are nonfossil fuel energy sources. In view of these objectives it is necessary that Montana's geothermal resources be investigated and the Bureau Director has given a top priority to cooperative studies toward this goal.

Montana is believed to have several types of geologic heat sources capable of development for space heating and possibly for electrical generation. The occurrence of very young volcanic rocks (extension of the Yellowstone Park volcanic fields) within the two valleys to be studied and the possibility of a post-Eocene pluton at depth (Witkind, 1974) suggest that these sites should rank at the top of a list of areas within Montana with excellent geothermal energy potential. The results of this study will provide the State of Montana with an assessment of the energy potential in terms of water temperatures at depth and estimated annual water volumes and British Thermal Units of usable head content that can be developed within the boundaries of the study area.

Objectives:

Objectives of the proposed research are to provide an areal hydrochemical data base and to interpret the significance of these data with respect to geologic factors and the geothermal energy resource potential of the upper parts of Red Rock Creek and Madison River valleys. Particular emphasis will be placed upon:

1. Location and field sampling of all springs and wells within the project area.

2. Correlation of the most promising geothermal areas with the controlling geologic variables.

3. Modeling and characterization of the geothermal resources using U.S. Geological Survey research computer programs and facilities.

<u>Methods of Investigation</u>:

A. Field Procedures:

1. Locate springs and wells within the study area.

2. Determine in the field: temperature, flow (springs) or yield (wells), specific conductance, pH, and silica content for wells and springs.

3. Measure stream flows and estimate the thermal and non-thermal contribution to base flow.

4. Study in detail the geology of areas suspected to contain geothermal cells.

5. Collect samples for standard chemical analysis.

6. Collect special samples for detailed chemical analysis.

B. Office and Laboratory Procedures:

1. Examine maps and aerial photographs to locate all identifiable wells and springs.

2. Determine the chemical quality of spring and well waters.

   a. Standard analyses include the determination of: Ca, Mg, Na, K, Fe, Mn, SiO_2, Al, HCO_3, CO_3, Cl, SO_4, F, pH, and specific conductance.

   b. Special analyses include all determinations in the standard analyses plus: NH_3, Sb, B, Li, Sr, As, Hg, U, Se, Br, I, and H_2S.

3. Plot well and spring locations on base maps. Contour overlay maps based upon water chemistry and geochemical calculations of equilibrium (at depth) water temperatures using silica and K-Na-Ca geothermometery models.

4. Code all data for input to state and federal data systems.

5. Compile and integrate data with related ongoing research projects.

6. Calculate the volume of thermal waters within each identified geothermal cell.

7. Develop initial models to describe the physical, thermal, chemical, and hydrologic conditions in the study area.

8. Write a final report on the study, which will include the following: the quantities of energy in each of the cells; the annual rate of natural dissipation of this energy; and a ranked list of high-potential sites within the study area, should the results indicate significant geothermal energy reserves.

Presentation of Results:

An annual progress report for limited distribution (ERDA and USGS) will be made available by March 31, 1978. The final report to ERDA will also be issued as a Montana Bureau of Mines and Geology Bulletin, with distribution to more than four hundred agencies and libraries throughout the United States. It is also expected that at least one paper resulting from the project will be submitted to an appropriate scientific journal.

Note on Personnel, Funding, Laboratory Facilities, and Work Schedule:

Professional resumes are presented in Appendix III. The Bureau is currently reviewing applications for a hydrologist position caused by resignation. Experience and interest in geothermal research will be one of the criteria in hiring this man.

Dr. Sonderegger is currently funded for one month's salary by ERDA as principal investigator on a geothermal research project entitled "A reconnaissance study of mine-water temperatures in hardrock mining districts of Montana" (Contract No. E(45-1) - 2426, TA2) which is scheduled to terminate May 15, 1977. There should be no conflict with time available or duties during the overlap period.

Laboratory instrumentation includes:

1 Model AA-4, Varian Techtion Atomic Absorption Spectrophotometer
1 Model 403, Perkin Elmer Atomic Absorption Spectrophotometer with background correction and auto-sample changer
1 Model 503, Perkin Elmer Atomic Abosrption Spectrophotometer with background correction and graphite furnace
1 Model S/N243, Spectrometrics Co. Plasma Source Echelle Spectrometer with qualitative comparator attachment

The laboratory has consistently done well on USGS interlaboratory standards for the last four years, since Laurence Wegelin became laboratory chief.

The project work plan and scheduling may be briefly summarized as follows: (a) spring of 1977, organize base maps, photos, etc., locate key points for stream flow gauging, review existing maps and data; (b) summer-fall 1977, reconnaissance field work and basic data collection; (c) winter-spring 1977-78, evaluate field data, work up preliminary models and locate key areas to test validity of models, write progress report; (d) summer-fall 1978, continue basic data collection for hydrologic budget, study key areas in detail to test models; (e) winter-spring 1978-79, refine models, input data to computer systems, write final report.

List of References and Persons Cited in Text

Coffin, Don, U.S. Geological Survey, Water Resources Division, Federal Building, Helena, Montana.

Coombs, Jim, and Muffler, L. J. P., 1973, Exploration for geothermal resources, <u>in</u> Kruger, P., and Otte, C., ed., Geothermal Energy, Stanford, California, Stanford Univ. Press, p. 95-128.

Godwin, L. H., Haigler, L. B., Rioux, R. L., White, D. E., Muffler, L. J. P., and Wayland, R. G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geol. Survey Circ. 647, 18 p.

Leonard, Robert, U.S. Geological Survey, Water Resources Division Federal Building, Helena, Montana.

Witkind, I. J., 1974, A possible concealed pluton in Beaverhead and Madison Counties, Montana, and Clark County, Idaho: U.S. Geol. Survey open-file report 74-312, 7 p.

APPENDIX I

Exhibits

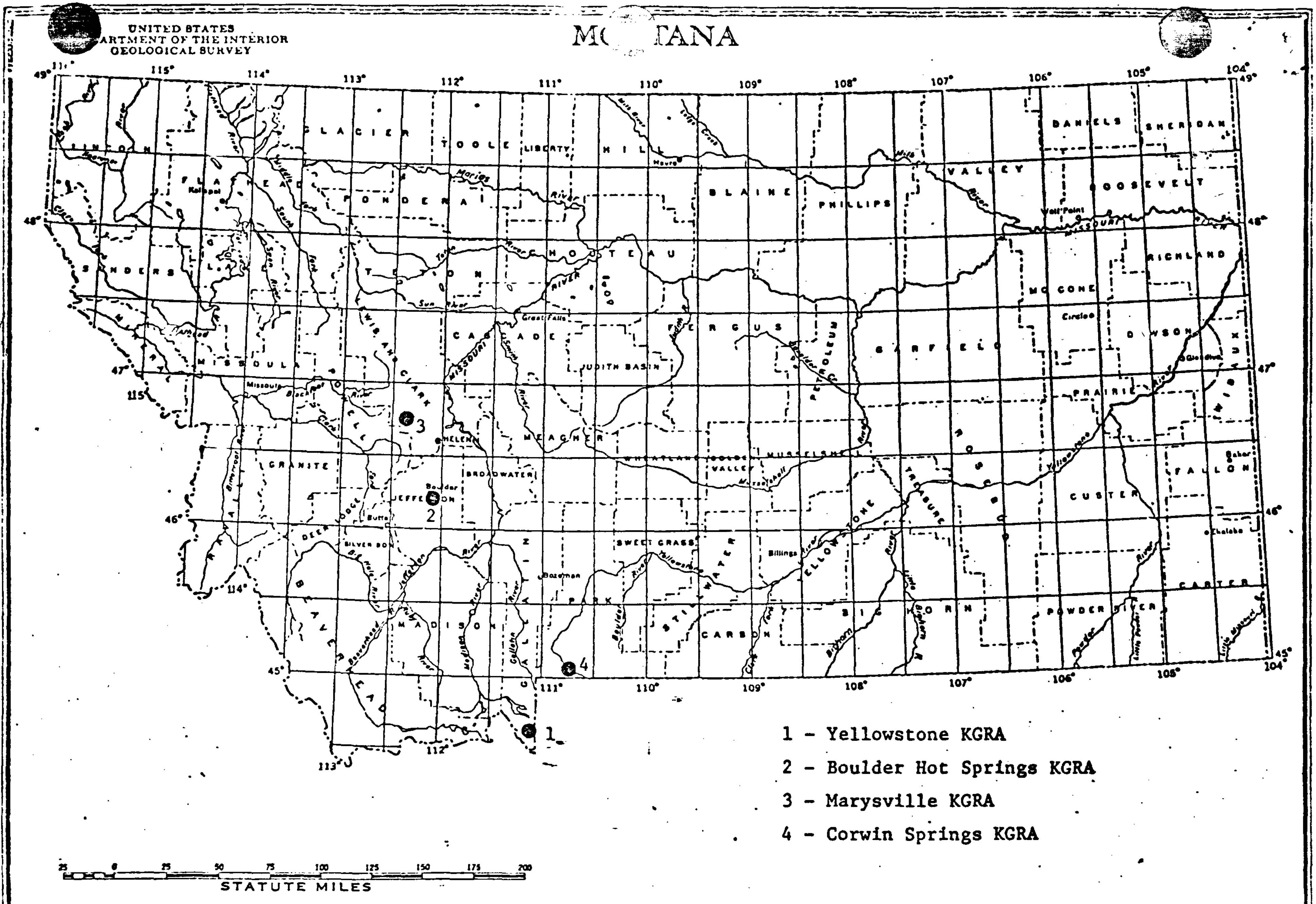

Exhibit 1. A map of Known Geothermal Resource Areas as of April 1, 1976.

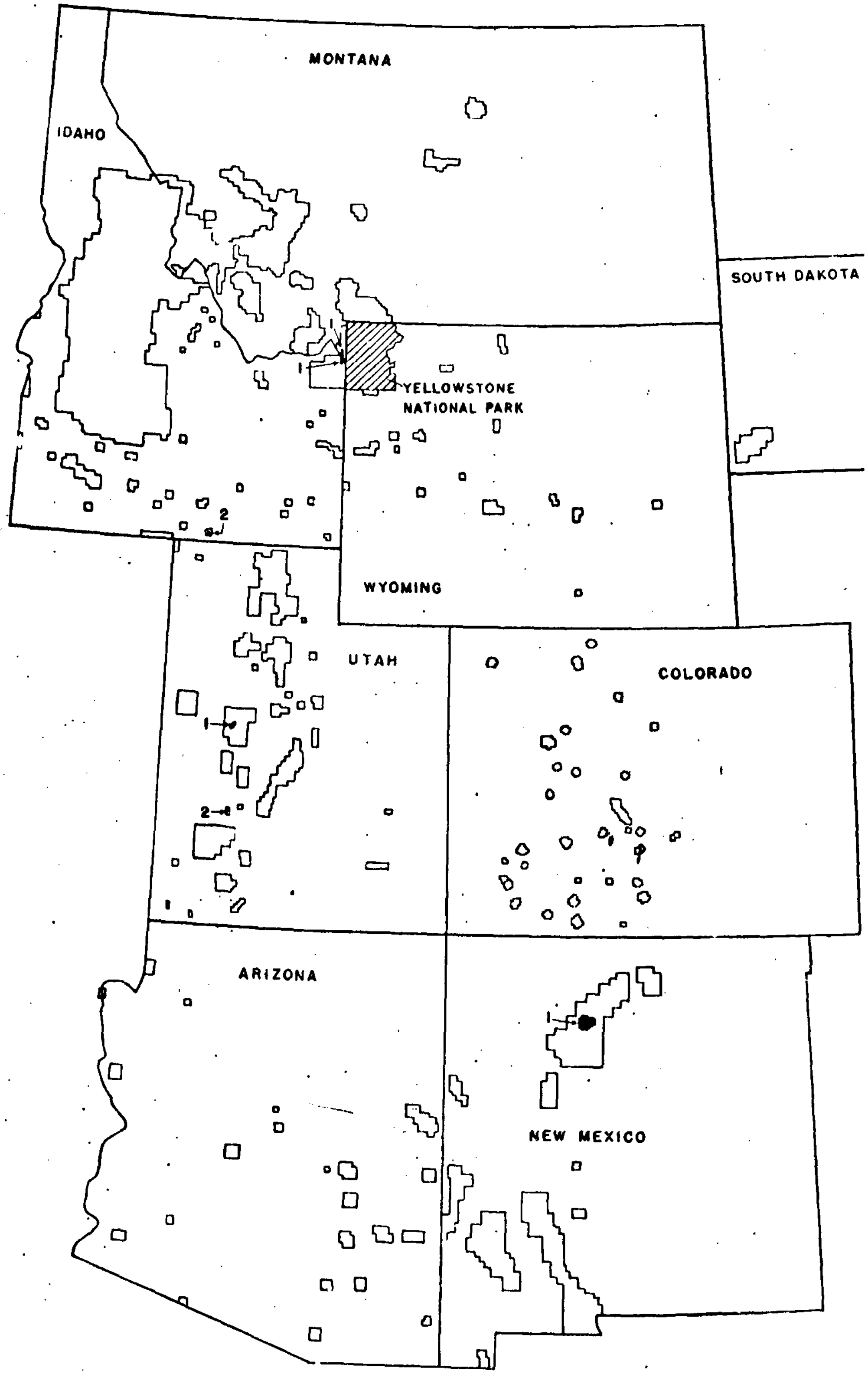

Exhibit 2. Outlined areas denote Potential Geothermal Resource Areas as of December 24, 1970 (from U.S. Geol. Survey Circular 647).

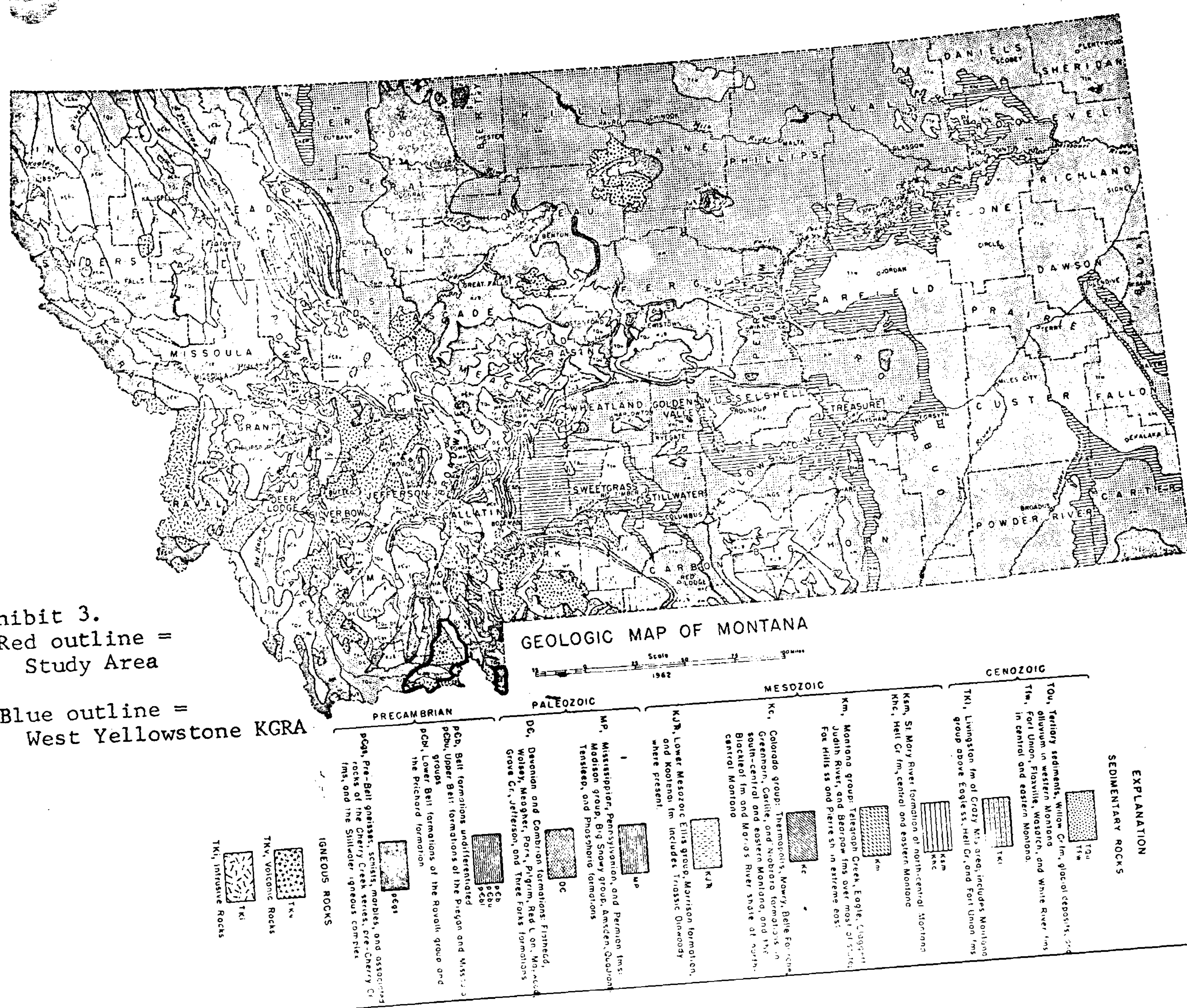

Exhibit 3.
Red outline =
Study Area

Blue outline =
West Yellowstone KGRA

APPENDIX II
Project Budget
April 1, 1977 - March 31, 1979

	Federal	State
Salaries and Wages		
Hydrogeologist 9 mo. 4.5/yr	$13,860 14,742	$4,620 3 mo
Secretary 1 mo.	655	
Draftsman ½ mo.	550	
Hydrotechnician 6 mo.	6,600	
Subtotal	21,665	4,620
Benefits (13.5% of salaries)	2,925	624
TOTAL SALARIES AND BENEFITS	24,590	5,244
Capital Equipment		
One Marsh-McBirney Model 201 portable water current meter with case and wading rod.	1,365	
Expendable Equipment and Supplies		
Field supplies--maps, aerial photos, field chemical testing materials, etc.	750	
Office and drafting supplies	300	
Miscellaneous equipment rental and repair	250	
Reference materials and copying	450	
	1,750	
Travel and Per Diem		
State vehicle (4-wheel drive) 7,500 miles @ $.20	1,500	
Per Diem 120 days @ $20/day	2,400	
Professional Meetings	1,250	
	5,150	
Other		
Computer application	1,000	
Contingencies	765	
Publication of final report	1,500	
	3,265	
Analytical Costs		
125 standard water analyses @ $42	5,250	
25 special water analyses @ $159	3,975	
	9,225	
TOTAL less indirect costs	45,345	5,244
Indirect costs (45.9% of wages and benefits as determined by HEW standard accounting procedures)	11,287	2,407
TOTAL COSTS	$56,632	$7,651

All items purchased for this study shall become the property of the Montana Bureau of Mines and Geology upon completion of the project.

APPENDIX III

Professional Resumes

April, 1976

RESUME

Name and Position:

Marvin R. Miller
Born May 9, 1941, Laramie, Wyoming
Married: 1968, one child
Chief, Hydrology Division, Montana Bureau of Mines and Geology
Research Associate Professor, Montana College of Mineral Science and Technology

Education:

A.B. in Geology, University of Montana, Missoula, Montana, June 1963
A.M. in Geology, Indiana University, Bloomington, Indiana, June 1965
Ph.D. in Hydrogeology, minors in Civil Engineering and Geomorphology, Indiana University, Bloomington, Indiana (currently completing work on dissertation).

Academic Honors:

Outstanding senior in geology at University of Montana 1963
National Defense Education Act (NDEA) 3-year fellowship in hydrogeology at Indiana University 1963-1966.
National Aeronautics and Space Administration fellowship in hydrogeology at Indiana University 1967.

Work Experience:

1965 Geologist, Humble Oil & Refining Co., Summer job
1966 Instructor, Indiana University, Summer job
1967 Instructor, Indiana University, Summer job
1967-1969 Instructor, Montana Tech, and Hydrogeologist, Montana Bureau of Mines and Geology
1969-1971 Assistant Professor, Montana Tech, and Hydrogeologist, Montana Bureau of Mines and Geology
1971-present Research Associate Professor, Montana Tech, and Chief, Hydrology Division, Montana Bureau of Mines and Geology. The position involves supervising, conducting, and directing technical ground-water, surface-water, and quality of water investigations. Additional duties include hydrogeologic research, teaching courses in ground-water geology, and assisting federal, state, and local organizations and individuals in developing and utilizing Montana's water resources. The hydrology division currently has a full-time staff of 14 in offices in Butte and Billings.

Current Research Interests:

Ground-water flow systems, water-quality changes within hydrologic systems, and ground-water exploration and development. Current research emphasis has been placed on the hydrogeologic aspects of the origin and development of dryland salinity problems throughout the Northern Great Plains.

Publications:

Miller, M. R., 1969, Water Resources of Eastern Montana, *in* Montana Geological Society Guidebook, 20th Ann. Field Conf., p. 239-243.

_______ 1971, Hydrogeology of saline-seep spots in dryland farm areas—a preliminary evaluation, *in* Proceedings of Saline Seep - Fallow Workshop, Great Falls, Montana, Feb. 22-23, 1971, 12 p.

_______and Juvan, Eddie, 1971, Possibilities of developing potable water supplies, north-central Montana, *in* Proceedings of Saline Seep - Fallow Workshop, Great Falls, Montana, Feb. 22-23, 1971, 9 p.

_______and Bond, E. W., 1972, an evaluation of weather modification in the Great Plains of Montana—Part 1 (ground water), *in* Impacts of Induced Rainfall on the Great Plains of Montana - An Interim Report: Montana Agricultural Experiment Station Research Report 26, p. 41-73.

Ferguson, Hayden, Brown, P. L., and Miller, M. R., 1972, Saline seeps on non-irrigated lands of the northern plains, *in* Proceedings on Control of Agriculture Related Pollution in the Great Plains, Lincoln, Nebraska: Great Plains Agricultural Council Publication No. 60, p. 169-191.

Miller, M. R., and Bond, E. W., 1973, Impacts of induced rainfall on the Great Plains Montana - Section 8 (ground-water hydrology) Final Report: Montana Agricultural Experiment Station Research Report 42, 74 p.

_______1973, Saline-seep development in Montana and adjacent areas—hydrogeological aspects, *in* Proceedings of Governor's Saline Seep Emergency Meeting, Helena, Montana, April 25, 1973, p. 23-28.

Bahls, Loren L., and Miller, M. R., 1973, Saline seep in Montana, *in* Second Annual Report, Montana Environmental Quality Council, p. 35-44.

Miller, M. R., 1974, Hydrogeochemical investigation of selected water sheds in southwestern Montana: Montana Univ. Joint Water Resources Research Center Report No. 60, 27 p.

_______and Bahls, L. L., 1975, Ground-water seepage and its effects on native soils: Montana Univ. Joint Water Resources Research Center Report No. 66, 56 p.

Brown, P. L., and Miller, M. R., 1975, Perennial cropping for saline seep control: American Soc. Agronomy Jour. (in press).

Miller, M. R., and others, 1976, An overview of saline-seep programs in the states and provinces of the Great Plains, *in* Regional Saline-seep Control Symposium, Bozeman, Montana: Montana Agricultural Experiment Station Research Report No. _____ (in press).

Brown, P. L., Cleary, E. C., and Miller, M. R., 1976, Water use and root depths of crops for saline seep control, *in* Regional Saline-seep Control Symposium, Bozeman, Montana: Montana Agricultural Experiment Station Research Report No. _____ (in press).

April, 1976

RESUME

Name: John Lawrence Sonderegger II
Born January 14, 1942, Madison, Wisconsin
Married, two children

Education:

B.S.I. - Geology, 1962-1966, University of Wisconsin
M.S. - Geology, Fall 1966, University of Tennessee[1], 1967-1969, University of Alabama
Ph.D. - Geochemistry, 1969-1970, Northwestern University[2], 1970-1973, New Mexico Tech[3]

Academic Honors:

University of Wisconsin - Instate Tuition Scholarship 1963-1966
Northwestern - N.D.E.A. Fellowship

Work Experience:

Montana Bureau of Mines and Geology - Research Assistant Professor and Hydrogeologist-
December 1974 to present.
Georgia Earth & Water Division - Geologist II - 1973-1974; Geologist III - 1974 to December 1974.
Geological Survey of Alabama - ¾ time as Geologist I - 1967-1969.

M.S. Thesis:

A photogeologic and structural study of a limestone terrane with emphasis on fractures affecting ground-water occurrence.

Ph.D. Dissertation:

A preliminary investigation of the dissolution kinetics of strontianite and witherite.

Publications:

Sonderegger, J. L., 1968, Geology of the Athens quadrangle, Alabama (abs): Jour. Alabama Acad. Sci., v. 39, no. 3, p. 211.

_______1969, Calculation of carbon dioxide partial pressure from chemical analyses of limestone ground water: Jour. Alabama Acad. Sci., v. 40, no. 4, p. 227-231.

_______1970, Hydrology of limestone terranes-photogeologic investigations: Geol. Survey Alabama Bull. 94-C, 27 p.

_______1974, Effect of Chattanooga shale facies distribution on the in situ formation of negative structures by ground-water solution (abs): Geol. Soc. America Abs. with Programs, v. 6, no. 4, p. 399.

_______1974, A preliminary investigation of strontianite dissolution kinetics (abs): Geol. Soc. America Abs. with Programs, v. 6, no. 7, p. 961.

_______1976, Hydrologic and geochemical controls on tailings pond drainage affecting Soda Butte Creek, Cooke City, Montana (abs): Geol. Soc. America Abs. with Programs, v. 8, no. 5 p. 634.

_______A tentative exploration model for the location of oxidized uranium deposits in fluvial sandstone: submitted to Econ. Geology.

_______and Billings, G. K., 1971, the geochemical cycle of molybdenum (abs): Geol. Soc. America Abs. with Programs, v. 3, no. 7, p. 712-713.

_______Brower, K. R., and LeFebre, V. G., 1976, A preliminary investigation of strontianite dissolution: Am. Jour. Sci., in press.

_______and Kelly, J. C., 1970, Hydrology of limestone terranes-geologic investigations: Geol. Survey Alabama Bull. 94-B, 146 p.

_______and Wallace, J. J., Jr., 1976, Final report: Acid mine drainage control-feasibility study, Cooke City, Montana: Report to Montana Department of Natural Resources for E. P. A. Grant No. S-802671, 197 p.

Billings, G. K., and Sonderegger, J. L., 1971, The geochemical cycle of molybdenum in our environment (abs): Am. Chem. Soc., Div. Water, Air and Waste Chem., Ann. Mtg., Washington, D. C.

Billings, G. K., Beane, R. E., Sonderegger, J. L., and Hayslip, D. L., 1972, Phase I: Qualitative mineralogical analysis and quantitative chemical analysis of selected shale samples from the Lyons, Kansas, nuclear-waste burial site: Oak Ridge Nat. Lab. Contract Research Report for Subcontract No. 3673, 22 p.

Wallace, J. J., Jr., Sonderegger, J. L., and Higgins, G. L., Jr., 1975, Annual report: Acid mine drainage control-feasibility study, Cooke City, Montana: Report to Montana Department of Natural Resources for E. P. A. Grant No. S-802671, 39 p.

Work in Progress:

An Atlas of Georgia's Ground-Water Quality by Sonderegger, Pollard, and Cressler, in final review for publication by the Georgia Department of Natural Resources, Earth and Water Division.

A reconnaissance study of mine-water temperatures in hardrock mining districts of Montana (with Don Lawson, MBMG).

Research Interests:

1. Field and laboratory studies of mineral-aqueous interactions which effect ground-water composition.

2. The use of ground-water chemistry in the evaluation of geothermal and uranium resource potential.

[1] Left for financial reasons.
[2] Left because of faculty changes in geochemistry.
[3] Degree granted in 1974.

PROFESSIONAL RESUME

Name: Laurence A. Wegelin
1021 West Diamond Street
Butte, Montana 59701
Telephone: (406) 792-8321 ext. 274 (work)
(406) 792-7213 (home)

Personal:
Birth date: 8/13/40 Married, four children 5'6" 156 lbs.
U.S. Citizen

Professional Experience: 11 years

Field: Analytical Chemistry - Inorganic

Education:

University of Wyoming, Laramie, Wyoming
Electrical Engineering, 7 semesters - 117 credit hours
GPA: 3.67/4.0 from 1959 to 1962

Professional Experience:

3/70 to present
Montana College of Mineral Science and Technology
Montana Bureau of Mines and Geology
Butte, Montana 59701

Present Position: Chief Chemist, Analytical Division

Immediate Supervisor: Dr. S. L. Groff, Director and State Geologist

Responsible for all chemical analyses required by the Bureau's Geology Division, Hydrology Division, and Energy Division as well as for chemical analyses requested by other State or Federal cooperating agencies, such as the U.S. Geological Survey, U.S.D.A. Forest Service, Environmental Protection Agency, the Bureau of Land Management, the Montana Department of Fish and Game, Montana Department of Agriculture, the Montana Department of Health and Environmental Sciences, and Montana Department of State Lands. This includes; chemical analyses of geological materials, surface and groundwater and coal; purchasing equipment and instrumentation; budgeting and staffing; and overall supervision of laboratory staff. Also responsible for: evaluating new analytical methods and improving existing ones; has maintained and demonstrated a high degree of analytical quality control for the last several years through a reference-sample exchange program with the U.S. Geological Survey and the Environmental Protection Agency as well as maintaining good internal control measures.

1/69 to 6/69 — Minerals Engineering Company, Lamps Division,
General Electric Company
P.O. Box 431
Dillon, Montana 59725

Position: Chief Chemist

Immediate supervisor: Blair T. Burwell Jr., General Manager

Was responsible for analytical quality control and the supervision of laboratory staff to furnish chemical analyses for three divisions of the operation. 1. Mining Division - to assure the removal of a specified grade of ore. 2. Mineral Dressing Division - to assure a specified concentrate was being produced. 3. Chemical Extraction Division - to assure a pure tungsten product was being produced. Also was responsible for the purchasing of laboratory equipment, instrumentation, and budgeting to operate the laboratory.

9/66 to 1/69 — Molybdenum Corporation of America - Research Center
P.O. Box 607
Louviers, Colorado 80131

Position: Chemist

Immediate supervisor: Edwin Tomasi, Chief Chemist

Performed chemical analyses for; 1. Production - trace metal analyses for quality control of six rare earth products. 2. Research and Development - chemical and trace metal analyses needed for engineering and process development. 3. Exploration and Geology - chemical analyses of geological material and ore.

8/65 to 9/66 — Colorado School of Mines Research Foundation, Inc.
Golden, Colorado 80401

Position: Technician

Immediate supervisor: James Drobnick, Manager, Chemical Extraction and Hydro-Metallurgical Division

Performed chemical analyses needed for various process design or process control projects undertaken by the administration. Also assisted in pilot-plant operations by monitoring or controlling one or more stages of several different test plants.

RESUME'

Personal:

Wesley Martin Bermel
Born April 8, 1952, Williston, North Dakota
Married, one child

Education:

B.S. - Geological Engineering (June, 1976), Montana College of Mineral Science and Technology

Professional Organizations:

Junior Member, American Association of Petroleum Geologists

Work Experience:

Currently employed by the Montana Bureau of Mines and Geology, Hydrology Division, as a Hydrotechnician (classified in June, 1975).

My present work assignments include: 1. To review subdivision environmental impact statements and make comments on the subdivision with respect to its effects on ground and surface water as well as potential flood danger. 2. To supervise six (6) student assistants which are presently collating all existing water quality information in the Fort Union Coal Region. 3. To supervise one (1) student who is presently doing some of Hydrology Division's computer programming and to control system design, computer programming and system analysis. 4. To construct plane table maps of hydrologic test areas. 5. To produce photographic materials such as black-and-white prints and color slides for Division use. 6. To perform routine technical work in collecting and processing geological data and materials: a. Specific conductivity surveys of ground and surface water; b. Well inventorying and monitoring; c. Aquifer testing.

Presently, I am one of several whom are supervising the collating of all ground-water information for the Fort Union Coal Region in Montana.

Preceding June, 1975, I was also employed by the Montana Bureau of Mines and Geology, Hydrology Division, as a student assistant; my responsibilities were centered around the supervision of coding Water Quality Data. However my main job was to write, revise, and update the Hydrology Division's programs. Associated with the programming, I was also involved in the developing of several Data Systems. Along with these responsibilities I also monitored our test wells throughout the state.

Other work done with the Bureau also includes two (2) years of work assiciated with the Silver Bow Creek drainage study. This involved water quality sampling, measuring field parameters such as pH, specific conductivity, EH, turbidity, and stream flow measurements.

During the summer of 1973, I was employed by the Anaconda Copper Mines Company where my job consisted of taking drill rig samples and splitting core when necessary.

Major Accomplishments Included:

Water Quality Data System
Printer Plot Routine
Water Level Program and Data Base
Well Appropriation Data Base and Associated Programs

Open File Reports:

Bermel, W.M., 1974, Conversion of Section-Township-Range to Latitude-Longitude.

____________, 1973, Mineral Identification, Question Answer Documentation.

____________, 1974, Recording on the IBM 1311 Disk System.

____________, 1974, Storage Data Preparation for Lat-long.

Bergantino, Robert, Bermel, W.M., 1975, Montana Geological Maps of Southeastern Montana at 1:250,000 scale.

Method of Payment

Payment in full will be $56,632, which may be made according to standard ERDA accounting procedures.

Approval Signatures

Submitted by:

Mr. Marvin R. Miller
Chief, Hydrology Division
Montana Bureau of Mines and Geology

Dr. John L. Sonderegger
Hydrogeologist
Montana Bureau of Mines and Geology

Approved by:

Dr. S. L. Groff
Director and State Geologist
Montana Bureau of Mines and Geology

Dr. Vernon Griffiths
Director of Research
Montana College of Mineral Science and Technology

Dr. Clayton R. Nichols
Division of Geothermal Energy
U.S. Energy Research and Development Administration

GL00972

TASK AGREEMENT NO. 2 UNDER
CONTRACT NO. E(45-1)-2426

[X] New Task

[ ] Continuation of work previously conducted under Contract No. ________________

TASK AGREEMENT between the UNITED STATED ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION ("ERDA") and MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY

TITLE: A STUDY OF MINE WATER TEMPERATURES IN HARDROCK MINING DISTRICTS OF MONTANA

EFFECTIVE DATE: May 15, 1976

DEFINITION - The term "Basic Contract" means the Special Research Support Agreement entered into between the parties hereto and designated Contract No. E(45-1)-2426

A-I. RESEARCH TO BE PERFORMED BY CONTRACTOR

The Contractor will conduct the research program outlined in its December 21, 1975 proposal entitled "A Reconnaissance Study of Mine-Water Temperature in Hardrock Mining Districts of Montana," which is hereby incorporated herein and made a part hereof by reference.

The objective of the program is a reconnaissance evaluation of thermal anomalies in western Montana through investigation of mine-water temperature and water chemistry.

In order to accomplish this objective, the Contractor will undertake three main tasks as follows:

1. Visit representative mines within each of the 199 Montana hardrock mining districts and record the following information for each site visited: Temperature measurement, conductivity, depth of the sample site and estimate of the flow. If waters having a temperature of 40°C or greater are encountered, samples will be collected according to the methods described by Presser and Barnes (1974).

2. Analyze hot water samples in the Montana Bureau of Mines and Geology laboratory. Laboratory analyses will include but not necessarily be restricted to Si, Na, K, Ca, Mg, Cl, B and Fl.

3. Interpret the results of the study in terms of the distribution of anomalous mine temperatures and water chemistries in Montana's hardrock mining districts.

TYPE OF WORK CODE (CIS): 3 Request payment of first 45% ($8,859.60) by voucher 6/11/76 [illegible]
[illegible]

Reports will include the following:

1. A tabulation of the results of the study which shall include the mine name, location by both latitude and longitude and temperature, conductance, flow rate and, for samples with temperatures 40°C or greater, chemical analyses.

2. A report interpreting the results of the investigation in terms of observed temperature and/or chemical anomalies which would seem to warrant more detailed investigations of specific areas.

Principal Investigator Dr. John L. Sonderegger will devote 100% time for one month.

A-II. WAYS AND MEANS OF PERFORMANCE

		Amount
(a)	Items for which support will be provided, as indicated in A-III below:	
(1)	Salaries and Wages	$ 8,080.00
	Principal Investigator J. L. Sonderegger, one month One mining field agent One student Secretarial - clerical help	
(2)	Equipment to be purchased or fabricated by the Contractor. Title is being vested with the Contractor pursuant to the Grant Act (PL 85-934)	$ 499.00
	Mine lamps, converter, and battery charger S-C-T meter and probes Thermometers, pack, and pack frame	
(3)	Travel	
	Domestic	$ 5,235.00
	Foreign	- 0 -
(4)	Other Direct Costs	$ 2,165.00
(5)	Indirect costs based upon predetermined rate of of 45.9% of direct salaries, wages and benefits.	$ 3,709.00

(b) Items, if any, significant to the performance of this contract, but excluded from computation of Support Cost and from consideration in proportion cost;

(1) Items to be contributed by the Contractor.
In accordance with Article B-II(c) of the Basic Contract, if a proposed Contractor contribution is included in this paragraph (b)(1), the Contractor shall maintain records adequate to permit ERDA to determine the extent of the contribution.

Salary of one mining field agent for one month

(2) Items to be contributed by the Government.

None

(c) Time or effort of Principal Investigator(s) contributed by Contractor but excluded from computation of Support Cost and from consideration in proportioning costs:

None

A-III. TOTAL ESTIMATED COST

The total estimated cost of items under A-II(a) above for the contract period stated in this Task Agreement is $19,688; ERDA will pay 100 percent of the actual costs of these items incurred during the contract period stated in this Task Agreement, subject to the provisions of Article IV and Article B-XXXIII of the Basic Contract. The estimated ERDA Support Cost for the contract period stated in this Task Agreement is $19,688.

The estimated ERDA Support Cost is funded as follows:

	Amount
(a) Estimated unexpended balance from the prior period(s)	$ - 0 -
(b) New funds for the current period	$ 19,688.00

The new funds being added in A-III(b) constitute the basis for advance payments provided under Article B-XIII.

A-IV. CONTRACT PERIOD

The period for performance under this Task Agreement shall commence on May 15, 1976, and expire on May 14, 1977.

A-V. SUPPORT CEILING

The Support Ceiling for contract period specified in this Task Agreement is $19,688.

A-VI. TERMS AND CONDITIONS

This Task Agreement is subject to the terms and conditions of the Basic Contract.

A-VII. PRINCIPAL INVESTIGATOR

The work shall be conducted under the direction of Dr. John L. Sonderegger or such other members of the Contractor's staff as may be mutually satisfactory to the parties.

A-VIII. GOVERNMENT PROPERTY

The following items of property procured or fabricated by the Contractor are hereby listed as "Government Property."

None

A-IX. DEVIATIONS

It is understood that Articles A-I and A-II above, a guide to the performance of this Task Agreement, may be deviated from by the Contractor subject to the specific requirements of the Basic Contract.

A-X. ADDITIONAL PROVISIONS

In addition to reporting requirements outlined in Article B-XXIII of the Basic Contract, twelve copies of the final report shall be sent to: U. S. Energy Research and Development Administration, Washington, D. C. 20545. Attn: Clayton R. Nichols, Division of Geothermal Energy.

AGREED TO THIS 12th DAY OF May, 1976.

UNITED STATES OF AMERICA
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

By: [signature]

Title: Supervisory Contracts Specialist

MONTANA SCHOOL OF MINERAL SCIENCE AND TECHNOLOGY

By: [signature]

Title: ______________

MODIFICATION NO. A001 TO TASK AGREEMENT NO. 2
UNDER CONTRACT NO. EY-76-S-06-2426 BETWEEN THE
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION ("ERDA") AND MONTANA COLLEGE OF
MINERAL SCIENCE AND TECHNOLOGY ("CONTRACTOR")

TITLE: A STUDY OF MINE WATER TEMPERATURES IN HARDROCK MINING DISTRICTS OF MONTANA

Effective as of May 15, 1977, Task Agreement No. 2 is modified as follows:

1. The period of performance under this Task Agreement is extended for one year commencing May 15, 1977, and expiring May 14, 1978.

2. The Support Ceiling under this Task Agreement is increased by $12,899 to $32,587 in order to cover costs of conducting the new work described herein during the period July 1, 1977, through September 30, 1977. These new tasks are to be conducted concurrently with work funded earlier, for which funds remain available under the contract.

3. The Research to be performed by the Contractor, the Ways and Means of Performance and the Total Estimated Cost thereof for the additional work to be performed during the period July 1, 1977, through September 30, 1977 are as follows:

A-I. <u>RESEARCH TO BE PERFORMED BY CONTRACTOR</u>

(a) The Contractor will conduct a reconnaissance investigation of potential geothermal reservoirs in the upper Centennial and Madison River Valleys.

(b) The Contractor will conduct a "Phase Zero" study of the geothermal potential of the Madison Limestone in central and eastern Montana. This will involve the survey of available data, coordination with ongoing, related water studies, and development of a plan for the assessment of the geothermal potential of the region.

Principal Investigator Dr. J. L. Sonderegger will devote 100 percent time for two and one-half months to the project.

A-II. <u>WAYS AND MEANS OF PERFORMANCE</u>

(a) Items for which support will be provided, as indicated in A-III below:

		Amount
(1)	Salaries and Wages (including fringe benefits)	$5,676

Principal Investigator J. L. Sonderegger
Technician
Student

3

Requested [illegible]

		Amount
(2)	Equipment to be purchased or fabricated by the Contractor. Title is being vested with Contractor pursuant to the Grant Act (PL 85-934)	$1,500
	Flow Meter	
(3)	Travel	
	Domestic	$2,500
	Foreign	$ - 0 -
(4)	Other Direct Costs	$ 618
(5)	Indirect costs based upon predetermined rate of 45.9 percent of direct salaries and wages	$2,605

(b) Items, if any, significant to the performance of this Task Agreement but excluded from computation of Support Cost and from consideration in proportioning cost:

(1) <u>Items to be contributed by the Contractor.</u> In accordance with Article B-II(c) of the Basic Contract, if a proposed Contractor contribution is included in this paragraph (b)(1), the Contractor shall maintain records adequate to permit ERDA to determine the extent of the contribution.

Contractor will contribute salary of professional staff for 1/2 month, salary of student assistant for 2 months, and supplies and expendable equipment of approximately $100.

(2) <u>Items to be contributed by the Government.</u>

None

(c) Time or effort of Principal Investigator contributed by Contractor but excluded from computation of Support Cost and from consideration in proportioning costs:

2-1/2 Months

A-III. TOTAL ESTIMATED COST

The total estimated cost of items under A-II(a) above for the contract period stated in this Task Agreement is $12,899; ERDA will pay 100 percent of the actual costs of these items incurred during the contract period stated in this Task Agreement, subject to the provisions of Article IV and Article B-XXVII of the Basic Contract. The estimated ERDA Support Cost for the contract period stated in this Task Agreement is $12,899.

	Amount
(a) Estimated unexpended balance from the prior period(s)	$ - 0 -
(b) New funds for the current period	$12,899

The new funds being added in A-III(b) constitute the basis for advance payments provided under Article B-XI.

A-IV. ADDITIONAL PROVISIONS

The Contractor will prepare the following reports on the additional tasks performed during the period July 1, 1977, through September 30, 1977.

(a) A report which summarizes the results of the reconnaissance investigation of the geothermal reservoir potential in the upper Centennial and Madison River Valleys will be prepared. The report will be based on a synthesis of existing geologic, hydrologic, geophysical, and geochemical data.

(b) A plan for the assessment of the geothermal potential of the Madison aquifer in the central and eastern Montana will be prepared. The plan will incorporate related programs of other State and Federal agencies.

In addition, the Contractor will submit a statement of costs for the additional tasks performed during the period July 1, 1977 through September 30, 1977.

The requirements for reports for previously funded work remain the same.

4. All other terms and conditions of this Task Agreement remain in full force and effect.

MODIFICATION NO. A001 TO
TASK AGREEMENT NO. 2 UNDER
CONTRACT NO. EY-76-S-06-2426

AGREED TO THIS ___19th___ DAY OF ___September___, 1977.

UNITED STATES OF AMERICA
UNITED STATES ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION

By: ____________________

Title: Chief, Contracts Branch

MONTANA SCHOOL OF MINERAL SCIENCE AND
TECHNOLOGY

By: ____________________

Title: Director of Research

ORIGINAL CONTRACT		Date	$
EY-76-S-06-2426		5-15-76 thru 5-14-77	$19,688
Mod. A001	EXT. TIME	5-15-77 to 5-14-78	
	NEW WORK	7-77 to 9-30-77	$12,899
Mod. A002	Coop NEW WORK	10-01-77 thru 9-30-79	$86,400
New Mod. A003 to be Approved	West Coop Prog New Work		$13,984

MONTANA
CONTRACT

MODIFICATION NO. A002 TO TASK AGREEMENT NO. 2
UNDER CONTRACT NO. EY-76-S-06-2426 BETWEEN THE
UNITED STATES DEPARTMENT OF ENERGY (DOE) AND
MONTANA COLLEGE OF MINERAL SCIENCE AND
TECHNOLOGY (CONTRACTOR)

TITLE: RECONNAISSANCE LOW AND MODERATE TEMPERATURE GEOTHERMAL SURVEY IN MONTANA (FORMERLY: A STUDY OF MINE WATER TEMPERATURES IN HARDROCK MINING DISTRICTS OF MONTANA)

Effective as of October 1, 1977, Task Agreement No. 2 is modified as follows:

1. The period of performance for the new work under this Task Agreement is extended for two years commencing October 1, 1977, and expiring September 30, 1979.

2. The Support Ceiling under this Task Agreement is increased by $86,400 to $118,987 in order to cover costs of conducting the new work described herein. These new tasks are to be conducted concurrently (through May 14, 1978) with work funded earlier, for which funds remain available under the contract.

3. The Research to be performed by the Contractor, the Ways and Means of Performance and the Total Estimated Cost thereof for the additional work to be performed during the period October 1, 1977, through September 30, 1979 are are follows:

A-I. RESEARCH TO BE PERFORMED BY CONTRACTOR

(a) Locate, sample and analyze all springs and wells in the Madison-Red Rock study area as a means of detecting possible hidden geothermal resources.

(b) Compile and analyze all available geologic and geophysical data relevant to potential geothermal resources in the study area.

(c) Develop models of the hydrologic systems within the Red Rock Creek and Madison River Valleys of southwestern Montana with emphasis on possible hydrothermal system development.

(d) Assist the U.S. Geological Survey and DOE in the update of the GEOTHERM data base for the State of Montana.

(e) Prepare a preliminary geothermal resource map for the State of Montana (scale 1:500,000), showing the known geographic distribution of low and moderate temperature geothermal resources.

Principal Investigator Dr. J. L. Sonderegger will devote 100 percent time for three months to the project.

A-II. WAYS AND MEANS OF PERFORMANCE

(a) Items for which support will be provided, as indicated in A-III below:

Type of Work Code (CIS): 3

||||

		Amount
(1)	Salaries and Wages (including fringe benefits)	$38,476
	Principal Investigator J. L. Sonderegger, 9 months Hydrogeologists Secretary Draftsman Hydrotechnician Student	
(2)	Equipment to be purchased or fabricated by the Contractor. Title is being vested with Contractor pursuant to the Grant Act (PL 85-934)	$ 4,500
	Comm-Stor RS-232	
(3)	Travel	
	Domestic	$ 7,500
	Foreign	$ - 0 -
(4)	Other Direct Costs	$18,225
(5)	Indirect costs based upon predetermined rate of 46% of direct salaries and wages	$17,699

(b) Items, if any, significant to the performance of this Task Agreement but excluded from computation of Support Cost and from consideration in proportioning cost:

(1) Items to be contributed by the Contractor.

In accordance with Article B-II(c) of the Basic Contract, if a proposed Contractor contribution is included in this paragraph (b)(1), the Contractor shall maintain records adequate to permit DOE to determine the extent of the contribution.

Salary of Principal Investigator for 3-1/2 months

(2) Items to be contributed by the Government.

None

(c) Time or effort of Principal Investigator contributed by Contractor but excluded from computation of Support Cost and from consideration in proportioning costs:

None

A-III. TOTAL ESTIMATED COST

The total estimated cost of items under A-II(a) above for the contract period stated in this Task Agreement is $86,400; DOE will pay 100 percent of the actual costs of these items incurred during the contract period stated in this Task Agreement, contingent upon apportionment of DOE funds by Office of Management and Budget, and subject to the provisions of Article IV and Article B-XXVII of the Basic Contract. The estimated DOE Support Cost for the contract period stated in this Task Agreement is $86,400.

The estimated ERDA Support Cost is funded as follows:	Amount
(a) Estimated unexpended balance from the prior period(s)	$ - 0 -
(b) New funds for the current period	[redacted]

The new funds being added in A-III(b) constitute the basis for advance payments provided under Article B-XI.

A-IV ADDITIONAL PROVISIONS

The Contractor will prepare the following reports on the new tasks to be performed during the period October 1, 1977, through September 30, 1979.

(a) A report detailing the geothermal potential of the upper Madison River Valley and Red Rock Creek area, southwestern Montana. The report will include analysis and interpretations of the water chemistry sampling program, the results of attempts to model the hydrologic system, and recommendations as to potential geothermal reservoirs suitable for development.

(b) A Montana geothermal data file of water analysis prepared for incorporation into the GEOTHERM data base.

(c) A preliminary State map (scale 1:500,000) showing the distribution of known geothermal resources in the State of Montana.

Monthly letter reports, quarterly reports, semiannual and annual technical progress reports, and a final report shall be submitted in accordance with the attached reporting guidelines.

The requirements for reports for previously funded work remain the same.

4. All other terms and conditions of this Task Agreement remain in full force and effect.

AGREED TO THIS Fifteenth DAY OF March, 1978

UNITED STATES OF AMERICA
UNITED STATES DEPARTMENT OF ENERGY

By: [signature]

Title: Chief, Laboratory & University Contracts Branch

MONTANA SCHOOL OF MINERAL SCIENCE AND TECHNOLOGY

By: [signature]

Title: Director of Research

GEOTHERMAL ENERGY DEVELOPMENT PROGRAM
REPORT REQUIREMENTS

Montana College of Mineral Science and Technology
(Contractor)

EY-76-S-06-2426
(P/R Number)

Reports

General reporting requirements for ERDA/DGE contractors are presented in ERDA-76/72 "Requirements and Procedures for Reporting Geothermal Information" dated July 1976. Reports should be prepared for this contract as follows:

	Frequency	Draft to Program Manager for Concurrence	Distribution Program Manager	Distribution TIC
Administrative Letter Report	Monthly	N/A	10	N/A
Technical Progress Report	Quarterly	3 weeks after end of reporting period	10	1 camera-ready copy
Final Report	Completion of contract effort	3 weeks after end of reporting period	10	1 camera-ready copy
Topical Reports	as required	as agreed with Program Manager	10	1 camera-ready copy

Reports Formats

The following will apply to all technical progress reports, topical reports and final reports:

(a) The cover page will be supplied by ERDA/DGE unless the contractor intends to use his corporate cover.

(b) Reports under this contract will all carry the number RLO/2426/T- . Report numbers will be assigned sequentially.

(c) The distribution category for reports prepared under this contract will be UC-66a3 as defined on page 16 of ERDA-76/72.

Maggie

MONTANA BUREAU OF MINES AND GEOLOGY
MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
BUTTE, MONTANA 59701
(406) 792-8321

Proposed
MOD A003
$34,400
Δ workscope
never approved -
as of 2/19/78

May 1, 1978

RECEIVED
MAY 4 1978
GEOTHERMAL ENERGY
BRANCH

Dr. Clayton Nichols
Division of Geothermal Energy
U.S. Department of Energy
Third Floor
20 Massachusetts Avenue, NW
Washington, D.C. 20545

Dear Dr. Nichols:

This is a cover letter with the proposal for adjustment of task goals as per our conversation yesterday (4/26/78) in Salt Lake City. On the advice of Sandra Smith (Richland contracts office) I am sending these proposals directly to you, and splitting the changes into two areas: one group of tasks not requiring new funds during this fiscal year, and a second task requiring additional funds during this fiscal year. The proposals follow the same logic expressed in my letter to you on 4/14/78 of this year.

Copies of the proposals will be sent to Sandra Smith and Maggie Widmayer to facilitate communication on the proposed changes.

Upon return from Salt Lake City, discussions with Dr. Charles Wideman were held concerning the establishment of an ongoing summer program of geophysical investigations at sites that have potential for direct application. They currently have adequate gravity, magnetic, and seismic equipment, and new resistivity equipment has been ordered. I would like to try merging their program with ours for the coming summer to see what kind of product can be obtained. If the results are good, I would then like to utilize the Department of Geophysics at the Montana College of Mineral Science and Technology in future summers at about the $15-20 K funding level. The proposed budget for their services for this summer has been kept down (10 K) by underestimating Wideman's time and providing all equipment rental costs.

Sincerely,

John

John Sonderegger
Hydrogeologist

JS:ch

Enclosures

Proposed Contract [redacted] to Task Agreement No. 2
under Contract No. EY-76-S-06-2426,
May 1, 1978, through September 30, 1978

Task Description:

$34,000 Δ work scope

1) Inventory approximately fifty thermal springs measuring temperature, discharge, pH, and specific conductance, by June 30, 1978, plus collection of selected samples for laboratory analysis.

2) Start the assistance program to state and local government to assist in evaluation of geothermal resource potential for direct application.

3) Attempt to expand the number of known thermal springs by investigating areas with suggestive geographic names and areas of orally reported but unconfirmed warm springs or shallow warm wells.

4) Start the transfer of ground-water chemical data (which includes field temperature) to the U.S. Geological Survey W.R.D. data file. It is estimated that data for 1,000 wells would be transfered by September 30, 1978.

A003 Modification

Budget for May 1, 1978, through September 30, 1978
(Requires reallocation of existing funds
but no new funding needed in FY 78)

		Federal	State
A.	Salaries, Wages, and Benefits		
	P.I., Sonderegger - 1 mo.	$	$1,647
	Hydrogeologist - 3 mo.	4,380	
	Technicians and students	2,000	
	Total salaries	$ 6,380	$1,647
	Benefits (14.5% of salaries)	925	239
	Salaries plus benefits	$ 7,305	$1,886
B.	Travel and Per Diem (100 days @ $62.50/day assuming 150 miles/day @ $.25/mile)	6,250	—
C.	Field Equipment, Supplies, and Research Materials	500	—
D.	Computer Applications (1,000 back analyses @ $16)	16,000	—
E.	Report costs	—	250
F.	Laboratory Costs (20 standard water analyses @ $50)	1,000	—
G.	Contingencies	—	250
H.	Indirect Costs (46% of A)	3,360	868
I.	Total Costs	[redacted]	$3,254

Signature Sheet

Proposed Budget Modification A003
(Federal $34,415; State $3,254)

Submitted by:

J L Sonderegger 5/1/78
Dr. J. L. Sonderegger
Hydrogeologist
Montana Bureau of Mines
and Geology

Approved by:

Dr. S. L. Groff, Director
and State Geologist
Montana Bureau of Mines
and Geology

Vernon Griffiths
Dr. Vernon Griffiths
Director of Research
Montana College of Mineral

Dr. Clayton Nichols
U.S. Department of Energy
Division of Geothermal Energy

Proposed Contract Modification A004, to Task Agreement No. 2
under Contract No. EY-76-S-06-2426,
May 1, 1978, through September 30, 1978

Task Description:

1) Start the West Yellowstone investigation as outlined in the November 1977 proposal.

2) Provide eight weeks of geophysical investigations at selected hot spring sites to increase knowledge about these areas and aid in selecting drill hole sites for communities.

A004 Modification

Budget for May 1, 1978, through September 30, 1978
(Requires additional funding in FY 78)

		Federal	State
A.	Salaries, Wages, and Benefits		
	P.I., Sonderegger - 1 mo.	$	$1,647
	Hydrogeologist - 4 mo.	4,667	
	Technician - ½ mo.	500	
	Geophysicist - 1 mo.	2,080	
	Students - 6 mo.	4,412	
	Total Salaries	$11,659	$1,647
	Benefits (14.5% of salaries)	1,691	239
	Total Salaries plus Benefits	$13,350	$1,886
B.	Travel and Per Diem	7,200	—
C.	Field Equipment, Supplies, and Research Materials	500	—
D.	Computer Applications	500	—
E.	Report Costs	500	250
F.	Contingencies	1,000	—
G.	Geophysical Equipment Rental	—	3,210
H.	Indirect Costs (46% of A)	6,141	868
I.	Total Costs	$29,191	$6,214

Signature Sheet

Proposed Budget Modification A004
(Federal $29,191; State $6,214)

Submitted by:

J L Sonderegger 5/1/78

Dr. J. L. Sonderegger
Hydrogeologist
Montana Bureau of Mines
and Geology

C Wideman

Dr. C. Wideman
Associate Professor of Geophysics
Montana College of Mineral
Science and Technology

Approved by:

S. L. Groff

Dr. S. L. Groff, Director
and State Geologist
Montana Bureau of Mines
and Geology

Vernon Griffiths

Dr. Vernon Griffiths
Director of Research
Montana College of Mineral
Science and Technology

Dr. Clayton Nichols
U.S. Department of Energy
Division of Geothermal Energy

MODIFICATION NO. A002 TO TASK AGREEMENT NO. 2
UNDER CONTRACT NO. EY-76-S-06-2426 BETWEEN THE
UNITED STATES DEPARTMENT OF ENERGY (DOE) AND
MONTANA COLLEGE OF MINERAL SCIENCE AND
TECHNOLOGY (CONTRACTOR)

TITLE: RECONNAISSANCE LOW AND MODERATE TEMPERATURE GEOTHERMAL SURVEY IN MONTANA (FORMERLY: A STUDY OF MINE WATER TEMPERATURES IN HARDROCK MINING DISTRICTS OF MONTANA)

Effective as of October 1, 1977, Task Agreement No. 2 is modified as follows:

1. The period of performance for the new work under this Task Agreement is extended for two years commencing October 1, 1977, and expiring September 30, 1979.

2. The Support Ceiling under this Task Agreement is increased by $86,400 to $118,987 in order to cover costs of conducting the new work described herein. These new tasks are to be conducted concurrently (through May 14, 1978) with work funded earlier, for which funds remain available under the contract.

3. The Research to be performed by the Contractor, the Ways and Means of Performance and the Total Estimated Cost thereof for the additional work to be performed during the period October 1, 1977, through September 30, 1979 are are follows:

A-I. RESEARCH TO BE PERFORMED BY CONTRACTOR

(a) Locate, sample and analyze all springs and wells in the Madison-Red Rock study area as a means of detecting possible hidden geothermal resources.

(b) Compile and analyze all available geologic and geophysical data relevant to potential geothermal resources in the study area.

(c) Develop models of the hydrologic systems within the Red Rock Creek and Madison River Valleys of southwestern Montana with emphasis on possible hydrothermal system development.

(d) Assist the U.S. Geological Survey and DOE in the update of the GEOTHERM data base for the State of Montana.

(e) Prepare a preliminary geothermal resource map for the State of Montana (scale 1:500,000), showing the known geographic distribution of low and moderate temperature geothermal resources.

Principal Investigator Dr. J. L. Sonderegger will devote 100 percent time for three months to the project.

A-II. WAYS AND MEANS OF PERFORMANCE

(a) Items for which support will be provided, as indicated in A-III below:

Type of Work Code (CIS): 3

Requested 1st 45%, #35,000, 4/13/78 JF

		Amount
(1)	Salaries and Wages (including fringe benefits)	$38,476
	Principal Investigator J. L. Sonderegger, 9 months Hydrogeologists Secretary Draftsman Hydrotechnician Student	
(2)	Equipment to be purchased or fabricated by the Contractor. Title is being vested with Contractor pursuant to the Grant Act (PL 85-934)	$ 4,500
	Comm-Stor RS-232	
(3)	Travel	
	Domestic	$ 7,500
	Foreign	$ - 0 -
(4)	Other Direct Costs	$18,225
(5)	Indirect costs based upon predetermined rate of 46% of direct salaries and wages	$17,699

(b) Items, if any, significant to the performance of this Task Agreement but excluded from computation of Support Cost and from consideration in proportioning cost:

(1) Items to be contributed by the Contractor.

In accordance with Article B-II(c) of the Basic Contract, if a proposed Contractor contribution is included in this paragraph (b)(1), the Contractor shall maintain records adequate to permit DOE to determine the extent of the contribution.

Salary of Principal Investigator for 3-1/2 months

(2) Items to be contributed by the Government.

None

(c) Time or effort of Principal Investigator contributed by Contractor but excluded from computation of Support Cost and from consideration in proportioning costs:

None

A-III. TOTAL ESTIMATED COST

The total estimated cost of items under A-II(a) above for the contract period stated in this Task Agreement is $86,400; DOE will pay 100 percent of the actual costs of these items incurred during the contract period stated in this Task Agreement, contingent upon apportionment of DOE funds by Office of Management and Budget, and subject to the provisions of Article IV and Article B-XXVII of the Basic Contract. The estimated DOE Support Cost for the contract period stated in this Task Agreement is $86,400.

The estimated ERDA Support Cost is funded as follows:	Amount
(a) Estimated unexpended balance from the prior period(s)	$ - 0 -
(b) New funds for the current period	$86,400

The new funds being added in A-III(b) constitute the basis for advance payments provided under Article B-XI.

A-IV ADDITIONAL PROVISIONS

The Contractor will prepare the following reports on the new tasks to be performed during the period October 1, 1977, through September 30, 1979.

(a) A report detailing the geothermal potential of the upper Madison River Valley and Red Rock Creek area, southwestern Montana. The report will include analysis and interpretations of the water chemistry sampling program, the results of attempts to model the hydrologic system, and recommendations as to potential geothermal reservoirs suitable for development.

(b) A Montana geothermal data file of water analysis prepared for incorporation into the GEOTHERM data base.

(c) A preliminary State map (scale 1:500,000) showing the distribution of known geothermal resources in the State of Montana.

Monthly letter reports, quarterly reports, semiannual and annual technical progress reports, and a final report shall be submitted in accordance with the attached reporting guidelines.

The requirements for reports for previously funded work remain the same.

MODIFICATION NO. A002 TO
TASK AGREEMENT NO. 2 UNDER
CONTRACT NO. EY-76-S-06-2426

4. All other terms and conditions of this Task Agreement remain in full force and effect.

AGREED TO THIS Fifteenth DAY OF March, 1978

UNITED STATES OF AMERICA
UNITED STATES DEPARTMENT OF ENERGY

By: [signature]
Title: Chief, Laboratory & University Contracts Branch

MONTANA SCHOOL OF MINERAL SCIENCE AND TECHNOLOGY

By: Vernon Griffiths
Title: Director of Research

GEOTHERMAL ENERGY DEVELOPMENT PROGRAM
REPORT REQUIREMENTS

Montana College of Mineral Science and Technology
(Contractor)

EY-76-S-06-2426
(P/R Number)

Reports

General reporting requirements for ERDA/DGE contractors are presented in ERDA-76/72 "Requirements and Procedures for Reporting Geothermal Information" dated July 1976. Reports should be prepared for this contract as follows:

	Frequency	Draft to Program Manager for Concurrence	Distribution Program Manager	Distribution TIC
Administrative Letter Report	Monthly	N/A	10	N/A
Technical Progress Report	Quarterly	3 weeks after end of reporting period	10	1 camera-ready copy
Final Report	Completion of contract effort	3 weeks after end of reporting period	10	1 camera-ready copy
Topical Reports	as required	as agreed with Program Manager	10	1 camera-ready copy

Reports Formats

The following will apply to all technical progress reports, topical reports and final reports:

(a) The cover page will be supplied by ERDA/DGE unless the contractor intends to use his corporate cover.

(b) Reports under this contract will all carry the number RLO/2426/T2 - Report numbers will be assigned sequentially.

(c) The distribution category for reports prepared under this contract will be UC-66a3 as defined on page 16 of ERDA-76/72.

Maggie

MONTANA BUREAU OF MINES AND GEOLOGY
MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
BUTTE, MONTANA 59701
(406) 792-8321

Proposed
Mod A003
$34,400
A work scope
never approved!
As of 7/19/78

May 1, 1978

RECEIVED
MAY 4 1978
GEOTHERMAL ENERGY
BRANCH

Dr. Clayton Nichols
Division of Geothermal Energy
U.S. Department of Energy
Third Floor
20 Massachusetts Avenue, NW
Washington, D.C. 20545

Dear Dr. Nichols:

This is a cover letter with the proposal for adjustment of task goals as per our conversation yesterday (4/26/78) in Salt Lake City. On the advice of Sandra Smith (Richland contracts office) I am sending these proposals directly to you, and splitting the changes into two areas: one group of tasks not requiring new funds during this fiscal year, and a second task requiring additional funds during this fiscal year. The proposals follow the same logic expressed in my letter to you on 4/14/78 of this year.

Copies of the proposals will be sent to Sandra Smith and Maggie Widmayer to facilitate communication on the proposed changes.

Upon return from Salt Lake City, discussions with Dr. Charles Wideman were held concerning the establishment of an ongoing summer program of geophysical investigations at sites that have potential for direct application. They currently have adequate gravity, magnetic, and seismic equipment, and new resistivity equipment has been ordered. I would like to try merging their program with ours for the coming summer to see what kind of product can be obtained. If the results are good, I would then like to utilize the Department of Geophysics at the Montana College of Mineral Science and Technology in future summers at about the $15-20 K funding level. The proposed budget for their services for this summer has been kept down (10 K) by underestimating Wideman's time and providing all equipment rental costs.

Sincerely,

John

John Sonderegger
Hydrogeologist

JS:ch

Enclosures

Proposed Contract Modification A003, to Task Agreement No. 2
under Contract No. EY-76-S-06-2426,
May 1, 1978, through September 30, 1978

Task Description:

1) Inventory approximately fifty thermal springs measuring temperature, discharge, pH, and specific conductance, by June 30, 1978, plus collection of selected samples for laboratory analysis.

2) Start the assistance program to state and local government to assist in evaluation of geothermal resource potential for direct application.

3) Attempt to expand the number of known thermal springs by investigating areas with suggestive geographic names and areas of orally reported but unconfirmed warm springs or shallow warm wells.

4) Start the transfer of ground-water chemical data (which includes field temperature) to the U.S. Geological Survey W.R.D. data file. It is estimated that data for 1,000 wells would be transfered by September 30, 1978.

A003 Modification

Budget for May 1, 1978, through September 30, 1978
(Requires reallocation of existing funds
but no new funding needed in FY 78)

		Federal	State
A.	Salaries, Wages, and Benefits		
	P.I., Sonderegger - 1 mo.	$	$1,647
	Hydrogeologist - 3 mo.	4,380	
	Technicians and students	2,000	
	Total salaries	$ 6,380	$1,647
	Benefits (14.5% of salaries)	925	239
	Salaries plus benefits	$ 7,305	$1,886
B.	Travel and Per Diem (100 days @ $62.50/day assuming 150 miles/day @ $.25/mile)	6,250	—
C.	Field Equipment, Supplies, and Research Materials	500	—
D.	Computer Applications (1,000 back analyses @ $16)	16,000	—
E.	Report costs	—	250
F.	Laboratory Costs (20 standard water analyses @ $50)	1,000	—
G.	Contingencies	—	250
H.	Indirect Costs (46% of A)	3,360	868
I.	Total Costs	$34,415	$3,254

MODIFICATION NO. A003 TO TASK AGREEMENT NO. 2
UNDER CONTRACT NO. EY-76-S-06-2426 BETWEEN
THE UNITED STATES DEPARTMENT OF ENERGY (DOE) AND
MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY (CONTRACTOR)

TITLE: Reconnaissance Low and Moderate Temperature Geothermal Survey in Montana

Effective as of June 1, 1978, Task Agreement No. 2 is modified as follows:

1. The Support Ceiling under this Task Agreement is increased by $13,984 to $132,971 in order to cover costs of conducting the new work described herein during the period June 1, 1978, through September 30, 1978. This new work is to be conducted concurrently with work funded earlier, for which funds remain available under the contract.

2. The Research to be performed by the Contractor, the Ways and Means of Performance and the Total Estimated Cost thereof for the additional work to be performed during the period June 1, 1978, through September 30, 1978 are as follows:

A-I. RESEARCH TO BE PERFORMED BY CONTRACTOR

The Contractor will conduct geologic and geographical logging on exploration wells to be drilled in the Deer Lodge Valley area of Montana. Principle Investigator Dr. John Sonderegger will devote approximately one week's time to the project.

A-II. WAYS AND MEANS OF PERFORMANCE

	Amount
(a) Items for which support will be provided, as indicated in A-III below:	
(1) Salaries and Wages (including fringe benefits)	$6,907
Geophysicist - 1 1/2 months 2 Students - 2 months	
(2) Equipment to be purchased or fabricated by the Contractor. Title is being vested with Contractor pursuant to the Grant Act (PL 85-934)	$ -0-

Type of Work Code (CIS): 3

Requested 1st 45%, $6,293.00 9/1/78

(3) Travel

Domestic	$1,138
Foreign	$ -0-

(4) Other Direct Costs	$2,900
(5) Indirect costs based upon predetermined rate of 44% of direct salaries and wages	$3,039

(b) Items, if any, significant to the performance of this Task Agreement but excluded from computation of Support Cost and from consideration in proportioning cost:

(1) Items to be contributed by the Contractor.

In accordance with Article B-II(c) of the Basic Contract, if a proposed Contractor contribution is included in this paragraph (b)(1), the Contractor shall maintain records adequate to permit DOE to determine the extent of the contribution.

None

(2) Items to be contributed by the Government.

None

(c) Time or effort of Principle Investigator contributed by the Contractor but excluded from computation of Support Cost and from consideration in proportioning costs:

One week

A-III. TOTAL ESTIMATED COST

The total esitmated cost of items under A-II(a) above for the contract period stated in this Task Agreement is $13,984; DOE will pay 100 percent of the actual costs of these items incurrred during the contract period stated in this Task Agreement, subject to the provisions of Article IV and Article B-XXVII of the Basic Contract. The estimated DOE Support Cost for the contract period stated in this Task Agreement is $13,984.

The estimated DOE Support Cost is funded as follows:	Amount
(1) Estimated unexpended balance from the prior period(s)	$ -0-
(2) New funds for the current period	$13,984

The new funds being added in A-III(b) constitute the basis foradvance payments provided under Article B-XI.

3. All other terms and conditions of this Task Agreement remain in full force and effect.

AGREED TO THIS 25th DAY OF August, 1978

UNITED STATES OF AMERICA
UNITED STATES DEPARTMENT OF ENERGY

By: [signature]
Title: Contracting Officer

Montana College of Mineral Science and Technology

By: [signature]
Title: Director of Research

Proposed Contract Modification A004, to Task Agreement No. 2
under Contract No. EY-76-S-06-2426,
May 1, 1978, through September 30, 1978

Task Description:

1) Start the West Yellowstone investigation as outlined in the November 1977 proposal.

2) Provide eight weeks of geophysical investigations at selected hot spring sites to increase knowledge about these areas and aid in selecting drill hole sites for communities.

A004 Modification

Budget for May 1, 1978, through September 30, 1978
(Requires additional funding in FY 78)

		Federal	State
A.	Salaries, Wages, and Benefits		
	P.I., Sonderegger - 1 mo.	$	$1,647
	Hydrogeologist - 4 mo.	4,667	
	Technician - ½ mo.	500	
	Geophysicist - 1 mo.	2,080	
	Students - 6 mo.	4,412	
	Total Salaries	$11,659	$1,647
	Benefits (14.5% of salaries)	1,691	239
	Total Salaries plus Benefits	$13,350	$1,886
B.	Travel and Per Diem	7,200	—
C.	Field Equipment, Supplies, and Research Materials	500	—
D.	Computer Applications	500	—
E.	Report Costs	500	250
F.	Contingencies	1,000	—
G.	Geophysical Equipment Rental	—	3,210
H.	Indirect Costs (46% of A)	6,141	868
I.	Total Costs	$29,191	$6,214

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO. M004
2. EFFECTIVE DATE
3. REQUISITION/PURCHASE REQUEST NO.
4. PROJECT NO. (If applicable)

5. ISSUED BY CODE
U.S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR CODE FACILITY CODE
NAME AND ADDRESS (Street, city, county, state, and ZIP Code)
Montana College of Mineral Science and Technology
Butte, Montana 59701
Attn: John Dunstan

8. ☐ AMENDMENT OF SOLICITATION NO. ________
DATED ________ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. Task Agreement No. 2 to DE-AS07-76ID1202
(Formerly EY-76-S-06-2426)
DATED 4/19/76 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS
☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.
Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:
(a) By signing and returning ____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS
(a) ☐ This Change Order is issued pursuant to ________
The Changes set forth in block 12 are made to the above numbered contract/order.
(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.
(c) ☒ This Supplemental Agreement is entered into pursuant to authority of mutual agreement of the parties.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

As requested by letter dated November 14, 1979, the period of performance for Task Agreement No. 2 is extended from September 30, 1979, to June 30, 1980.

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☒ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☐ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN ____ COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY ________ (Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY [signature] (Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print)
16. DATE SIGNED

18. NAME OF CONTRACTING OFFICER (Type or print)
J. P. Anderson, Chief
Contract Administration Branch

19. DATE SIGNED 2/1/80

File M.2.4
Contract # 2426

DEC 21 1978

RECEIVED
DEC 22 1978
GEOTHERMAL ENERGY BRANCH

Dr. Vernon Griffiths
Director of Research
Montana College of Mineral Science
and Technology
Butte, Montana 59701

Subject: CONTRACT NO. EY-76-S-06-2426 — Change to DE-AS07-76ID12029 (?)

[PRESENT CONTRACT NO 79ID12033]

Dear Dr. Griffiths:

As discussed by telephone between J. O. Lee of my staff and John Dunsten of Montana College of Mineral Science and Technology, the subject contract has been transferred to the DOE Idaho Operations Office for administering. All future invoices and business correspondence should be directed to the following address:

U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

ATTENTION: R. E. Simonds, Director
Contracts Management Division

The amounts listed below have been paid under the contract which leaves a balance of $64,273.80 against the Task Agreement (TA) No. 2 of the contract:

1. TA No. 2:	
1st 45%	$8,859.60
2nd 45%	8,859.60
2. TA No. 2 Mod A001:	
1st 45%	5,805.00
3. TA No. 2 Mod. A002:	
1st 45%	38,880.00
4. TA No. 2 Mod. A003:	
1st 45%	6,293.00
Total Paid to Date:	$68,697.20

The contract number is also changed from EY-76-S-06-2426 to ~~DE-AT07-76ET28415~~. DE-AS07-76ID12029

If you have further questions concerning this contract please direct them to J. O. Lee at telephone 208-526-1838.

Very truly yours,

Original Signed By
R. E. Simonds

R. E. Simonds, Director
Contracts Management Division

bcc: Ruth Nelson
✓L. L. Mink
E. G. Jones

CAB	RDB	FMD	CMD
JOLee:ahb	LLMink	EGJones	RESimonds
JPAnderson			
12/19/78			

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO.: M005
2. EFFECTIVE DATE: 6-30-80
3. REQUISITION/PURCHASE REQUEST NO.:
4. PROJECT NO. *(If applicable)*:

5. ISSUED BY — CODE:
U.S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY *(If other than block 5)* — CODE:

M. 2. 4

7. CONTRACTOR NAME AND ADDRESS — CODE: — FACILITY CODE:
(Street, city, county, state, and ZIP Code)

Montana College of Mineral Science
and Technology
Butte, Montana 59701

Attn: John Dunstan

8. ☐ AMENDMENT OF SOLICITATION NO. ?
DATED ______ *(See block 9)*
Task Agreement No. 2 to
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-AS07-76ID12029
(formerly EY-76-S-06-2426)
DATED 4-19-76 *(See block 11)*

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning ______ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGEMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA *(If required)*

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☐ This Change Order is issued pursuant to ______
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Mutual Agreement of the Parties
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

Pursuant to Participant's letter dated June 23, 1980, the period of performance for Task Agreement No. 2 is extended from June 30, 1980 to December 30, 1980.

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☒ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☐ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN ______ COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY ______
(Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY ______
(Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER *(Type or print)*

16. DATE SIGNED

18. NAME OF CONTRACTING OFFICER *(Type or print)*
Nell W. Fraser

19. DATE SIGNED
JUL 1 1 1980

DOE FORM-152 Rev. 10-77

U. S. DEPARTMENT OF ENERGY

COOPERATIVE AGREEMENT

PURSUANT TO AUTHORITY OF PL 93-410, PL 93-438, PL 93-473, PL 93-577, and PL 95-91

1a. Agreement No.: DE-FC07-79ID12033

1b. Modification No.:

2. Agreement Period
From: February 15, 1979 To: February 14, 1980

3. Participant Name and Address
Montana College of Mineral Science and Technology
Butte, Montana 59701

4. Participant Type
- [x] Educational
- [ ] Nonprofit
- [ ] State or Local Government
- [ ] Profit

5. Project Title
Additional Geothermal Studies in Montana

6. Project Will Be Conducted Per
See Article I

7. Technical Reports Are Required
See Article VI

8. Principal Investigator(s) or Program Director(s) Name and Address
John L. Sonderegger
Montana College of Mineral Science & Technology, Montana Bureau of Mines & Geology, Butte, Montana 59701

9. DOE Program Officer (Name and Address)
L. L. Mink, Resource Definition Branch
DOE - Idaho Operations Office
550 Second St., Idaho Falls, ID 83401
Telephone No. 208-526-0638

10. Accounting and Appropriation Data

11. Method of Payment
- [ ] % At Award. % When Requested. % Upon Receipt of Final Report
- [ ] Letter of Credit
- [ ] Reimbursement
- [x] Other (specify) See Article III

12. Submit Vouchers, if any, to Agreements Officer Unless Otherwise Specified in this Block
Director, Contracts Management Div., Idaho Operations Office
550 Second St., Idaho Falls, ID 83401

13. Funding Sources

Source	Amount
DOE	$ 99,917.00
Participant	$ 10,778.00
Total Funding:	$ 110,695.00

14. Remarks:

15. Amount Obligated By This Action $ 99,917.00

16. DOE Issuing Office (Name and Address)
Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401

COOPERATIVE AGREEMENT

THIS AGREEMENT, effective the 26th day of February 1979, by and between the UNITED STATES OF AMERICA (hereinafter called the "Government"), acting through the DEPARTMENT OF ENERGY (hereinafter called "DOE") and MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY (hereinafter called the "Participant") located at Butte, Montana;

WITNESSETH THAT:

WHEREAS, the Participant began performing research as a Contractor to DOE under Contract No. EY-76-S-06-2426, leading to development of geothermal resources in the State of Montana; and

WHEREAS, DOE is interested in continuing the work that was started under Contract No. EY-76-S-06-2426; and

WHEREAS, the Participant has submitted a proposal to continue work and DOE desires to furnish financial assistance for completion of this work; and

WHEREAS, this Agreement is authorized by the Department of Energy Organization Act (Public Law 95-91), Sections 7(a)(2) and 8 of Public Law 93-577, and Sections 103(5) and 107(a) of Public Law 93-438;

NOW, THEREFORE, DOE and the Participant agree as follows:

ARTICLE I - DESCRIPTION OF RESPONSIBILITIES

Responsibilities - The Participant shall furnish a statewide inventory of known geothermal resources, compile data and transfer data to federal data banks, compile and update maps, assist other invetigators working in Montana, and assist local and state Government agencies concerning utilization of geothermal resources. This work shall include the following in accordance with Participant's Proposal titled "Additional Geothermal Studies in Montana," incorporated herein by reference and made a part hereof:

1. Complete the Centennial Valley project.

2. Provide geophysical information (especiallv-seismic) about "valley structure" in the vicinity of known hot springs, and hydrogeologic studies and selected hot springs.

3. Complete the transfer of ground-water data to the U. S. Geological Survey, Water Resources Division data banks.

ARTICLE I - DESCRIPTION OF RESPONSIBILITIES (Cont'd)

4. Begin a study of the geothermal resources in the vicinity of West Yellowstone, Montana.

5. Meet goals and deadlines for data compilation, temperature-gradient studies, and map presentation of various data bases.

6. Evaluate the ability of airborn heat-sensing imagery to detect the discharge of thermal waters to major streams.

7. Conduct test drilling at Ennis or in the Deer Lodge Valley, depending upon the interpretation of the geophysical data for these areas.

ARTICLE II - ESTIMATE OF COST AND OBLIGATION OF FUNDS

A. The total estimated cost of performing the work under this Agreement is One Hundred Ten Thousand Six Hundred Ninety-Five Dollars ($110,695.00). For performance of work under this Agreement, the agreed share ratio is 90.263% DOE, 9.736% Participant of total allowable costs. The Participant shall be reimbursed by DOE for not more than 90.263% of the costs of the project determined to be allowable in accordance with Article A-I of the General Provisions entitled "Allowable Costs." The remaining 9.763% or more of the costs of the project so determined shall constitute the Participant's share for which it will not be reimbursed by DOE. The total cost to DOE is hereby established as Ninety-Nine Thousand Nine Hundred Seventeen Dollars ($99,917.00) and this amount is also the maximum amount of the project which is subject to reimbursement by DOE unless such maximum cost is changed in writing by the Contracting Officer.

B. Final payment will not be made until the Final Report is received and accepted by the Contracting Officer. In no event will the final 5% of the amount of obligated funds be paid to the Participant until DOE has received the Final Report and the Final Cost Report described in Article VI A. of this Cooperative Agreement.

ARTICLE III - METHOD AND BASIS OF PAYMENT

A. The Participant shall receive 25% of DOE's share ($24,979.00) at the time this Agreement is executed. The balance becomes payable in periodic installments as requested by the Participant and approved by DOE. Requests for payment shall not be more frequent than monthly, and the request should contain a cost breakdown showing the amount requested, the total amount requested to date, and the total cost of the project to date, including the value of the Participant's cost sharing as provided for in Article II of this Agreement. The total amount paid by DOE will not exceed the amount specified in Article II.

ARTICLE III - METHOD AND BASIS OF PAYMENT (Cont'd)

B. Final payment will not be made until the Final Report is received and accepted by the Contracting Officer. In no event will the final 5% of the amount of obligated funds be paid to the Participant until DOE has received the Final Report and the Final Cost Report described in Article VI.A. of this Cooperative Agreement.

ARTICLE IV - TERM OF AGREEMENT

Work under this Agreement shall be accomplished during the period from February 15, 1979 through February 14, 1980. The period of this Agreement may be extended as mutually agreed upon by DOE and the Participant.

ARTICLE V - PROJECT MANAGEMENT, DEFINITIONS AND REPORTING

A. In addition to DOE personnel, the Participant agrees to permit non-DOE personnel who are under contract with DOE, and identified from time to time by the Contracting Officer, to assist the DOE Project Manager in performance of his duties to have necessary access to the Participant's and/or major subcontractors' records pertaining to the project. All correspondence with the subcontractors from DOE will be made through the Participant.

B.1. DOE's Program Officer on this project and the person who shall be the Participant's contact for all matters pertaining to this Agreement shall be the following-named person or such other person(s) as may be designated by the Contracting Officer:

L. L. Mink
Resource Definition Branch
Idaho Operations Office, DOE
550 Second Street
Idaho Falls, Idaho 83401
Telephone 208-526-0638

2. The Participant's Project Director for the work under this Agreement will be the following person or such other person(s) as may be mutually acceptable to the parties:

John L. Sonderegger
Montana College of Mineral
Science and Technology
Montana Bureau of Mines & Geology
Butte, Montana 59701
Telephone 406-792-8321

ARTICLE V - PROJECT MANAGEMENT, DEFINITIONS AND REPORTING (Cont'd)

C. The term "DOE" means the United States Department of Energy or any duly authorized representative thereof, including the Contracting Officer except for the purpose of deciding an appeal under this article entitled "Disputes."

D. The term "Contracting Officer" means the person executing this Agreement on behalf of DOE, and includes his successors or any duly authorized representative of any such person.

ARTICLE VI - PROJECT INFORMATION

A. The following reports, as required by DOE Uniform Contractor Reporting System, Volume 1, February 1978, shall be submitted to the DOE Program Officer:

Type	Frequency	Draft to Program Officer for Concurrence	Distribution Program Officer	TIC
Contract Management Summary Report	Monthly	N/A	8	N/A
Technical Status Report	Monthly	N/A	8	N/A
Hotline Report	As Required	N/A	8	N/A
Final Report	Completion of Contract	3 weeks after end of reporting period	8	1 camera-ready copy

B. Content of Reports

(1) Contract Management Summary Report - A single-page graphic presentation of integrated cost; major milestones, and manpower for rapid visual analysis and trend forecasting.

(2) Technical Status Report - A periodic report to communicate to DOE management an assessment of contract status; explain variances and problems; and discuss any other areas of concern or achievements.

(3) Hot Line Report - A hardcopy report by the fastest means available (TWX, etc.) documenting critical problems, emergency situations, and important technical breakthroughs.

ARTICLE VI - PROJECT INFORMATION (Cont'd)

(4) Final Technical Report - Very comprehensive report outlining objectives, accomplishments, problems encountered, and steps taken to overcome problems. Plan set forth in Task V of Article A-I shall be included in the final report.

ARTICLE VII - CHANGES AND MODIFICATIONS

Any changes or modifications to this Agreement or in the scope of work to be performed shall be made by mutual written agreement of the parties. A change may be initiated by either party to this Agreement. The Contracting Officer shall have the authority to determine what constitutes a change.

ARTICLE VIII - TERMINATION

A. It is the express intent of DOE and the Participant to fund their respective cost participation for the project.

B. Notwithstanding the foregoing, it is understood that the Participant may at any time, upon giving sixty (60) days prior written notice to DOE, terminate this Agreement for its convenience for any reason.

C. In the event of termination, it is expected that the parties will cooperate with each other to reasonably phase out the Participant's costs and cost commitments, including cost liabilities to third parties; provided, however, that the total amount obligated by the Government under this Agreement shall not be exceeded. Moreover, upon any such termination the Participant agrees to promptly, upon DOE's request, transfer to DOE all information resulting from the work performed to the date of the termination notice.

D. In the event of termination, the Government agrees to pay the Participant 90.263% of all allowable costs for termination, and the Participant shall:

1. Place no further orders or subcontracts for materials, services, or facilities, intended to be invoiced to the Government for its contribution.

2. Terminate all orders and subcontracts to the extent that they relate to the performance of work terminated by the Notice of Termination and intended to be invoiced to the Government for its contribution.

3. Notwithstanding 1. and 2. above, the Participant has the right to proceed with such orders and subcontracts should it decide to continue performance of the work at its expense only.

ARTICLE VIII - TERMINATION (Cont'd)

E. After a termination, the Participant shall submit to the Contracting Officer its termination claim. Such claim shall be submitted promptly but in no event later than one (1) year from the effective date of termination unless one or more extensions in writing are granted by the Contracting Officer. Upon failure of the Participant to submit its termination claim within the time allowed, the Contracting Officer may determine, on the basis of information available to him, the amount, if any, due to the Participant by reason of the termination and shall thereupon pay to the Participant the amount so determined.

F. Costs claimed, agreed to, or determined pursuant to this article must constitute allowable costs as defined in Article A-1 of the Appendix A of this Agreement.

G. Any termination notice rendered by either DOE or the Participant shall be sent by registered mail with return receipt requested.

H. If in the opinion of DOE, the Participant fails to substantially perform under this Agreement, and does not cure such failure within a reasonable time, after written notice of such failure by the Contracting Officer, DOE may by written notice to the Participant terminate this Agreement. Such termination notice, signed by the Contracting Officer, shall be effective upon receipt by the Participant. The Government shall not be liable for the incurrence of any obligations under this Agreement from the date of the receipt of such termination notice. Upon any such termination, the Participant agrees to promptly, upon DOE's request, transfer to DOE all information resulting from the work performed to the date of the termination notice.

I. Except with respect to defaults of subcontractors, the Participant shall not be in default by reason of failure to substantially perform under this Agreement if such failure arises out of causes beyond the control and without the fault or negligence of the Participant. Such causes may include, but are not restricted to, acts of God or of the public enemy, acts of the Government in either its sovereign or contractual capacity, fires, floods, epidemics, quarantine restrictions, strikes, freight embargoes, and unusually severe weather, but in every case the failure to perform must be beyond the control and without the fault or negligence of the Participant. If the failure to substantially perform is caused by the failure of a subcontractor to perform or make progress, and if such failure arises out of causes beyond the control of both the Participant and a subcontractor, and without the fault or negligence of either of them, the Participant shall not be deemed to be in default unless the supplies or services to be furnished by the contractor were reasonably obtainable from other sources. Upon request of the Participant, if the Contracting Officer shall determine that failure to perform was occasioned by any one or more of the said causes, this Agreement shall be revised accordingly, subject to the rights of DOE under paragraph B. above.

ARTICLE IX - LIABILITY AND INDEMNIFICATION

The Government will not be liable for payment of damages for injuries to any person, or loss of life or personal property, or loss suffered or sustained and arising from the work performed under this Agreement. The Participant agrees to indemnify and save the Government harmless from any and all claims, demands, damages, actions, costs, or charges against the Government arising as the result of the above-mentioned injuries, damages, or loss, except for any such damages or claims arising out of the negligent act of the Government or its employees in the course of their official duties.

ARTICLE X - USE OF INFORMATION

All data and information generated, derived or obtained from the activities provided for herein, and this Agreement, will be public information.

ARTICLE XI - ADDITIONAL CONTRACT PROVISIONS

Appendix A, attached hereto and made a part hereof, sets forth additional general provisions of this Agreement.

IN WITNESS WHEREOF, the parties hereto have executed this document as of the day and year first above written.

THE UNITED STATES OF AMERICA

BY THE DEPARTMENT OF ENERGY

By ______________________
R. E. Simonds, Director
Contracts Management Division
Idaho Operations Office
Contracting Officer

Witnesses as to signature of Participant:

(Signature)

JOHN DUNSTAN
Name (typed)
Montana College of Mineral Science & Technology, Butte, MT 59701
(Address)

(Signature)

GLORIA WILLIAMS
Name (typed)
Montana College of Mineral Science & Technology, Butte, MT 59701
(Address)

MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY

By Vernon Griffiths

VERNON GRIFFITHS
Name (typed)

Title DIRECTOR OF RESEARCH
Montana College of Mineral Science & Technology, Butte, MT 59701
(Business Address)

I, VICTOR BURT, certify that I am the DIRECTOR OF FISCAL AFFAIRS of the Participant named under this document, that that VERNON GRIFFITHS, who signed this document on behalf of the Participant, was then DIRECTOR OF RESEARCH of said Participant; that said document was duly signed for and in behalf of said Participant by authority of its governing body, and is within the scope of its legal powers.

IN WITNESS WHEREOF, I have hereunto affixed my hand and the seal of said corporation this 16th day of February 1979.

~~Secretary~~
Director of Fiscal Affairs

(CORPORATE SEAL)

APPENDIX A
GENERAL PROVISIONS
COOPERATIVE AGREEMENTS

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APPENDIX A

GENERAL PROVISIONS

COOPERATIVE AGREEMENTS

ARTICLE A-I - ALLOWABLE COST

Costs shall constitute allowable costs as specified in Title 41, Code of Federal Regulations Part 1-15 of the Code of Federal Regulations in effect on the date of this Agreement.

ARTICLE A-II - APPROVAL OF SUBCONTRACTS

All subcontracts and purchase orders in excess of $10,000 shall require the written approval of the Contracting Officer.

ARTICLE A-III - PUBLIC INFORMATION RELEASES

The parties agree that public disclosure or dissemination of new data or information arising out of the feasibility assessment will be coordinated by the parties, it being understood that the intent of both the Participant and DOE is to release all data and information to the greatest practicable extent in order to achieve the objective of obtaining maximum public value from the results of this project. It is understood that the foregoing is not intended to afford either party the right to prevent a public release by the other; however, nothing in this article shall impair the rights of the parties set forth elsewhere in this Agreement, including but not necessarily limited to the article entitled "Patent Rights."

ARTICLE A-IV - AUDIT

A. The Participant shall maintain, and the Contracting Officer or his representative shall have the right to examine books, records, documents, and other evidence and accounting procedures and practices, sufficient to reflect properly all direct and indirect costs of whatever nature claimed to have been incurred and anticipated to be incurred for the performance of this Agreement. Such right of examination shall include inspection at all reasonable times of the Participant's plants, or such parts thereof, as may be engaged in the performance of this Agreement.

B. The materials described above, shall be made available at the office of the Participant, at all reasonable times, for inspection, audit or reproduction, until the expiration of three (3) years from the date of final payment under this Agreement or such lesser time specified in Title 41, Code of Federal Regulations Part 1-20 and for such lesser period, if any, as is required by applicable statute, or by other articles of this Agreement, or by (1) and (2) below:

ARTICLE A-IV - AUDIT (Cont'd)

(1) If this Agreement is completely or partially terminated, the records relating to the work terminated shall be made available for a period of three (3) years from the date of any resulting final settlement.

(2) Records which relate to appeals under the "Disputes" article of this Agreement, or litigation or the settlement of claims arising out of the performance of this Agreement, shall be made available until such appeals, litigation, or claims have been disposed of.

ARTICLE A-V - OFFICIALS NOT TO BENEFIT

No member of or delegate to Congress, or resident commissioner, shall be admitted to any share or part of this Agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this Agreement if made with a corporation for its general benefit.

ARTICLE A-VI - COVENANT AGAINST CONTINGENT FEES

The Participant warrants that no person or selling agency has been employed or retained to solicit or secure this Agreement upon an agreement or understanding for a commission, percentage brokerage, or contingent fee, excepting bona fide employees or bona fide established commercial or selling agencies maintained by the Participant for the purpose of securing business. For breach or violation of this warranty the Government shall have the right to annual this Agreement without liability or in its discretion to deduct from the Agreement price or consideration, or otherwise recover, the full amount of such commisison, percentage, brokerage, or contingent fee.

ARTICLE A-VII - EXAMINATION OF RECORDS BY COMPTROLLER GENERAL

A. The Participant agrees that the Comptroller General of the United States or any of his duly authorized Government employees shall, until the expiration of three (3) years after final payment under this Agreement, unless DOE authorizes their prior disposition, have access to and the right to examine any directly pertinent books, documents, papers, and records of the Participant involving transactions related to this Agreement.

ARTICLE A-VII - EXAMINATION OF RECORDS BY COMPTROLLER GENERAL (Cont'd)

B. The Participant further agrees to include in all its subcontracts hereunder a provision to the effect that the subcontractor agrees that the Comptroller General of the United States or any of his duly authorized Government employees shall, until the expiration of three (3) years after final payment under the subcontract, or such lesser time specified in either Appendix M of the Armed Services Procurement Regulation or the Federal Procurement Regulations Part 1-20, as appropriate, have access to and the right to examine any directly pertinent books, documents, papers, and records of such subcontractor, involving transactions related to the subcontract. The term "subcontract" as used in this article excludes (1) purchase orders not exceeding $10,000 and (2) subcontracts or purchase orders for public utility services at rates established for uniform applicability to the general public.

C. The periods of access and examination described in A. and B., above, for records which relate to (1) appeals under the "Disputes" article of this Agreement, (2) litigation or the settlement of claims arising out of the performance of this Agreement, or (3) costs and expenses of this Agreement as to which exception has been taken by the Comptroller General or any of his duly authorized representatives, shall continue until such appeals, litigation, claims or exceptions have been disposed of.

ARTICLE A-VIII - ASSIGNMENT OF CLAIMS

Pursuant to the provisions of the Assignment of Claims Act of 1940, as amended (31 U.S.C. 203, 41 U.S.C. 15), claims for moneys due or to become due the Participant from the Government under this Agreement may be assigned to a bank, trust company, or other financing institution, including any Federal lending agency, and may thereafter be further assigned and reassigned to any such institution. Any such assignment or reassignment shall cover all amounts payable under this Agreement and not already paid, and shall not be made to more than one party, except that any such assignment or reassignment may be made to one party as agent or trustee for two or more parties participating in such financing. Unless otherwise provided in this Agreement, payments to assignee of any moneys due or to become due under this Agreement shall not, to the extent provided in said Act, as amended, be subject to reduction or setoff.

ARTICLE A-IX - PERMITS

Except as otherwise directed by the Contracting Officer, the Participant shall procure all necessary permits or licenses and abide by all applicable laws, regulations, and ordinances of the United States and of the State, territory, and political subdivision in which the work under this Agreement is performed.

ARTICLE A-X - DISPUTES

A. Except as otherwise provided in this Agreement, any dispute concerning a question of fact arising under this Agreement shall be decided by the Contracting Officer, who shall reduce his decision to writing and mail or otherwise furnish a copy thereof to the Participant. The decision of the Contracting Officer shall be final and conclusive unless within thirty (30) days from the date of receipt of such copy, the Participant mails or otherwise furnishes to the Contracting Officer a written appeal addressed to DOE. The decision of DOE or its duly authorized representative for the determination of such appeals shall be final and conclusive unless determined by a court of competent jurisdiction to have been fraudulent, or capricious, or arbitrary, or so grossly erroneous as necessarily to imply bad faith, or not supported by substantial evidence. In connection with any appeal proceeding under this article, the Participant shall be afforded an opportunity to be heard and to offer evidence in support of its appeal. Pending final decision of a dispute hereunder, the Participant shall proceed diligently with the performance of this Agreement and in accordance with the Contracting Officer's decision.

B. This "Disputes" article does not preclude consideration of law questions in connection with decisions provided for in paragraph A, above: Provided, That nothing in this Agreement shall be construed as making final the decision of any administrative official, representative, or board on a question of law.

ARTICLE A-XI - PAYMENT OF INTEREST ON PARTICIPANT'S CLAIMS

A. If an appeal is filed by the Participant from a final decision of the Contracting Officer under the "Disputes" article of this Agreement, denying a claim arising under the Agreement, simple interest on the amount of the claim finally determined owed by the Government shall be payable to the Participant. Such interest shall be at the rate determined by the Secretary of the Treasury pursuant to Public Law 92-41, 85 Stat. 97, from the date the Participant furnishes to the Contracting Officer its written appeal under the "Disputes" article of this Agreement, to the date of (1) a

ARTICLE A-XI - PAYMENT OF INTEREST ON PARTICIPANT'S CLAIMS (Cont'd)

final judgment by a court of competent jurisdiction, or (2) mailing to the Participant of a supplemental agreement for execution either confirming completed negotiations between the parties or carrying out a decision of a board of contract appeals.

B. Notwithstnding A., above, (1) interest shall be applied only from the date payment was due, if such date is later than the filing of appeal, and (2) interest shall not be paid for any period of time that the Contracting Officer determines the Participant has unduly delayed in pursuing its remedies before a board of contract appeals or a court of competent jurisdiction.

ARTICLE A-XII - SEX DISCRIMINATION PROHIBITED

No person shall on the ground of sex be excluded from participation in, be denied a license under, be denied the benefits of, or be subjected under any program or activity carried on or receiving Federal assistance under any title of this Act (P. L. 93-438).

ARTICLE A-XIII - CIVIL RIGHTS

The Participant agrees that no person in the United States shall, on the ground of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subject to discrimination under any program or activity for which the Participant receives Federal financial assistance from DOE.

ARTICLE A-XIV - DISCRIMINATION AGAINST HANDICAPPED PROHIBITED

The Participant agrees that no otherwise qualified handicapped individual in the United States [as defined in Section 7(6) of the Act], shall, solely by reason of his handicap, be excluded from the participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance.

ARTICLE A-XV - SMALL AND MINORITY BUSINESS PARTICIPATION

It is the policy of DOE to ensure that small and minority businesses have a reasonable opportunity to participate in the projects which it supports. In accordance with this policy, the Participant will make a reasonable effort to ensure fair consideration and utilization of small and minority businesses in purchases and subcontracts awarded by the Participant under this Agreement.

ARTICLE A-XVI - PREFERENCE FOR U. S. FLAG AIR CARRIERS

A. It is the policy of the United States that all Federal agencies and Government contractors and subcontractors utilize U. S. flag air carriers for international air transportation of personnel and cargo.

B. The Participant agrees to utilize U. S. flag air carriers to the maximum extent practicable in connection with the performance of this Agreement in the transportation by air of any personnel and cargo between the United States and a foreign country, or between foreign countries.

C. The terms used in this article have the following meanings:

(1) "International air transportation" means transportation by air of personnel and cargo from the United States to a foreign country, between two or more foreign countries, and between a foreign country and the United States.

(2) "U. S. flag air carrier" means one of a class of air carriers holding a certificate of public convenience and necessity issued by the Civil Aeronautics Board, approved by the President, authorizing operations between the United States and/or its territories and one or more foreign countries.

(3) The term "United States" incudes the fifty States, Commonwealth of Puerto Rico, possessions of the United States and the District of Columbia.

(4) "Practicable" includes (i) satisfactory servicing of agency programs, and (ii) timely deliveries at fair and reasonable prices.

D. The Participant shall include the substance of this article, including this paragraph D. in each subcontract or purchase order hereunder which may involve air transportation between the United States and a foreign country, or between foreign countries.

ARTICLE A-XVII - CLEAN AIR AND WATER

A. The Participant agrees as follows:

(1) To comply with all the requirements of section 114 of the Clean Air Act, as amended (42 U.S.C. 1857, et seq., as amended by P. L. 91-604) and section 308 of the Federal Water Pollution Control Act (33 U.S.C. 1251, et seq., as amended by P. L. 92-500), respectively, relating to inspection, monitoring, entry, reports and information, as

ARTICLE A-XVII - CLEAN AIR AND WATER (Cont'd)

well as other requirements specified in section 114 and section 308 of the Air Act and the Water Act, respectively, and all regulations and guidelines issued thereunder before the award of this Agreement.

(2) That no portion of the work required by this Agreement will be performed in a facility listed on the Environmental Protection Agency List of Violating Facilities on the date when this Agreement was awarded unless and until the EPA eliminates the name of such facility or facilities from such listing.

(3) To use its best efforts to comply with clean air standards and clean water standards at the facility in which the Agreement is being performed.

(4) To insert the substance of the provisions of this article into any nonexempt contract, including this subparagraph A.(4).

B. The terms used in this article have the following meanings:

(1) The term "Air Act" means the Clean Air Act, as amended (42,U.S.C. 1857, et seq., as amended by P. L. 91-604).

(2) The term "Water Act" means Federal Water Pollution Control Act, as amended (33 U.S.C. 1251 et seq., as amended by P. L. 92-500).

(3) The term "clean air standards" means any enforceable rules, regulations, guidelines, standards, limitations, orders, controls, prohibitions, or other requirements which are contained in, issued under, or otherwise adopted pursuant to the Air Act or Executive Order 11738, an applicable implementation plan as described in section 110(d) of the Clean Air Act [42 U.S.C. 1857c-5(d)], an approved implementation procedure or plan under section 111(c) or section 111(d), respectively, of the Air Act (42 U.S.C. 1157(c)-6(c) or (d), or an approved implementation procedure under section 112(d) of the Air Act [42 U.S.C. 1857c-7(d)].

(4) The term "clean water standards" means any enforceable limitation, control, condition, prohibition, standard, or other requirement which is promulgated pursuant to the Water Act or contained in a permit issued to a discharger by the Environmental Protection Agency or by a State under an approved program, as authorized by section 402 of the Water Act (33 U.S.C. 1342), or

ARTICLE A-XVII - CLEAN AIR AND WATER (Cont'd)

by local government to ensure compliance with pretreatment regulations as required by section 307 of the Water Act (33 U.S.C. 1317).

(5) The term "compliance" means compliance with clean air or water standards. Compliance shall also mean compliance with a schedule or plan ordered or approved by a court of competent jurisdiction, the Environmental Protection Agency or an air or water pollution control agency in accordance with the requirements of the Air Act or Water Act and regulations issued pursuant thereto.

(6) The term "facility" means any building, plant, installation, structure, mine, vessel, or other floating craft, location, or site of operations, owned, leased, or supervised by a contractor or subcontractor, to be utilized in the performance of a contract or subcontract. Where a location or site of operations contains or includes more than one building, plant, installation, or structure, the entire location or site shall be deemed to be a facility except where the Director, Office of Federal Activities, Environmental Protection Agency, determines that independent facilities are collocated in one geographical area.

ARTICLE A-XVIII - RIGHTS IN TECHNICAL DATA - SHORT FORM

A. Definitions. The definitions of terms set forth in 41 CFR 9-9.201 apply to the extent these terms are used herein.

B. Allocation of Rights.

(1) The Government shall have:

(i) Unlimited rights in technical data first produced or specifically used in the performance of this Agreement;

(ii) The right of the Contracting Officer or his representatives to inspect at all reasonable times up to three (3) years after final payment under this Agreement all technical data first produced or specifically used in the Agreement (for which inspection the Participant or its subcontractor shall afford proper facilities to DOE);

ARTICLE A-XVIII - RIGHTS IN TECHNICAL DATA (Cont'd)

(iii) The right to have any technical data first produced or specifically used in the performance of this Agreement delivered to the Government as the Contracting Officer may from time to time direct during the progress of the work or in any event as the Contracting Officer shall direct upon completion or termination of this Agreement.

(2) The Participant shall have: The right to use for its private purposes, subject to patent, security or other provisions of this Agreement, technical data it first produces in the performance of this Agreement provided the data requirements of this Agreement have been met as of the date of the private use of such data. The Participant agrees that to the extent it receives or is given access to proprietary data or other technical, business or financial data in the form of recorded information from DOE or a DOE contractor or subcontractor, the Participant shall treat such data in accordance with any restrictive legend contained thereon, unless use is specifically authorized by prior written approval of the Contracting Officer.

C. Copyrighted Material.

(1) The Participant agrees to, and does hereby grant to the Government, and to its officers, agents, servants and employees acting within the scope of their duties:

(i) A royalty-free nonexclusive, irrevocable license to reproduce, translate, publish, use, and dispose of and to authorize others so to do, all coyrightable material first produced or composed in the performance of this Agreement by the Participant, its employees or any individual or concern specifically employed or assigned to originate and prepare such material; and

(ii) A license as aforesaid under any and all copyrighted or copyrightable works not first produced or composed by the Contractor in the performance of this contract but which are incorporated in the material furnished under the Agreement, provided that such license shall be only to the extent the Participant now has, or prior to completion or final settlement of the Agreement may acquire, the right to grant such license without becoming liable to pay compensation to others solely because of such grant.

ARTICLE A-XVIII - RIGHTS IN TECHNICAL DATA (Cont'd)

(2) The Participant agrees that it will not knowingly include any material copyrighted by others in any written or copyrightable material furnished or delivered under this Agreement without a license as provided for in subparagraph (1)(ii) hereof, or without the consent of the copyright owner, unless it obtains specific written approval of the Contracting Officer for the inclusion of such copyrighted material.

ARTICLE A-XIX - REPORTING OF ROYALTIES

If this contract is in an amount which exceeds $10,000 and if any royalty payments are directly involved in the contract or are reflected in the contract price to the Government, the Participant agrees to report in writing to the Patent Counsel (with notification by Patent Counsel to the Contracting Officer) during the performance of this contract and prior to its completion or final settlement the amount of any royalties or other payments paid or to be paid by it directly to others in connection with the performance of this contract together with the names and addresses of licensors to whom such payments are made and either the patent numbers involved or such other information as will permit identification of the patents or other basis on which the royalties are to be paid. The approval of DOE of any individual payments or royalties shall not stop the Government at any time from contesting the enforceability, validity or scope of, or title to, any patent under which a royalty or payments are made.

ARTICLE A-XX - PATENT RIGHTS - SHORT FORM

A. Definitions.

(1) "Subject Invention" means any invention or discovery of the Contractor conceived or first actually reduced to practice in the course of or under this contract, and includes any art, method, process, machine, manufacture, design, or composition of matter, or any new and useful improvement thereof, or any variety of plants, whether patented or unpatented, under the Patent Laws of the United States of America or any foreign country.

(2) "Patent Counsel" means the DOE Patent Counsel assisting the procuring activity.

B. Invention Disclosures and Reports.

(1) The Participant shall furnish the Patent Counsel (with notification by Patent Counsel to the Contracting Officer):

ARTICLE A-XX - PATENT RIGHTS - SHORT FORM (Cont'd)

(i) A written report containing full and complete technical information concerning each Subject Invention within 6 months after conception or first actual reduction to practice whichever occurs first in the course of or under this Agreement, but in any event prior to any on sale, public use, or public disclosure of such invention known to the Participant. The report shall identify the Agreement and inventor and shall be sufficiently complete in technical detail and appropriately illustrated by sketch or diagram to convey to one skilled in the art to which the invention pertains a clear understanding of the nature, purpose, operation, and to the extent known, the physical, chemical, biological, or electrical characteristics of the invention;

(ii) Upon request, but not more than annually, interim reports on a DOE-approved form listing Subject Inventions for that period and certifying that all Subject Inventions have been disclosed or that there were no such inventions; and

(iii) A final report on a DOE-approved form within 3 months after completion of the Agreement work listing all Subject Inventions and certifying that all Subject Inventions have been disclosed or that there were no such inventions.

(2) The Participant agrees that the Government may duplicate and disclose Subject Invention disclosures and all other reports and papers furnished or required to be furnished pursuant to the Agreement.

C. Allocation of Principal Rights.

(1) Assignment to the Government. The Participant agrees to assign to the Government the entire right, title, and interest throughout the world in and to each Subject Invention, except to the extent that rights are retained by the Participant under paragraphs C.(2) and D. of this article.

(2) Greater Rights Determinations. The Participant, or the employee-inventor with authorization of the Participant, may request greater rights than the nonexclusive license and the foreign patent rights provided in paragraph D. of this

ARTICLE A-XX - PATENT RIGHTS - SHORT FORM (Cont'd)

article on identified inventions in accordance with the procedure and criteria of 41 CFR 9-9.109-6. A request for a determination of whether the Participant or the employee-inventor is entitled to retain such greater rights must be submitted to the Patent Counsel (with notification by Patent Counsel to the Contracting Officer) at the time of the first disclosure of the invention pursuant to subparagraph B.(1) of this article or not later than 9 months after conception or first actual reduction to practice, whichever occurs first, or such longer period as may be authorized by the Patent Counsel (with notification by Patent Counsel to the Contracting Officer) for good cause shown in writing by the Participant. The information to be submitted for a greater rights determination is specified in 41 CFR 9-9.109-6(e).

D. Minimum Rights to the Participant. The Participant reserves a revocable, nonexclusive, paid-up license in each patent application filed in any country on a Subject Invention and any resulting patent in which the Government acquires title. Revocation shall be in accordance with the procedure of subparagraphs C.(2) and (3) of the clause in 41 CFR 9-9.107-5(a). The Participant also has the right to request foreign rights in accordance with the procedures of paragraph (c)(4) of the clause in 41 CFR 9-9.107-5(a).

E. Employee and Subcontractor Agreements. Unless otherwise authorized in writing by the Contracting Officer, the Participant shall:

(1) Obtain patent agreements to effectuate the provisions of the Patent Rights article from all persons who perform any part of the work under this Agreement except nontechnical personnel, such as clerical employees and manual laborers.

(2) Unless otherwise authorized or directed by the Contracting Officer, the Participant shall include the Patent Rights article of 41 CFR 9-9.107-5(a) or 41 CFR 9-9.107-6, as appropriate, modified to identify the parties in any subcontract hereunder having as a purpose the conduct of research,

(3) Promptly notify the Contracting Officer in writing upon the award of any subcontract containing a Patent Rights article by identifying the subcontractor, the work to be performed under the subcontract, and the dates of award and estimated completion. Upon the request of the Contracting Officer the Participant shall furnish a copy of the subcontract to such requester.

ARTICLE A-XX - PATENT RIGHTS (Cont'd)

F. Atomic Energy.

(1) No claim for pecuniary award or compensation under the provisions of the Atomic Energy Act of 1954, as amended, shall be asserted by the Participant or its employees with respect to any invention or discovery made or conceived in the course of or under this Agreement.

(2) Except as otherwise authorized in writing by the Contracting Officer, the Participant will obtain patent agreements to effectuate the provisions of subparagraph F.(1) of this article from all persons who perform any part of the work under this Agreement, except nontechnical personnel such as clerical employees and manual laborers.

G. Publication. In order that information concerning scientific or technical developments conceived or first actually reduced to practice in the course of or under the contract is not permaturely published so as to adversely affect patent interest of DOE, the Participant agrees to submit to the Patent Counsel for patent review a copy of each paper 60 days prior to its intended publication date. The Participant may publish such information after expiration of a 60-day period following such submission or prior thereto if specifically approved by Patent Counsel, unless the Participant is informed in writing within the 60-day period, that in order to protect patentable subject matter, publication must further be delayed. In this event, publicaiton shall be delayed up to 100 days beyond the 60-day period or such longer period as mutually agreed to.

ARTICLE A-XXI - NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT

(The provisions of this article shall be applicable only if the amount of this Agreement exceeds $10,000.)

A. The Participant shall report to the Contracting Officer, promptly and in reasonable written detail, each notice or claim of patent or copyright infringement based on the performance of this Agreement of which the Participant has knowledge.

B. In the event of any claim or suit against the Government on account of any alleged patent or copyright infringement arising out of the performance of this Agreement or out of the use of any supplies furnished or work

ARTICLE A-XXI - NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (Cont'd)

or services performed hereunder, the Participant shall furnish to the Government when requested by the Contracting Officer, all evidence and information in possession of the Participant pertaining to such suit or claim. Such evidence and information shall be furnished at the expense of the Government except where the Participant has agreed to indemnify the Government.

C. This article shall be included in all subcontracts.

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

1. AMENDMENT/MODIFICATION NO.: A001
2. EFFECTIVE DATE: 9/30/79
3. REQUISITION/PURCHASE REQUEST NO.: 07-79ID12033.501
4. PROJECT NO. (If applicable):

5. ISSUED BY — CODE:
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) — CODE:

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) — CODE — FACILITY CODE
Montana College of Mineral Science and Technology
Butte, Montana 59701
Attention: John Dunstan

8. ☐ AMENDMENT OF SOLICITATION NO. ____ DATED ____ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-FC07-79ID12033 DATED ____ (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS
☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.
Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:
(a) By signing and returning ____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS
(a) ☐ This Change Order is issued pursuant to ____
The Changes set forth in block 12 are made to the above numbered contract/order.
(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.
(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Public Law 95-91 and other applicable laws
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

1. The total estimated cost is increased by $2,070 from $110,695.00 to $112,765.00.

2. The total cost to DOE is increased by $1,868 from $99,917.00 to $101,785.00.

3. Add Article XII - Government Property to read as follows:

   The following items of property procured or fabricated by the Contractor are hereby listed as "Government property":

   One digital thermometer with conductor cable and associated equipment - $2,070.00.

4. Add Article A - XXII - Property Items to Appendix A to read as follows:

Continued . . . .

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 2 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY Vernon Griffith (Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY [signature] (Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print)

16. DATE SIGNED: 9/26/79

18. NAME OF CONTRACTING OFFICER (Type or print): J. P. Anderson, Chief Contract Administration Branch

19. DATE SIGNED: 9/27/79

☆ U.S. GOVERNMENT PRINTING OFFICE: 1967—264-006

ARTICLE A-XXII PROPERTY ITEMS

A. Except as otherwise provided in this paragraph A. and paragraph B. of this Article A-XXII, title to all materials, supplies and equipment purchased or otherwise acquired by the Participant in the performance of its research activities shall be and remain in the Participant. Said materials, supplies, and equipment shall be used for the benefit of research under this Agreement and any extensions or successor Agreements hereto and, provided there is no interference with said research, shall be made available for use by investigators working on any Federal research agreement at the same location. Subject to these priorities, the materials, supplies, and equipment may be used as the Participant wishes. Except as otherwise agreed in writing, title to any items of property listed as "Government property" shall pass directly to the Government; such property shall be subject to paragraphs B., C., D., E., and F. of this Article B-VII.

B. Subject to the mutual agreement of DOE and the Participant, the Government may furnish the Participant items of equipment, materials, supplies, or facilities for use by the Participant in the performance of the Agreement work; title to these items shall remain in the Government unless otherwise agreed in writing. Such items of property and the items of property listed elsewhere in this Agreement as Government property, are hereinafter referred to as "Government property." Title to Government Property shall not be affected by the incorporation or attachment thereof to any property not owned by the Government nor shall any such property, or any part thereof, be or become a fixture or lose its identity as personalty by reason of affixation to any realty.

C. To the extent practicable, the Participant shall cause all items of Government property to be suitably marked with an identifying mark or symbol indicating that the items are the property of the Government. The Participant shall maintain, at all times and in a manner satisfactory to DOE, records showing the use and disposition of Government property. Such records shall be subject to DOE inspection at all reasonable times and DOE shall at all reasonable times have access to the premises wherein any items of Government property are located. Unless otherwise authorized in writing by DOE, the Participant shall use Government property only for the purposes of this Agreement; provided, however, that the Participant is hereby authorized to use items of equipment constituting Government property for other Federal research contracts to the extent such use (1) does not interfere with its work under this Agreement, (2) is not prohibited by provisions of the other Federal contracts, and (3) is promptly reported by the Participant to DOE under this Agreement.

D. The Participant shall promptly notify DOE of any loss or destruction of or damage to Government property. It is understood that the Participant shall not be liable for any such loss, destruction, or damage, unless same results from wilful misconduct or lack of good faith on the part of any corporate officer of the Participant, or of one or more of the Participant's representatives having supervision or direction of all or substantially all of the activities under this Agreement. If the Participant is liable for any such loss, destruction, or damage, it shall promptly account therefor to the satisfaction of DOE; if the Contractor is not liable therefor, and is indemnified, reimbursed, or otherwise compensated for such loss, destruction, or damage, it shall promptly account therefor to the satisfaction of DOE.

E. With the written approval of DOE, the Participant may sell, transfer, or otherwise dispose of items of Government property to such parties and upon such terms as so approved, or itself acquire title to items of Government property upon such terms as may be mutually agreed upon in writing by the Participant and DOE. The proceeds of any such disposition, and any agreed price of any such Participant acquisition, shall be paid by the Participant to the Government, or credited on account of DOE payments to be made under this Agreement, as DOE may direct. Subject to the other provisions of this Agreement, the Participant shall deliver Government property to DOE upon request (suitably packed and shipped at the Government's expense).

F. The Participant shall utilize for the benefit of the work under this Agreement such items of property available to the Participant by reason of its activities under other Federal research Agreements as are appropriate for utilization under this Agreement pursuant to the provisions of the pertinent Federal Agreements.

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 5

1. AMENDMENT/MODIFICATION NO.	2. EFFECTIVE DATE	3. REQUISITION/PURCHASE REQUEST NO.	4. PROJECT NO. (If applicable)
A002	1/1/80		

5. ISSUED BY CODE
U.S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) CODE

File M.2.4

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) CODE FACILITY CODE

Montana College of Mineral Science
and Technology
Butte, Montana 59701

Attention: John Dunstan

8. ☐ AMENDMENT OF SOLICITATION NO. ______
DATED ______ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-FC07-79ID12033
DATED 2/26/79 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning ______ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☐ This Change Order is issued pursuant to ______
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Public Law 95-91 et al.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

A. Add the following to Article I - <u>DESCRIPTION OF RESPONSIBILITIES</u>:

"This work shall include the following in accordance with the Participant's proposal titled "Expanded Geothermal Studies in Montana," which is incorporated by reference and made a part hereof:

8. Complete field studies in the West Yellowstone, Little Bitterroot Valley, and Radersburg areas.

9. Complete heat sensing imagery study.

10. Provide data to USGS GEOTHERM files; provide data compilations to DOE as part of the resource inventory program.

Continued....

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 3 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY Vernon Griffith (signature)
(Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY Nell W. Fraser (signature)
(Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print)	16. DATE SIGNED	18. NAME OF CONTRACTING OFFICER (Type or print)	19. DATE SIGNED
		Nell W. Fraser, Director Contracts Management Division	MAY 5 1980

30-101-01

U.S. GOVERNMENT PRINTING OFFICE: 1967—264-008

Article I - DESCRIPTION OF RESPONSIBILITIES (Cont'd)

11. Acquire all available geoscience information on holes in Eastern Montana; inventory all warm wells and springs for bottom hole temperatures, producing formation, and water chemistry.

12. Detailed geologic/geophysical studies will be conducted in the Deer Lodge - Anaconda Valley, Helena Valley, and a third site to be chosen. Studies will include collating and interpreting all available geoscience information in the study areas, sampling all available springs and wells for bottom hole temperatures, flow rates, and water chemistry. Deep resistivity studies will be conducted in the Deer Lodge - Anaconda Valley; a microseismic study will be conducted in the Helena Valley. The final product for each of these study areas will be a detailed scientific report defining the resource potential within the study area and the possible uses for geothermal energy by the surrounding communities.

None of the drilling work resulting from this Modification is authorized at this time."

B. Article II - ESTIMATE OF COST AND OBLIGATION OF FUNDS is revised to read as follows:

"A. The total estimated cost of performing the work under this Agreement is Five Hundred Ninety-Two Thousand Four Hundred Twenty-Four Dollars ($592,424.00). For performance of work under this Agreement, the agreed share ratio is 87.226% DOE, 12.774% Participant of total allowable costs. The Participant shall be reimbursed by DOE for not more than 87.226% of the costs of the project determined to be allowable in accordance with Article A-I of the General Provisions entitled 'Allowable Costs.' The remaining 12.774% or more of the costs of the project so determined shall constitute the Participant's share for which it will not reimbursed by DOE. The total cost to DOE is hereby established as Five Hundred Sixteen Thousand Seven Hundred Forty-Eight Dollars ($516,748.00) and this amount is also the maximum amount of the project which is subject to reimbursement by DOE unless such maximum cost is changed in writing by the Contracting Officer.

B. The total amount of funds obligated under this Agreement by DOE is Two Hundred Seventy Thousand Seven Hundred Eighty-Five Dollars ($270,785.00). The balance of $245,963 will be obligated when and if funds become available."

Article II - ESTIMATE OF COST AND OBLIGATION OF FUNDS (Cont'd)

The cost of this Agreement and obligation of funds is summarized as follows:

	Montana Share	DOE Share	Total Est. Cost	DOE Funds Obligated
Original Contract	$ 10,778	$ 99,917	$110,695	$ 99,917
Inc. per Mod A001	202	1,868	2,070	1,868
Inc. per Mod A002	64,696	414,963	479,659	169,000
Total	$ 75,676	$516,748	$592,424	$270,785
% Share	12.774%	87.226%	100%	

C. Article IV - TERM OF AGREEMENT, is revised to extend the term from February 14, 1980 to September 2, 1981.

D. Article VI - PROJECT INFORMATION, is changed to read as follows:

"Reports shall be submitted to the DOE Program Officer in accordance with the attached Form CR-537, as required by the DOE Uniform Contractor Reporting System, Volume 1."

E. Article VIII - TERMINATION, paragraph D. is revised to change the DOE share from 90.263% to 87.226%.

F. Article XII - GOVERNMENT PROPERTY, is revised to add the following items as Government Property:

One deep resistivity set (transmitter and receiver) - $12,000.00.
Two microseismic units - $3,500.00 each.

G. Add Article XIII - DATE OF INCURRENCE OF COSTS, as follows:

"The Participant shall be entitled to reimbursement for costs incurred in an amount not to exceed $10,000 on or after January 1, 1980, which, if incurred after this Modification had been entered into, would have been reimbursable under the provisions of this Modification."

H. Add Article XXIII - LIMITATION OF FUNDS to Appendix A to read as follows:

"ARTICLE XXIII - LIMITATION OF FUNDS (COST-SHARING)

A. It is estimated that the total cost to the Government for the performance of this agreement will not exceed the estimated cost set forth in the Article II, and the Participant agrees to use his best efforts to perform the work specified in the Article I and all obligations under this contract within such estimated cost to the Government plus the share of the cost of performance agreed to be borne by the Participant, as set forth in the Article II.

br:7H-B3

ARTICLE XXIII - LIMITATION OF FUNDS (COST-SHARING) (Cont'd)

B. The amount presently available for payment by the Government and allotted to this Agreement, the items covered thereby, the Government's share of the cost thereof, and the period of performance which it is estimated the allotted amount will cover, are specified in this Agreement. It is contemplated that from time to time additional funds will be allotted to this Agreement up to the full estimated cost to the Government set forth in the Article II. The Participant agrees to perform or have performed work on this Agreement up to the point at which the total amount paid and payable by the Government pursuant to the terms of the Agreement approximates but does not exceed the total amount actually allotted by the Government to the Agreement.

C. If at any time the Participant has reason to believe that the costs which he expects to incur in the performance of this Agreement in the next succeeding 60 days, when added to all costs previously incurred, will exceed 75 percent of the total of the amount then allotted to the Agreement by the Government plus the Participant's corresponding share, the Participant shall notify the Contracting Officer in writing to that effect. The notice shall state the estimated amount of additional funds required to continue performance for the period set forth in the Agreement. Sixty days prior to the end of the period specified in the Agreement the Participant will advise the Contracting Officer in writing as to the estimated amount of additional funds, if any, that will be required for the timely performance of the work under the Agreement or for such further period as may be specified in the Agreement or otherwise agreed to by the parties. If, after such notification, additional funds are not allotted by the end of the period set forth in the Agreement or an agreed date substituted therefor, the Contracting Officer will, upon written request by the Participant, terminate this Agreement pursuant to the provisions of the "Termination" article on such date. If the Participant, in the exercise of his reasonable judgment, estimates that the funds available will allow him to continue to discharge his obligations hereunder for a period extending beyond such date, he shall specify the later date in his request, and the Contracting Officer, in his discretion, may terminate on that later date.

D. Except as required by other provisions of this Agreement specifically citing and stated to be an exception from this clause, the Government shall not be obligated to reimburse the Participant for costs incurred in excess of the amount from time to time allotted by the Government to the Agreement, and the Participant shall not be obligated to continue performance under the Agreement (including actions under the "Termination" article) or otherwise to incur costs in excess of the total of the amount then allotted to the Agreement by the Government plus the Participant's corresponding share, unless and until the Contracting Officer has notified the Participant in writing that the amount allotted by the Government has been increased and has specified in such notice an increased amount constituting the total amount then allotted by the Government to the Agreement. To the extent the total of the amount allotted by the

ARTICLE XXIII - LIMITATION OF FUNDS (COST-SHARING) (Cont'd)

Government plus the Participant's corresponding share exceeds the estimated cost set forth in Article II, such estimated cost shall be correspondingly increased. Any increase in such estimated cost shall be allocated in accordance with the formula set forth in Article II governing such increases. No notice, communication, or representation in any other form or from any person other than the Contracting Officer shall affect the amount allotted by the Government to this Agreement. In the absence of the specified notice, the Government shall not be obligated to reimburse the Participant for any costs in excess of the total amount then allotted by the Government to the Agreement, whether those excess costs were incurred during the course of the Agreement or as a result of termination. When and to the extent that the amount allotted by the Government to the Agreement has been increased, any costs incurred by the Participant in excess of the total of the amount previously allotted by the Government plus the Participant's corresponding share shall be allowable to the same extent and in the same percentage as if such costs had been incurred after such increase in the amount allotted; unless the Contracting Officer issues a termination or other notice and directs that the increase is solely for the purpose of covering termination or other specified expenses.

E. Change orders issued pursuant to the "Changes" article of this Agreement shall not be considered an authorization to the Participant to exceed the amount allotted by the Government in Article II in the absence of a statement in the change order, or other modification, increasing the amount allotted.

F. Nothing in this article shall affect the right of the Government to terminate this Agreement. In the event this Agreement is terminated, property produced or purchased under the Agreement shall be distributed in accordance with the "Property" article."

OE Form CR-517
(1-78)

U. S. DEPARTMENT OF ENERGY

REPC ING REQUIREMENTS CHECKLIST

(See Instructions on Reverse)

FORM APPROVED
OMB NO. 38R-0190

. IDENTIFICATION Montana College of Mineral Science and Technology	2. OBLIGATION INSTRUMENT: DE-FC07-79ID12033

. REPORTING REQUIREMENTS

. PROJECT MANAGEMENT	Frequency	B. TECHNICAL INFORMATION REPORTING	Frequency
1. ☐ Management Plan		1. ☒ Notice of Energy RD&D Project (SSIE)	O
2. ☐ Milestone Schedule & Status Report		2. ☒ Technical Progress Report	Q
3. ☐ Cost Plan		3. ☒ Topical Report	Y
4. ☐ Manpower Plan		4. ☒ Final Technical Report	F
5. ☒ Contract Management Summary Report	M	C. PMS/MINI-PMS	
6. ☒ Project Status Report	M	1. Cost Performance Report	
7. ☒ Cost Management Report	M	☐ Format 1 WBS	
8. ☐ Manpower Management Report		☐ Format 2 Functional	
9. ☒ Conference Record	A	☐ Format 3 Baseline	
10. ☒ Hot Line Report	A	☐ Format 5 Problem Analysis	
		2. ☐ Cost/Schedule Status Report	
		3. ☐ Management Control System Description	
		4. ☐ Summary System Description	
		5. ☐ WBS Dictionary	

REQUENCY CODES:
A – As Required
C – Contract Change
F – Final (End of Contract)
M – Monthly
O – One Time (Soon After Contract Award)
Q – Quarterly
S – Semi-Annually
X – Mandatory for Delivery with Proposals/Bid
Y – Yearly or Upon Contract Renewal

SPECIAL INSTRUCTIONS

ıbmit all reports to the DOE Program Officer at Idaho Operations Office (ID) as indicated ·low:

.5 and 6 - Six copies are due at ID within fifteen days after end of the calendar month.

1 - Two copies are due at ID within fifteen days after Cooperative Agreement Award.

2 - Six copies are due at ID within fifteen days after end of the calendar quarter.

3 - Six copies are due not less than forty-five days prior to completion of the yearly term.

4 - Submit in draft forty-five days prior to completion date of Cooperative Agreement. After thirty days for DOE review, submit eleven copies including one camera-ready copy.

7 - Three copies are due at ID 20 days after the end of the calendar month.

ATTACHED HEREWITH

☐ Report Distribution List

☐ WBS/Reporting Category

PREPARED BY (Signature and date):	7. REVIEWED BY (Signature and date):
Margaret L. [signature] 12/27/79	Elizabeth M. [signature]

M.2.4

JAN 8 1980

Montana College of Mineral Science
and Technology
Butte, Montana 59701

ATTENTION: John Dunstan

SUBJECT: MODIFICATION NO. A002 TO COOPERATIVE AGREEMENT NO. DE-FC07-79ID12033

Gentlemen:

You are hereby authorized effective January 1, 1980, to begin work and incur costs up to a maximum of $10,000 of DOE's share under proposed Modification No. A002 to the subject agreement pending execution of the formal modification. Work is to be performed in accordance with your proposal, "Expanded Geothermal Studies in Montana," dated November 6, 1979, and the proposed Addendum, except that no drilling is authorized at this time.

The resulting modification will include the following article:

> "Date of Incurrence of Costs - The Participant shall be entitled to reimbursement for costs incurred in an amount not to exceed $10,000 on or after January 7, 1980, which, if incurred after this modification had been entered into, would have been reimbursable under the provisions of this modification."

If negotiations fail and a modification is not executed by the parties, DOE shall not be liable for any obligations by the Participant arising out of this letter.

Please indicate your acceptance of this action by signing in the space indicated below and returning one copy to this office.

Any questions you have should be directed to Elizabeth Hyster /(208) 526-1229/ of my staff.

Very truly yours,

Original Signed By
J. P. Anderson

J. P. Anderson
Contracting Officer
Chief, Contract Administration Branch
Contracts Management Division

ACCEPTANCE:

Name ______________________________

Title ______________________________

Date ______________________________

bcc: M. Widmayer
E. G. Jones

CAB EMHyster:mh 1/4/80 | E&T MAWidmayer | P&B FSSmith | FM EGJones | OCC KLHoewing | CAB JPAnderson

M.2.4

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

1. AMENDMENT/MODIFICATION NO.	2. EFFECTIVE DATE	3. REQUISITION/PURCHASE REQUEST NO.	4. PROJECT NO. (If applicable)
A003	9-15-80	07-80ID12033.503	

5. ISSUED BY CODE
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR CODE FACILITY CODE
NAME AND ADDRESS (Street, city, county, state, and ZIP Code)
Montana College of Mineral Science and Technology
Butte, Montana 59701
Attn: John Dunstan

8.
☐ AMENDMENT OF SOLICITATION NO.
DATED (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-FC07-79ID12033
DATED 2-26-79 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning ____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGEMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☐ This Change Order is issued pursuant to
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Public Law 95-91 et. al.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

1. Delete the following from Article I - DESCRIPTION OF RESPONSIBILTIES:

"None of the drilling work resulting from this Modification is authorized at this time."

2. Article II - ESTIMATE OF COST AND OBLIGATION OF FUNDS is revised to read as follows:

"A. The total estimated cost of performing the work under this Agreement is Six Hundred Eleven Thousand Six Hundred Twenty-Four Dollars ($611,624.00). For performance of work under this Agreement, the agreed share ratio is 86.842% DOE, 13.158% Participant of total allowable costs. The Participant shall be reimbursed by DOE, subject to Paragraph B, for not more than 86.842% of the costs of the project determined to be allowable in accordance with Article A-I of the General Provisions entitled "Allowable Costs". The remaining 13.158% or more of the costs of the project so determined

continued

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 3 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY Vernon Griffiths (Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY Nell W. Fraser (Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print)	16. DATE SIGNED	18. NAME OF CONTRACTING OFFICER (Type or print)	19. DATE SIGNED
VERNON GRIFFITHS DIRECTOR OF RESEARCH	9/25/80	Nell W. Fraser	SEP 15 1980

★U.S.GPO:1979-0-281-187/3001

shall constitute the Participant's share for which it will not be reimbursed by DOE. The total costs to DOE, subject to the future obligation of additional funds, is hereby established as Five Hundred Thirty-One Thousand One Hundred Forty-Eight Dollars ($531,148.00) and this amount is also the maximum amount of the project which is subject to reimbursement by DOE unless such maximum cost is changed in writing by the Contracting Officer.

B. The total amount of funds obligated under this Agreement by DOE is Three Hundred Eighty-Five Thousand One Hundred Eighty-Five Dollars ($385,185.00). The balance of $145,963.00 will be obligated when and if funds become available.

C. The total amount of funds obligated under this Agreement by DOE is inclusive of Thirty-Three Thousand Four Hundred Dollars ($33,400.00) of capital equipment funds. The amount of capital equipment funds shall be treated as a separate ceiling which shall be not be exceeded.

The estimated cost and share totals are summarized below:

	Montana Share	DOE Share	Total Est. Cost	DOE Funds Obligated
Original Contract	$10,778	$ 99,917	$110,695	$ 99,917
Inc. per Mod. A001	202	1,868	2,070	1,868
Inc. per Mod. A002	64,696	414,963	479,659	169,000
Inc. per Mod. A003	4,800	14,400	19,200	114,400
Total	$80,476	$531,148	$611,624	$385,185
% Share	13.158%	86.842%		

3. Article VIII - TERMINATION, Paragraph D. is revised to change the DOE share from 87.226% to 86.842%.

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

PAGE 1 OF 1

1. AMENDMENT/MODIFICATION NO. A004
2. EFFECTIVE DATE
3. REQUISITION/PURCHASE REQUEST NO. 07-81ID12033.501
4. PROJECT NO. (If applicable)

5. ISSUED BY CODE
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) CODE

7. CONTRACTOR NAME AND ADDRESS CODE FACILITY CODE
(Street, city, county, state, and ZIP Code)
Montana College of Mineral Science and Technology
Butte, Montana 59701
Attn: John Dunstan

8.
☐ AMENDMENT OF SOLICITATION NO. ______
DATED ______ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-FC07-79ID12033
DATED 2-26-79 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.

Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods:

(a) By signing and returning ______ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGEMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS

(a) ☐ This Change Order is issued pursuant to ______
The Changes set forth in block 12 are made to the above numbered contract/order.

(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.

(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Public Law 95.91 et. al.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

1. Article II - ESTIMATE OF COST AND OBLIGATION OF FUNDS, Paragraph B. is revised to increase the total amount of funds obligated by DOE to a new total of Five Hundred Thirty-One Thousand One Hundred Forty-Eight Dollars ($531,148.00).

The estimated cost and share totals are summarized below:

	Montana Share	DOE Share	Total Est. Cost	DOE Funds Obligated
Basic Agreement	$ 10,778	$ 99,917	$110,695	$ 99,917
Inc. per Mod. A001	202	1,868	2,070	1,868
Inc. per Mod. A002	64,696	414,963	479,659	169,000
Inc. per Mod. A003	4,800	14,400	19,200	114,400
Inc. per Mod. A004	-0-	-0-	-0-	145,963
Total	$ 80,476	$531,148	$611,624	$531,148
Percentage Share	13.158%	86.842%		

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 3 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY Vernon Griffiths (Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY William C. Drake (Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print)
VERNON GRIFFITHS
DIRECTOR OF RESEARCH

16. DATE SIGNED 4/6/81

18. NAME OF CONTRACTING OFFICER (Type or print)
William C. Drake

19. DATE SIGNED 4/10/81

STANDARD FORM 30, JULY 1966
GENERAL SERVICES ADMINISTRATION
FED. PROC. REG. (41 CFR) 1-16.101

AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

1. AMENDMENT/MODIFICATION NO.: M005
2. EFFECTIVE DATE: See Blk 19
3. REQUISITION/PURCHASE REQUEST NO.: 07-81ID12033.503
4. PROJECT NO. (If applicable):

5. ISSUED BY — CODE:
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

6. ADMINISTERED BY (If other than block 5) — CODE:

7. CONTRACTOR NAME AND ADDRESS (Street, city, county, state, and ZIP Code) — CODE — FACILITY CODE
Montana College of Mineral Science and Technology
Butte, Montana 59701
Attn: John Dunstan

8. ☐ AMENDMENT OF SOLICITATION NO. ____ DATED ____ (See block 9)
☒ MODIFICATION OF CONTRACT/ORDER NO. DE-FC07-79ID12033 DATED 2-26-79 (See block 11)

9. THIS BLOCK APPLIES ONLY TO AMENDMENTS OF SOLICITATIONS
☐ The above numbered solicitation is amended as set forth in block 12. The hour and date specified for receipt of Offers ☐ is extended, ☐ is not extended.
Offerors must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation, or as amended, by one of the following methods. (a) By signing and returning ____ copies of this amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGEMENT TO BE RECEIVED AT THE ISSUING OFFICE PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If, by virtue of this amendment you desire to change an offer already submitted, such change may be made by telegram or letter, provided such telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

10. ACCOUNTING AND APPROPRIATION DATA (If required)

11. THIS BLOCK APPLIES ONLY TO MODIFICATIONS OF CONTRACTS/ORDERS
(a) ☐ This Change Order is issued pursuant to ____
The Changes set forth in block 12 are made to the above numbered contract/order.
(b) ☐ The above numbered contract/order is modified to reflect the administrative changes (such as changes in paying office, appropriation data, etc.) set forth in block 12.
(c) ☒ This Supplemental Agreement is entered into pursuant to authority of Public Law 95.91 et. al.
It modifies the above numbered contract as set forth in block 12.

12. DESCRIPTION OF AMENDMENT/MODIFICATION

The term of this Agreement is hereby extended from September 2, 1981 to February 28, 1982.

Except as provided herein, all terms and conditions of the document referenced in block 8, as heretofore changed, remain unchanged and in full force and effect.

13. ☐ CONTRACTOR/OFFEROR IS NOT REQUIRED TO SIGN THIS DOCUMENT ☒ CONTRACTOR/OFFEROR IS REQUIRED TO SIGN THIS DOCUMENT AND RETURN 2 COPIES TO ISSUING OFFICE

14. NAME OF CONTRACTOR/OFFEROR
BY Vernon Griffiths (Signature of person authorized to sign)

17. UNITED STATES OF AMERICA
BY William C. Drake (Signature of Contracting Officer)

15. NAME AND TITLE OF SIGNER (Type or print): VERNON GRIFFITHS, DIRECTOR OF RESEARCH
16. DATE SIGNED: 9/10/81
18. NAME OF CONTRACTING OFFICER (Type or print): William C. Drake
19. DATE SIGNED: 9/4/81

☆U.S.GPO:1980-0-311-153/5520

DE-FC07-79ID12033
mod

E FORM PF-799A (TEST)
AUGUST 1978

MONTANA

U. S. DEPARTMENT OF ENERGY

PROCUREMENT/FINANCIAL ASSISTANCE REQUEST-AUTHORIZATION

NCTE
MOD 6 - TASKS-$ & TIME

. TO CMD

. FROM INITIATING OFFICE E&T Division Geothermal

. INITIAL: [X] UPDATE: [ ] 4. PROCUREMENT: [ ] FINANCIAL ASSISTANCE: [ ]

. PR NUMBER: ________________ 6. PR CORRECTION LETTER: _ 7. RELATED PR NUMBER: ______________

CTION IDENTIFICATION

. TITLE: Montana State Resource Assessment DE-FC07-79ID12033
Modification for No Cost Time Extension

. UNSOLICITED PROPOSAL NO: __________ 10. PROJECT NO: ____________________ 11. CFDA NO: ______

. PRODUCT OR SERVICE:* ____ 13. SUPPORT SERVICES: YES [ ] NO [ ] 14. CONSULTANT AWARD: YES [ ] NO [ ]

. CONTROLLED DELIVERABLE:* ___ 16. REPORT/DRAWING REQ: YES [ ] NO [ ] IF YES, ATTACH DETAILS.

. CLASSIFICATION OF MATERIALS/WORK: _ U — UNCLASSIFIED C — CONFIDENTIAL S — SECRET T — TOP SECRET

. GOVERNMENT PROPERTY: _ F — FURNISHED P — PURCHASED N — NOT INVOLVED IF CODE F OR P, ATTACH DETAILS.

WARD PLANNING

. AWARD AS ORDER UNDER BIN: ________________

. DESIRED AWARD DATE: __ __ __ (MONTH DAY YEAR) 21. KIND OF AWARD ACTION:* LQ 22. TYPE OF AWARD:* I IF CODE T, ATTACH DETAILS.

. IF MULTI-YEAR AWARD, INDICATE NUMBER OF YEARS: _ 24. TYPE SOLICITATION INSTRUMENT: * __

. EXTENT OF COMPETITION:* __ IF COMPETITIVE, ATTACH TECHNICAL EVALUATION PLAN. IF NON—COMPETITIVE, ATTACH JUSTIFICATION. REF: DOE-PR 9-3.805.51 or 9-4.909(f).

. SOURCE SELECTION PROCEDURE: _ 1 — A-E 2 — SEB 3 — OTHER 4 — NONE

. FOR A-E, SHOW ESTIMATED CONSTRUCTION COST IN DOLLARS: __________

WARDEE

IF COMPETITIVE, HAS LIST OF SOURCES BEEN ATTACHED? YES [ ] NO [ ] IF NON—COMPETITIVE, COMPLETE 28 - 31.

. NAME: Montana Bureau of Mines & Geology 29. ADDRESS: Butte Mt 59701

. DIVISION: Mont College Mineral Science & Technology Attn John Sonderegger

. GOCO/LAB: _ A — GOCO/LAB B — GOCO/NON—LAB C — NON-GOCO/LAB D — NOT APPLICABLE

NANCIAL

AWARD VALUE — DOLLAR AMOUNT

. GOV'T SHARE -0-

. TOTAL ___________

. CONSIDERATION IN KIND, LOAN, OR LOAN GUARANTEE DATA REPORTED ON PR—799C: [ ]

. PROJECT PERIOD: FROM 9 30 82 (MONTH DAY YEAR) THRU 9 30 83 (MONTH DAY YEAR)

CURRENT FY FUNDS COMMITTED

36. B&R NUMBER	37. FUND CLASS	38. DOLLAR AMOUNT
_________	-	__________
_________	-	__________
_________	-	__________

. FROM PR—799B (PART A) ___________

. TOTAL THIS PR -0-

. FUNDING PERIOD: FROM __ __ __ (MONTH DAY YEAR) THRU __ __ __ (MONTH DAY YEAR)

. APPROPRIATION SYMBOL: ___________

. ALLOTMENT SYMBOL: ___________

. OBJECT CLASS: ____

PROJECT MANAGER

45. NAME: S M Prestwich

46. SIGNATURE: SM Prestwich

47. DATE: 04 20 82 (MONTH DAY YEAR) 48. OFFICE CODE: ________

49. FTS TELEPHONE NUMBER: ________

PROGRAM OFFICIAL

50. NAME: R E Wood

51. SIGNATURE: E Gilmore for R E Wood

52. DATE: 4-20-82 (MONTH DAY YEAR)

CERTIFYING OFFICIAL

53. NAME: E. S. Smith

I HEREBY CERTIFY THAT THE FUNDS CITED IN ITEM 40 ARE AVAILABLE.

54. SIGNATURE: ____________________

55. DATE: (MONTH DAY YEAR)

SEE BACK OF FORM FOR CODES

RECEIVED

MAR 2 6 1982

ADVANCED TECHNOLOGY
BRANCH

MONTANA BUREAU OF MINES AND GEOLOGY
MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
BUTTE, MONTANA 59701
406/496-4166

March 24, 1982

Susan Prestwich
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

Dear Susan:

Joseph Donovan has resigned his position with the Bureau effective at the end of March; this leaves us short handed for the upcoming field season, and required that I take over all of his current work. This summer's projected geothermal work schedule included: (a) field work in the vicinity of Ennis (drilling), Anaconda (mapping and drilling at end of the field season), White Sulphur Springs (geologic map evaluation and drilling if there was any money left), and hydrologic work (tentative: near Hot Springs, in cooperation with the Flathead reservation, and near Bozeman), and (b) the compilation of the final report and "blind prospects" map.

We would have probably needed to request a three month no-cost extension to adequately perform those tasks. With Joe leaving, there are two basic options available:

(1) Reduce the allotted task description to what can be completed by October 1, 1982, and reduce the budget proportionately; or

(2) extend the project duration to the end of FY 83 at no cost to DOE.

I do not think that we can hire a new person to replace Joe earlier than August 1, 1982 and most likely his replacement will not be working before September. Because we are in the final stages of the project, much of the work is interpretive, requiring comparisons of one area and its known resources with similar geologic settings. A new person will be of limited value at this stage, and I would prefer sole responsibility for producing the final reports on the geologic and hydrologic investigations.

The question of how to proceed is yours. I would prefer accomplishing all of the tasks over the longer time frame. This, however, may not be in harmony with DOE objectives. As soon as you can provide me with a decision as to the approach to take, I will work up revised schedules, cost estimates, and milestone charts for the project.

Sincerely,

John Sonderegger

John Sonderegger
Hydrogeologist

JS:blm

STATE: Montana

ORGANIZATION: Col. Mineral Science & Technology PHONE: 406-496-4159

PRINCIPAL INVESTIGATOR/CONTACT: John Sonderegger/Charles Wideman

CONTRACT NO.: DE-FC07-79ID12033* DATE: 2/15/79

EST. COMPLETION: 2/14/80 ORIGINAL AMOUNT OBLIGATED DOE: $99,917

*Orig. EY-S-06-2426 (5/17/76) $19,688

·Changed to DE-AS07-76ID12029 (R.E. Simonds Letter of 12/19/78). Have letter and a Mod 005 to this Contract No.

·Changed to DE-FC07-79ID12033 ? No Documentation.

CONTRACTOR: 10,778

TOTAL: $110,695

MODIFICATIONS:

NUMBER	DATE	DESCRIPTION	AMOUNT DOE	AMOUNT CONTRACTOR
002	10/1/77	(#2426) Add Tasks - Increase Funds	$ 86,400	-
003	5/1/78	Request - Modify Tasks - Increase Funds Not DOE Approved? Have no DOE Documentation of Mod 003 on this contract.		
		New Contract (12033) issued 2/15/79	$ 99,917	$10,778
001	?	Additional Funds (Equipment?)	1,868	202
002	1/1/80	Add Tasks 8-12: Add Funds: T.E. to 9/2/81	414,963	64,696
003	9/15/80	Increase Funding	14,000	4,800
004	4/6/81	Doe Funds Allocated to Total	$531,148	$80,476
005	9/4/81	N.C.T.E. to 2/28/82		

DELIVERABLE STATUS:

TASK NO.	DESCRIPTION	DATE DUE	RECEIVED OR ITEM #
Per Mod 002 (2426)	1. Madison/Red Rock Springs & Wells	9/30/79	7
Per Mod 002 (2426)	2. Compile Geologic/Geophysical Data Madison/Red Rock Springs & Wells	9/30/79	7,3
Per Mod 002 (2426)	3. Model Red Rock Creek-Madison Riv. Val.	9/30/79	7,3,4
Per Mod 002 (2426)	4. Geotherm File Input	9/30/79	USGS CIRC 790
Per Mod 002 (2426)	5. Geothermal User Map	9/30/79	1/82
	New Contract (12033) 2/15/79		8
1. 2/15/79	Complete Centennial Valley Project.	2/14/80	7
2. 2/15/79	Provide Geophys. (Seismic) & Hydrology around known Hot Springs	2/14/80	1 THRU 12, 15
3.	Complete Groundwater data transfer to USGS	2/14/80	IN FED. COMPUTERS/200 Q W DATA SYS
4.	Begin Yellowstone Geoth. Study	2/14/80	N.A.
5.	Meet deadlines on Temp. Grad. Studies - Map data	2/14/80	DONE (NO NEW DATA) ALSO #5&6 IN PRESS
6.	Evaluate Airborn-Heat Sensing Imagery - Thermal discharge to major streams.		N.A.-SEE TASK #9

(Cont'd on P. 2)

CONTRACT COMPLETION DATE:

TOTAL FUNDS EXPENDED DOE:

CONTRACTOR:

TOTAL:

STATE: Montana (Cont'd)

ORGANIZATION: PHONE:

PRINCIPAL INVESTIGATOR/CONTACT:

CONTRACT NO.: DE-FC07-79ID12033 DATE:

EST. COMPLETION: ORIGINAL AMOUNT OBLIGATED DOE:

CONTRACTOR:

TOTAL:

MODIFICATIONS:

NUMBER	DATE	DESCRIPTION	AMOUNT DOE	AMOUNT CONTRACTOR

DELIVERABLE STATUS:

TASK NO.	DESCRIPTION	DATE DUE	RECEIVED
New Contract (Cont'd)			
7.	Conduct Test Drilling at Ennis or Deer Lodge	2/14/80	12
	Per Mod 002: 1/1/80 Time Extension to	9/2/81	
8.	Complete West Yellowstone-Little Bitterroot-Radersberg	9/2/81	10, -5-14
9.	Complete Heat Sensing Imagery Study	9/2/81	in press
10.	Provide Data to Geotherm.	9/2/81	USGS CIRC 790
11.	Acquire Geoscience Data on Eastern Montana Drill Holes	9/2/81	6, 8
12.	Geol./Geophys. studies: Deer Lodge - Anaconda, Helena Valleys and third site to be chosen.		12-1, -13, 14
	Mod 005 N.C.T.E. to	2/28/82	
8/7/81	Revised SOW for FY82: Add Geoscience Study - White Sulphur Springs: Norris Area: Predictive model for geoth. w/without surface manifestations.		in prep.

(Cont. on P. 3)

CONTRACT COMPLETION DATE:

TOTAL FUNDS EXPENDED DOE:

CONTRACTOR:

TOTAL:

STATE: Montana (Cont'd) CONTRACT NO.: DE-FC07-79ID12033

SUMMARY OF DELIVERABLES STATUS

	DESCRIPTION	TASK NO.	DATE RECEIVED	ITEM
	• Drilling Report: State Nursery Test Well #1. Sonderegger		2/16/82	1
	• Sub-Surface Investigation - Bozeman Hot Spring - Donovan, et.al.		2/16/82	2
	• Structure of Centennial and Madison Valleys - Schofield.		2/16/82	3
	• Geol. & Geoth. Resources - E. Centennial Valley - Sonderegger		2/16/82	4
	• Drilling of Campaqua Geoth. #1 - Hot Springs MT. - Donovan, et.al.		2/16/82	5
	• Geothermal User Map		1/82	6
	Geothermal Resources of the Upper Centennial and Madison Valleys - Sonderegger, et. al.		2/80	7
DOE/ID/12079-39	Geothermal Resources in Montana - Sonderegger and Schmidt		4/81	8
	Problems of Trace Element Ratios and Geothermometry - Sonderegger and Donovan		4/81	9
	Geophysical Investigations of certain Montana Geoth. Areas-Wideman,et.al		4/81	10
	Geochemical Evaluation of shallow dilution of Geothermal Water - Donovan, et. al.		4/81	11
QURI →	Deer Lodge Valley Investigations - Wideman, et. al.		4/82	12
April,82	Quarterly Report: 5/13/81 - Boulder Area - Wideman		5/81	13
	Field Check of Geology-Southern Townsend Basin - Straw		5/82	14
	Calculated Reservoir Temps-in Quarterly Report 6/16/79		6/79	15

COMMENTS AND ACTION ITEMS:

(7-86)

M2.4

NOTICE OF FINANCIAL ASSISTANCE AWARD
(See instructions on Reverse)

Under the authority of Public Law 93-410, 93-438, 93-473, 93-577, and 95-91 and subject to legislation, regulations and policies applicable to *(cite legislative program title)*: National Geothermal Resource Assessment Program

1. PROJECT TITLE
Additional Geothermal Studies in Montana

2. INSTRUMENT TYPE
☐ GRANT ☒ COOPERATIVE AGREEMENT

3. RECIPIENT *(Name, address, zip code, area code and telephone no.)*
Montana College of Mineral Science & Technology
Butte, Montana 59701

4. INSTRUMENT NO.
DE-FC07-79ID12033

5. AMENDMENT NO.
A006

6. BUDGET PERIOD
FROM: 2-15-79 THRU: 9-30-82

7. PROJECT PERIOD
FROM: 2-15-79 THRU: 9-30-82

8. RECIPIENT PROJECT DIRECTOR *(Name and telephone No.)*
John Sonderegger

9. RECIPIENT BUSINESS OFFICER *(Name and telephone No.)*
John Dunstan

10. TYPE OF AWARD
☐ NEW ☒ CONTINUATION ☐ RENEWAL
☐ REVISION ☐ SUPPLEMENT

11. DOE PROJECT OFFICER *(Name, address, zip code, telephone No.)*
S.M.Prestwich, Energy & Technology Division
U.S.Department of Energy, 550 Second Street
Idaho Falls, ID 83401 (208) 526-1147

12. ADMINISTERED FOR DOE BY *(Name, address, zip code, telephone No.)*
E. M. Hyster
U. S. Department of Energy
R&D Contracts Br., Contracts Mgmt. Div.
550 Second Street, Idaho Falls, ID 83401
(208) 526-1229

13. RECIPIENT TYPE
☐ STATE GOV'T ☐ INDIAN TRIBAL GOV'T ☐ HOSPITAL ☐ FOR PROFIT ORGANIZATION ☐ C ☐ P ☐ SP ☐ INDIVIDUAL
☐ LOCAL GOV'T ☒ INSTITUTION OF HIGHER EDUCATION ☐ OTHER NONPROFIT ORGANIZATION ☐ OTHER *(Specify)*

14. ACCOUNTING AND APPROPRIATIONS DATA

a. Appropriation Symbol	b. B & R Number	c. FT/AFP/OC	d. CFA Number
89X0224.91	AM 1510		

15. EMPLOYER I.D. NUMBER/SSN

16. BUDGET AND FUNDING INFORMATION

a. CURRENT BUDGET PERIOD INFORMATION

1) DOE Funds Obligated This Action	$ 143,097
2) DOE Funds Authorized for Carry Over	$ -0-
3) DOE Funds Previously Obligated in this Budget Period	$ 531,148
4) DOE Share of Total Approved Budget	$ 674,245
5) Recipient Share of Total Approved Budget	$ 107,926
6) Total Approved Budget	$ 782,171

b. CUMULATIVE DOE OBLIGATIONS

(1) This Budget Period *[Total of lines a.(1) and a.(3)]*	$ 674,245
(2) Prior Budget Periods	$ -0-
(3) Project Period to Date *[Total of lines b. (1) and b. (2)]*	$ 674,245

17. TOTAL ESTIMATED COST OF PROJECT $ 782,171
(This is the current estimated cost of the project. It is not a promise to award nor an authorization to expend funds in this amount.)

18. AWARD/AGREEMENT TERMS AND CONDITIONS

This award/agreement consists of this form plus the following:

a. Special terms and conditions (if grant) or schedule, general provisions, special provisions (if cooperative agreement)

b. Applicable program regulations *(specify)* National Geothermal Resource Assessment Program *(Date)* N/A

c. DOE Assistance Regulations, 10 CFR Part 600, as amended, Subparts A and ☐ B (Grants) or ☒ C (Cooperative Agreements).

d. Application/proposal dated May 13, 1981. ☐ as submitted ☒ with changes as negotiated

19. REMARKS

20. EVIDENCE OF RECIPIENT ACCEPTANCE
Vernon Griffiths 19 Feb '82
(Signature of Authorized Recipient Official) *(Date)*
VERNON GRIFFITHS
(Name)
DIRECTOR OF RESEARCH
(Title)

21. AWARDED BY
William C. Drake 2/8/82
(Signature) *(Date)*
William C. Drake
(Name)
Contracting Officer
(Title)

1. Article I - DESCRIPTION OF RESPONSIBILITIES is revised to add the following tasks:

13. Project Management

The Participant shall provide overall project management and timely reporting as required by the attached DOE Form CR-537. The Participant will administer subcontracts and conduct field monitoring as required. The Participant will exchange information and otherwise cooperate with the USGS, UURI/ESL, and others as identified by DOE.

14. User Assistance

The Participant will accept referrals under the User Assistance program and provide assistance to the private sector in the area of resource assessment.

15. Geothermal State Map

The Participant will complete data compilation and publish through NOAA a Montana State Geothermal Map.

16. White Sulphur Springs Study

The Participant will study the White Sulphur Springs area using geology, geophysics, and water chemistry as initial tools. The Participant will seek funds from the Renewable Energy Division of the Montana Department of Natural Resources for test drilling at White Sulphur Springs in order to confirm the size of the resource.

17. Norris Area Study

The Participant will conduct a study of the Norris area using appropriate geophysical, geological, geothermal techniques to see if geothermal resources can be identified beyond those presently known. A final report will be published.

18. Summary Study

The Participant will draw together into a coherent model the information from geothermal studies in Montana. Part one of this study will be the identification of the controls for the several types of systems in Montana. Part two will be a speculative discussion of areas without surface manifestation that appear most favorable for a "blind" resource to exist. Publication of the results of this task in either MBMG or Technical Journal format will constitute the final technical report under this Agreement.

Modification No. A006
DE-FC07-79ID12033

2. Article II - ESTIMATE OF COST AND OBLIGATION OF FUNDS is revised to read as follows:

"A. The total estimated cost of performing the work under this Agreement is Seven Hundred and Eight-Two Thousand One Hundred and Seventy-One Dollars ($782,171.00). For performance of work under this Agreement, the agreed share ratio is 86.2% DOE, 13.8% Participant of total allowable costs. The Participant shall be reimbursed by DOE for not more than 86.2% of the costs of the project determined to be allowable in accordance with Article A-I of the General Provisions entitled "Allowable Costs." The remaining 13.8% or more of the costs of the project so determined shall constitute the Participant share for which it will not be reimbursed by DOE. The total costs to DOE subject to the future obligation of additional funds, is hereby established as Six Hundred Seventy-Four Thousand Two Hundred Forty-Five Dollars ($674,245.00), and this amount is also the maximum amount of the project which is subject to reimbursement by DOE unless such maximum cost is changed in writing by the Contracting Officer.

B. The total amount of funds obligated under this Agreement by DOE is Six Hundred Seventy-Four Thousand Two Hundred Forty-Five Dollars ($674,245.00).

C. The total amount of funds obligated under this Agreement by DOE is inclusive of Thirty-Three Thousand Four Hundred Dollars ($33,400.00) of capital equipment funds. The amount of capital equipment funds shall be treated as a separate ceiling which shall not be exceeded.

The estimated cost and share totals are summarized below:

	Montana Share	DOE Share	Total Estimated Cost	DOE Funds Obligated
Original Contract	$ 10,778	$ 99,917	$110,695	$ 99,917
Inc. per Mod. A001	202	1,868	2,070	1,868
Inc. per Mod. A002	64,696	414,963	479,659	169,000
Inc. per Mod. A003	4,800	14,400	19,200	114,400
Inc. per Mod. A004	-0-	-0-	-0-	145,963
Inc. per Mod. A005	-0-	-0-	-0-	-0-
Inc. per Mod. A006	27,450	143,097	170,547	143,097
Total	$107,926	$674,245	$782,171	$674,245
% Share	13.8%	86.2%		

3. Article IV - TERM OF AGREEMENT is revised to extend the term from February 28, 1982 to September 30, 1982.

4. Article V - PROJECT MANAGEMENT, DEFINITIONS AND REPORTING is revised to change the DOE Program Manager from L. L. Mink to S M. Prestwich.

5. Article VI - PROJECT INFORMATION is changed to refer to the DOE Form CR-537 attached to this Modification No. A006.

6. Article VIII - TERMINATION, paragraph D., is revised to change the DOE share from 86.842% to 86.2%.

7. Article A-XX - PATENT RIGHTS - SHORT FORM is deleted and the attached article entitled PATENT RIGHTS - July 1981 substituted therefore.

DOE Form CR-537
(1-78)

U. S. DEPARTMENT OF ENERGY

REPORTING REQUIREMENTS CHECKLIST

(See Instructions on Reverse)

FORM APPROVED
OMB NO. 38R-0190

1. IDENTIFICATION Geothermal Resource Assessment in Montana	2. OBLIGATION INSTRUMENT: Modification No. A006 to Contract No. FC07-79ID12033

3. REPORTING REQUIREMENTS

A. PROJECT MANAGEMENT	Frequency	B. TECHNICAL INFORMATION REPORTING	Frequency
1. ☐ Management Plan		1. ☐ Notice of Energy RD&D Project (SSIE)	
2. ☐ Milestone Schedule & Status Report		2. ☐ Technical Progress Report	
3. ☐ Cost Plan		3. ☒ Topical Report	A
4. ☐ Manpower Plan		4. ☒ Final Technical Report	Y
5. ☒ Contract Management Summary Report	M	C. PMS/MINI-PMS	
6. ☒ Project Status Report	M	1. Cost Performance Report	
7. ☐ Cost Management Report		☐ Format 1 WBS	
8. ☐ Manpower Management Report		☐ Format 2 Functional	
9. ☐ Conference Record		☐ Format 3 Baseline	
10. ☐ Hot Line Report		☐ Format 5 Problem Analysis	
		2. ☐ Cost/Schedule Status Report	
		3. ☐ Management Control System Description	
		4. ☐ Summary System Description	
		5. ☐ WBS Dictionary	

FREQUENCY CODES:
A — As Required
C — Contract Change
F — Final (End of Contract)
M — Monthly
O — One Time (Soon After Contract Award)
Q — Quarterly
S — Semi-Annually
X — Mandatory for Delivery with Proposals/Bid
Y — Yearly or Upon Contract Renewal

4. SPECIAL INSTRUCTIONS

A.5., A.6. - Copies are due within fifteen days after end of the calendar month.

B.3 - Submit in draft after completion of work as indicated in Statement of Work After DOE approval is received, submit copies as required on attached "Report Distribution List."

b.4. - Submit 2 copies in draft forty-five days prior to completion date of contract term. After DOE approval is received, submit in fianl including one camera-ready copy.

5. ATTACHED HEREWITH:

☒ Report Distribution List ☐
☐ WBS/Reporting Category ☐

6. PREPARED BY (Signature and date):	7. REVIEWED BY (Signature and date):

ID F-129 (Rev. 08-79)
Ref. DOE 13302
(use with DOE CR-537)

U.S. DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE
REPORT DISTRIBUTION LIST

Contract No.

DE-FC07-79ID 12033

Modification No. A006

Addressees	Management Plan	Milestone Schedule & Status Report	Cost Plan	Manpower Plan	Contract Management Summary Report	Project Status Report	Cost Management Report	Manpower Management Report	Conference Record	Hot Line Report	Notice of Energy RD&D Project (SSIE)	Technical Progress Report	Topical Report	Final Technical Report	Cost Performance Report	Cost/Schedule Status Report	Management Control System Description	Summary System Description	WBS Dictionary
U.S. Department of Energy Idaho Operations Office 550 Second Street Idaho Falls, Idaho 83401																			
Attn: Susan Prestwich, Program Manager - Energy and Technology Division					2	2								2	12				
Attn: Nell W. Fraser, Director Contracts Management Div.					1	1								1	1				
Attn: E. G. Jones, Director Financial Management Div.					1														
Dave Lombard U.S. Department of Energy, DGE MS: 3344, Federal Building 12th and PA. N.W. Washington, D.C. 20461					2	2								2	2				
Duncan Foley UURI 420 Chipeta Way, Suite 120 Salt Lake City, Utah 84108					1	1								1	1				

Number of Report Copies

Special Instructions

PATENT RIGHTS - CONTRACTS WITH SMALL BUSINESS FIRMS OR NONPROFIT ORGANIZATIONS - JULY 1981

a. Definitions

(1) "Invention" means any invention or discovery which is or may be patentable or otherwise protectable under Title 35 of the United States Code (USC).

(2) "Subject Invention" means any invention of the contractor conceived or first actually reduced to practice in the performance of work under this contract.

(3) "Practical Application" means to manufacture in the case of a composition or product, to practice in the case of a process or method, or to operate in the case of a machine or system; and, in each case, under such conditions as to establish that the invention is utilized and that its benefits are, to the extent permitted by law or Government regulations, available to the public on reasonable terms.

(4) "Made" when used in relation to any invention means the conception or first actual reduction to practice of such invention.

(5) "Small Business Firm" means a small business concern as defined at Section 2 of Public Law 85-536 (15 USC 632) and implementing regulations of the Administrator of the Small Business Administration. For the purpose of this clause, the size standard for small business concerns involved in Government procurement, contained in 13 CFR 121.3-8, and in subcontracting, contained in 13 CFR 121.3-12, will be used.

(6) "Nonprofit Organization" means universities and other institutions of higher education or an organization of the type described in section 501(c)(3) of the Internal Revenue Code of 1954 (26 USC 501a) or any nonprofit scientific or educational organization qualified under a state nonprofit organization statute.

(7) "Patent Counsel" means the Department of Energy (DOE) patent counsel assisting the DOE contracting activity.

b. Allocation of Principal Rights

The contractor may retain the entire right, title, and interest throughout the world to each subject invention subject to the provisions of this clause. With respect to any subject invention in which the contractor retains title, the Federal Government shall have a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world for which the contractor has elected to retain title.

c. Invention Disclosure, Election of Title and Filing of Patent Applications by Contractor

(1) After a subject invention has been disclosed in writing by the inventor(s) to contractor personnel responsible for the administration of patent matters, the contractor will:

(i) Disclose such invention to the Patent Counsel within six months;

(ii) Elect whether or not to retain title to any such invention by notifying the Patent Counsel within twelve months of disclosure to the contractor but in any event, at least three months (unless shortened by the Contracting Officer) before (a) a public use or on sale of the invention occurs, (b) a manuscript describing the invention is submitted for publication without assurances of confidentiality, or (c) the invention is otherwise made available to the public;

(iii) File its initial patent application on an elected invention within two years after election; and

(iv) File patent applications in additional countries within either ten months of the corresponding initial patent application, or six months from the date a license is granted by the Commissioner of Patents and Trademarks to file foreign patent applications when such filing was prohibited for security reasons.

(2) Requests for extention of the time for disclosure to the Patent Counsel, election and filing, where reasonable, will normally be granted.

(3) The disclosure to the Patent Counsel shall be in the form of a written report and shall identify the contract under which the invention was made and the inventor(s). It shall be sufficiently complete in technical detail to convey a clear understanding of the nature, purpose, operation, and, to the extent known, the physical, chemical, biological or electrical characteristics of the invention. The report shall also identify any publication, on sale or public use of the invention and whether a manuscript describing the invention has been submitted for publication and accepted at the time of disclosure.

d. Forfeiture of Title

(1) The contractor will convey to DOE, upon written request, title to any subject invention:

(i) If the contractor fails to disclose or elect the subject invention within the times specified in c above, or elects not to retain title.

(ii) In those countries in which the contractor fails to file patent application within the times specified in c above; provided, however, that if the contractor has filed a patent application in a country after the times specified in c above but prior to its receipt of the written request of the Patent Counsel, the contractor shall continue to retain title in that country; or

(iii) In any country in which the contractor decides not to continue the prosecution of any application for, to pay the maintenance fees on, or defend in a reexamination or opposition proceeding on, a patent on a subject invention.

e. Minimum Rights to Contractor

The contractor will retain a nonexeclusive, royalty-free license throughout the world in each subject invention to which the Government obtains title except if the contractor fails to disclose the subject invention within the times specified in c above. This license extends to, and is revocable and transferable, as follows:

(1) The contractor's license extends to its domestic subsidiaries and affiliates, if any, within the corporate structure of which the contractor is a part and includes the right to grant sublicense of the same scope to the extent the contractor was legally obligated to do so at the time the contract was awarded. The license is transferable only with the approval of DOE except when transferred to the successor of that part of the contractor's business to which the invention pertains.

(2) The contractor's domestic license may be revoked or modified by DOE to the extent necessary to achieve expeditious practical application of the subject invention pursuant to an application for an exclusive license submitted in accordance with 10 CFR 781. This license will not be revoked in that field of use or the geographical areas in which the contractor has achieved practical application and continues to make the benefits of the invention reasonably accessible to the public. The license in any foreign country may be revoked or modified at the discretion of DOE to the extent the contractor, its licensees, or its domestic subsidiaries or affiliates have failed to achieve practical application in that foreign country.

(3) Before revocation or modification of the license, DOE will furnish the contractor a written notice of its intention to revoke or modify the license, and the contractor will be allowed thirty days (or such other time as may be authorized by DOE for good cause shown by the contractor) after the notice to show cause why the license should not be revoked or modified. The contractor has the right to appeal, in accordance with 10 CFR 781, any decision concerning the revocation or modification of its license.

f. Contractor Action to Protect Government's Interest

(1) The contractor agrees to execute or to have executed and promptly deliver to the Patent Counsel all instruments necessary to:

(i) Establish or confirm the rights the Government has throughout the world in those subject inventions for which the contractor retains title, and

(ii) Convey title to DOE when requested under d above and to enable the Government to obtain patent protection throughout the world in that subject invention.

(2) The contractor agrees to require, by written agreement, its employees, other than clerical and nontechnical employees, to disclose promptly in writing to personnel identified as responsible for the administration of patent matters and in a format suggested by the contractor each subject invention made under this contract in order that the contractor can comply with the disclosure provisions of c above and to execute all papers necessary to file patent applications on subject inventions and to establish the Government's rights in the subject inventions. The disclosure format should require, as a minimum, the information requested by subparagraph c 3 above. The contractor shall instruct such employees through the employee agreements or other suitable educational programs on the importance of reporting inventions in sufficient time to permit the filing of patent applications prior to U.S. or foreign statutory bars.

(3) The contractor will notify the Patent Counsel of any decision not to continue prosecution of a patent application, pay maintenance fees, or defend in a reexamination or opposition proceeding on a patent, in any country, not less than thirty days before the expiration of the response period required by the relevant patent office.

(4) The contractor agrees to include, within the specification of any United States patent application and any patent issuing thereon covering a subject invention, the following statement, "This invention was made with Government support under (identify the contract) awarded by the Department of Energy. The Government has certain rights in this invention."

(5) The contractor agrees to:

(i) Provide a report prior to the close-out of the contract listing all subject inventions;

(ii) Provide notification of all subcontracts for experimental, developmental, demonstration, or research work, the identity of the patent rights clause therein, and copy of each subcontract upon request;

(iii) Provide promptly a copy of the patent application, filing date, and serial number; and patent number and issue date for any subject invention in any country in which the contractor has applied for patents.

g. Subcontracts

(1) The contractor will include this clause, suitably modified to identify the parties, in all subcontracts, regardless of tier, for experimental, developmental or research work to be performed in the United States by a small business firm or a nonprofit organization. The subcontractor will retain all rights provided for the contractor in this clause, and the contractor will not, as part of the consideration for awarding the subcontract, obtain rights in the subcontractor's subject inventions.

(2) The contractor will include in all other subcontracts, regardless of tier, for experimental, developmental, demonstration, or research work the patent rights clause required by 41 CFR 9-9.107-5(a).

h. Reporting on Utilization of Subject Inventions

The contractor agrees to submit on request periodic reports no more frequently than annually on the utilization of a subject invention or on efforts at obtaining such utilization that are being made by the contractor or its licensees or assignees. Such reports shall include information regarding the status of development, date of first commercial sale or use, gross royalties received by the contractor, and such other data and information as DOE may reasonably specify. The contractor also agrees to provide additional reports as may be requested by DOE in connection with any march-in proceeding undertaken by DOE in accordance with paragraph j of this clause. To the extent data or information supplied under this section is considered by the contractor, its licensee or assignee to be privileged and confidential and is so marked, the agency agrees that, to the extent permitted by 35 USC 202(c)(5), it will not disclose such information to persons outside the Government.

i. Preference for United States Industry

Notwithstanding any other provision of this clause, the contractor agrees that neither it nor any assignee will grant to any person the exclusive right to use or sell any subject invention in the United States unless such person agrees that any products embodying the subject invention or produced through the use of the subject invention will be manufactured substantially in the United States. However, in individual cases, the requirement for such an agreement may be waived by DOE upon a showing by the contractor or its assignee that reasonable but unsuccessful efforts have been made to grant licenses on similar terms to potential licensees that would be likely to manufacture substantially in the United States or that under the circumstances domestic manufacture is not commercially feasible.

j. March-in Rights

The contractor agrees that with respect to any subject invention in which it has acquired title, DOE has the right in accordance with the procedures in OMB Bulletin 81-22 to require the contractor, an assignee or exclusive licensee of a subject invention to grant a nonexclusive, partially exclusive, or exclusive license in any field of use to a responsible applicant or applicants, upon terms that are reasonable under the circumstances, and if the contractor assignee, or exclusive licensee refuses such a request, DOE has the right to grant such a license itself if DOE determines that:

(1) Such action is necessary because the contractor or assignee has not taken, or is not expected to take within a reasonable time, effective steps to achieve practical application of the subject invention in such field of use;

(2) Such action is necessary to alleviate health or safety needs which are not reasonably satisfied by the contractor, assignee, or their licensees;

(3) Such action is necessary to meet requirements for public use specified by federal regulations and such requirements are not reasonably satisfied by the contractor, assignee, or licensees; or

(4) Such action is necessary because the agreement required by paragraph i of this clause has not been obtained or waived or because a licensee of the exclusive right to use or sell any subject invention in the United States is in breach of such agreement.

k. Special Provisions for Contracts with Nonprofit Organizations

(1) Rights to a subject invention in the United States may not be assigned without the approval of DOE, except where such assignment is made to an organization which has as one of its primary functions the management of inventions and which is not, itself, engaged in or does not hold a substantial interest in other organizations engaged in the manufacture or sale of products or the use of processes that might utilize the invention or be in competition with embodiments of the invention (provided that such assignee will be subject to the same provisions as the contractor);

(2) The contractor may not grant exclusive licenses under United States patents or patent applications in subject inventions to persons other than small business firms for a period in excess of the earlier of:

(i) five years from first commercial sale or use of the invention; or

(ii) eight years from the date of the exclusive license excepting that time before regulatory agencies necessary to obtain premarket clearance, unless on a case-by-case basis, DOE approves a longer exclusive license. If exclusive field of use licenses are granted, commercial sale or use in one field of use will not be deemed commercial sale or use as to other fields of use, and a first commercial sale or use with respect to a product of the invention will not be deemed to end the exclusive period to different subsequent products covered by the invention.

(3) The contractor will share any royalties collected on a subject invention with the inventor; and

(4) The balance of any royalties or income earned by the contractor with respect to subject inventions, after payment of expenses (including payments to inventors) incidental to the administration subject inventions, will be utilized for the support of scientific research or education.

NOTICE OF FINANCIAL ASSISTANCE AWARD
(See Instructions on Reverse)

MONTANA M.2.4

Under the authority of Public Law 93-410 and subject to legislation, regulations and policies applicable to (cite legislative program title):

Geothermal Research, Development and Demonstration Act of 1974

1. PROJECT TITLE
Additional Geothermal Studies in Montana

2. INSTRUMENT TYPE
[ ] GRANT [X] COOPERATIVE AGREEMENT

3. RECIPIENT (Name, address, zip code, area code and telephone no.)
Montana College of Mineral Science & Technology
Butte, Montana 59701

4. INSTRUMENT NO.
DE-FC07-79ID12033

5. AMENDMENT NO.
M007

6. BUDGET PERIOD
FROM: 2/15/79 THRU: 9/30/83

7. PROJECT PERIOD
FROM: 2/15/79 THRU: 9/30/83

8. RECIPIENT PROJECT DIRECTOR (Name and telephone No.)
John Sonderegger
(406)496-4159

9. RECIPIENT BUSINESS OFFICER (Name and telephone No.)
John Dunstan
(406) 496-4101

10. TYPE OF AWARD
[ ] NEW [ ] CONTINUATION [ ] RENEWAL
[ ] REVISION [X] SUPPLEMENT

11. DOE PROJECT OFFICER (Name, address, zip code, telephone No.)
S.M. Prestwich, E&T (208) 526-1147
DOE-Idaho Operations Office
550 Second St., Idaho Falls, ID 83401

12. ADMINISTERED FOR DOE BY (Name, address, zip code, telephone No.)
E. M. Hyster (208) 526-1229
U. S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, Idaho 83401

13. RECIPIENT TYPE
[ ] STATE GOV'T [ ] INDIAN TRIBAL GOV'T [ ] HOSPITAL [ ] FOR PROFIT ORGANIZATION [ ] C [ ] P [ ] SP [ ] INDIVIDUAL
[ ] LOCAL GOV'T [X] INSTITUTION OF HIGHER EDUCATION [ ] OTHER NONPROFIT ORGANIZATION [ ] OTHER (Specify)

14. ACCOUNTING AND APPROPRIATIONS DATA

a. Appropriation Symbol	b. B & R Number	c. FT/AFP/OC	d. CFA Number
N/A	N/A		

15. EMPLOYER I.D. NUMBER/SSN

16. BUDGET AND FUNDING INFORMATION

a. CURRENT BUDGET PERIOD INFORMATION

(1) DOE Funds Obligated This Action	$ -0-
(2) DOE Funds Authorized for Carry Over	$ -0-
(3) DOE Funds Previously Obligated in this Budget Period	$ 674,245
(4) DOE Share of Total Approved Budget	$ 674,245
(5) Recipient Share of Total Approved Budget	$ 107,926
(6) Total Approved Budget	$ 782,171

b. CUMULATIVE DOE OBLIGATIONS

(1) This Budget Period (Total of lines a.(1) and a.(3))	$ 674,245
(2) Prior Budget Periods	$ -0-
(3) Project Period to Date (Total of lines b. (1) and b. (2))	$ 674,245

17. TOTAL ESTIMATED COST OF PROJECT $ 782,171

(This is the current estimated cost of the project. It is not a promise to award nor an authorization to expend funds in this amount.)

18. AWARD/AGREEMENT TERMS AND CONDITIONS

This award/agreement consists of this form plus the following:

a. Special terms and conditions (if grant) or schedule, general provisions, special provisions (if cooperative agreement)

b. Applicable program regulations (specify) National Geothermal Resource Assessment Program (Date) N/A

c. DOE Assistance Regulations, 10 CFR Part 600, as amended, Subparts A and [ ] B (Grants) or [X] C (Cooperative Agreements).

d. Application/proposal dated 3/24/82, [X] as submitted [ ] with changes as negotiated

19. REMARKS

20. EVIDENCE OF RECIPIENT ACCEPTANCE

Vernon Griffiths June 14th 82
(Signature of Authorized Recipient Official) (Date)

VERNON GRIFFITHS
(Name)
DIRECTOR OF RESEARCH
(Title)

21. AWARDED BY

William C Drake 6/4/82
(Signature) (Date)

William C. Drake
(Name)
Contracting Officer
(Title)

File - Book #163

DRILLING REPORT:

STATE NURSERY TEST WELL

NO. 1

Joseph Donovan
John Sonderegger

Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Montana 59701

Supported by
U. S. Department of Energy

CONTRACT NO. DE-FC07-79ID12033

TEST WELL NO. 1

INTRODUCTION

A geothermal test well was sited and drilled approximately 0.8 miles (1.3 km) east of Broadwater Hot Springs, near Helena, Montana. The site is on the property of the State Nursery, along the north side of Ten Mile Creek. The purpose of the drilling was to test a thermal infrared imagery anomaly and to evaluate whether a source of warm water for space heating of a series of new greenhouses could be developed to replace ones destroyed in the spring 1981 flooding of Ten Mile Creek.

SITING AND LOCATION

The test well was sited in T. 22 N., R. 4 W., section 22 CD. This location is on a small low-intensity thermal anomaly apparent on infrared imagery flown over the Broadwater Hot Springs area in September 1977. It is also near the contact between a late Cretaceous granite body and Belt sediments (Proterozoic) of the Helena Formation. The well was sited at the intersection of the projection of this contact with the long axis of a small colluvium-filled draw, which probably represents a fault or pronounced joint plane cutting through the Precambrian section. The exploration rationale was to investigate the infrared anomaly, assuming that hot water circulation is encouraged along the granite-limestone contact, particularly near an intersecting fault. The infrared anomaly was not the largest or the most intense in the vicinity, but was the only one which was located on State Nursery property.

LOCAL GEOLOGY

The test well site is located near the center of a gently-dipping anticlinal structure across which are exposed lower Belt sediments of the

Precambrian Helena, Empire, and Spokane Formations, as mapped at a scale of 1:48,000 by Knopf (1963) (Figure 1). The anticline is, according to Knopf's map, intruded by a late Cretaceous granite-adamellite stock associated with a late stage of the Boulder Batholith. In the field, a pre-drilling site investigation of the granite-limestone contact approximately 200 feet (65 m) from the test site was made. Chilled margins in the granite and obvious contact metamorphism in the sediments (viz., calc-silicates or argillic alteration products) were not evident at the outcrop. Therefore, it was tentatively interpreted that the contact could be either of fault or intrusive origin.

DRILLING SUMMARY

The test well was spudded with a churn drill operated by the Montana Department of Highways Core Drill Section on 10/19/81. 6" I.D. well casing was driven through poorly-sorted colluvial sand, clay, and cobbles derived from the rock outcrops immediately upslope, dominated by Helena Formation quartzite and limestone. Solid bedrock was encountered in the well at 27 feet (8.2 m) below ground surface, where the casing was set and the cable tool rig moved off the hole. A Failing 1500 air rotary rig was moved onto the hole on 10/21/81 to proceed into bedrock with a tungsten carbide chisel-tooth tricone bit. However, due to insufficient pull-down pressure on the rig, it was unable to penetrate deeper than 33 feet (10.1 m). A water well contractor (Lindsay Drilling of Clancy, MT) was mobilized on the hole on 10/26/81 with an Ingersoll-Rand TH-60 air rotary rig. Drilling proceeded rapidly with an air hammer to a depth of 280' (85.3 m) under open hole conditions.

No significant amount of water was obtained in the overburden

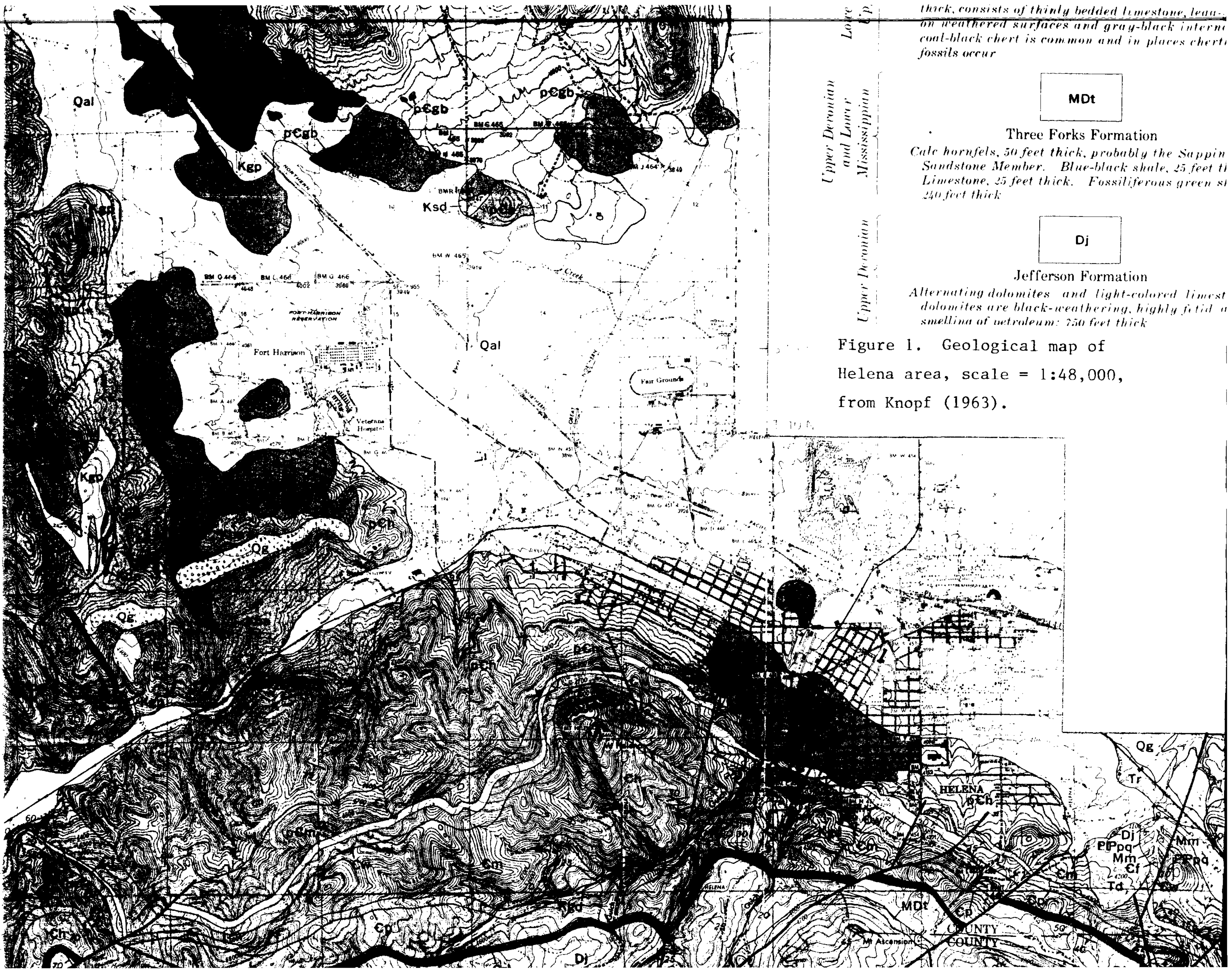

Figure 1. Geological map of Helena area, scale = 1:48,000, from Knopf (1963).

Tr

Rhyolite

Td

Dacite

Kp

iest Pass Leucomonzonite
pple pattern, leucosyenite
border facies

Ksd

yenodiorite, d=2.70-2.78

ownite gabbro, d=3.02-3.18

Shonkinite, d=2.86
West of Austin

Kgp

anodiorite porphyry and
related porphyries

Kgd

Granodiorite, undivided

Kgr

raphophyre, d=2.67-2.70

Kog

orthoclase gabbro and gabbro,
undivided

te porphyry, includes some
that is synbathylithic

Gabbro, d=2.97-3.06

Kal

Alaskite and aplite, d=2.57-2.61

Muscovite-biotite granite,
d=2.61

Biotite adamellite, d=2.65

Kpg

Porphyritic granodiorite,
d=2.65-2.71

Nonporphyritic granodiorite equigranular equivalent of the porphyritic granodiorite

Kc

Clancy Granodiorite,
d=2.67-2.75

Ku

Unionville Granodiorite (d=2.78)
including its basic facies granogabbro (d=2.85)

Andesite, basalt, and rhyodacite
Granodiorite undivided

TERTIARY OR YOUNGER

CRETACEOUS

PRECAMBRIAN

Figure 1 (cont.). Map legend from Knopf (1963).

CAMBRIAN

Hasmark Dolomite

Upper part, light-colored dolomite. Lower part thick-bedded dark dolomite mottled in bizarre patterns. Density 2.81 to 2.86. Commonly is metamorphosed to white marble

Park Argillite

Dark compact rock (d=2.72 to 2.80), locally fossiliferous. Thickness, 200 feet

Cm

Meagher Limestone

Upper part, massive pure limestone, 280 feet thick. Lower part, thin-bedded impure limestone, 360 feet thick

Wolsey Formation

Micaceous siltstone, largely detrital quartz, muscovite, and biotite, and possibly glauconite; phyllitic appearance on bedding surfaces; 200 feet thick

Cf

Flathead Quartzite

White, vitreous; almost 100 percent quartz; 90 to 170 feet thick

PRECAMBRIAN

Greenhorn Mountain Quartzite

Feldspathic quartzite with about 15 percent of clear limpid microcline. Upper third is well stratified in beds averaging 1 to 2 inches. Lower part, massively bedded, 1,800 feet thick. Density 2.58 to 2.62

Marsh Formation

Argillites, commonly deep-red, maroon, purple, and violet, with interbedded quartzite in belts as much as 500 feet thick, cross-bedded siltstones, and laminites containing casts of salt crystals; 3,000 feet thick

Helena Dolomite

Siliceous dolomite, buff-weathering, and subordinate limestone; 4,000 feet thick. Collenia *bioherms are common. Density of dolomite 2.76 to 2.82*

[illegible]ire and Spokane Formations

[illegible] argillites, deep-red argillites (brick-red, maroon, and lavender), and clear-green fine-grained feldspathic quartzite; 1,000 feet thick

Dg

material. A good flow of water was obtained from permeable zones in the limestone from 90-120 feet (27-37 m) and from fractures associated with the granite-limestone contact and within the granite itself, from 120-150 feet (36-46 m). Yield by air lift was estimated by the driller at 100-150 gallons per minute, although this is by no means a precise value. The specific capacity of each producing zone is not known.

The water-producing zones were subject to caving and sloughing at several levels between 110-150 feet (34-46 m). For this reason the driller did not remove the drill string from the hole after water was encountered; to continue much deeper than 280 feet (85.3 m) a steel liner would have had to have been set to prevent the sloughing from endangering the drill string.

A temperature log (Figure 2) was run while the rig was still on the hole, running the thermistor down the inside of the drill steel to penetrate the sloughed zone. The water ranged from 9.8°-12.8°C from top to bottom. The ten foot spacing on the readings was inadequate to delineate water producing zones in detail, but does describe in general the zone from 120-140' (36-43 m) as being an aquifer. Temperature gradients in the bottom 80 feet (25 m) of the hole, which the driller had indicated had produced no additional water, ranged from 3.3°-16.4°C/km, with an average of about 9°C/km, far less than a 'normal' conductive geothermal gradient of 25°C/km. This was interpreted to indicate that (a) no warm water source (>30°C) was located within a few hundred feet of the bottom of the hole, and (b) the depressed gradient at the bottom of the well suggests an extensive cold water reservoir, either below or around the 280 foot (85 m) depth of the test well. For this reason, and due to the additional expense of the liner needed to pursue deepening of the well, the well was drilled no deeper than 280 feet and the rig demobilized on 10/27/81.

Geophysical logs (gamma, SP, and resistivity) were run on the hole after drilling (Figure 2). Water-bearing fractures in both the limestone and the granite can be recognized by a characteristic high SP-low resistivity signature. Unfractured dry granite is characterized by generally higher gamma values and a slightly higher frequency and amplitude of transient noise-like spikes in the gamma curve, probably due to gamma radiation from potassium in clots of biotite.

DRILL CUTTINGS

Both cable tool and rotary cuttings were fine, ranging from 0.1-5 mm in size, with rarely a few larger chips mixed in. Cuttings were sampled in the field and returned to the lab, where they were washed to remove the fine carbonate flour which coated many of them, sieved to obtain the coarser than 100 mesh fraction, and split. One split was saved for storage, while the other was used for microscopic examination and, for intervals for which there was sufficient sample, for carbonate determinations. Carbonates were determined using an acid digestion-pressure bomb technique, using the washed sieved fraction. Cuttings were pulverized in a Buehler puck mill prior to bomb carbonate determination, to assure complete digestion of carbonates.

The drill cuttings log (Table 1) indicate that the Helena Formation at this site is generally a weakly calcareous, well-crystallized siliceous limestone or calcareous quartzite, with secondary calcite precipitated along the fracture planes. The granite is of relatively homogenous composition: quartz, biotite, plagioclase, and potassium feldspar, in most cases relatively fresh, although the biotite in some zones has been strongly weathered and oxidized, staining the surrounding rock a bright orange with iron hydroxide weathering products. The biotite is fine-grained and subhedral to euhedral, sometimes occurring in euhedral subsequent hexagonal plates in the cuttings, characteristic of plutonic biotite.

The first trace of granite in the bedrock cuttings occurs at 110' (33.5 m). This sample is composed almost exclusively of granite cuttings (limestone <15%). The next deeper sample (120', 36.6 m) showed about 35% granite cuttings but was dominantly limestone fragments. The next deeper sample (120-140', 36-43 m)) was almost exclusively granite cuttings again (limestone <15%), with an amount of carbonate material that could be accounted for by contamination from the open-hole or sloughing portion of the hole above the drilling depth. It seems likely that about 8 feet (2.4 m) of granite was drilled through at 110-118 feet (33.5-36.0 m) then about 6 feet (1.8 m) of limestone, and finally back into granite from 123 feet (37.5 m) to total depth (see geophysical logs, Figure 2). This makes a fault block hypothesis for the igneous sedimentary contact seem unlikely; the contact is probably of intrusive origin despite the apparent lack of chilled margins in outcrop.

INTERPRETATION AND SUMMARY

The test well site was picked to investigate a thermal imagery anomaly located near a suspected fault. The well was drilled to 280 feet (85 m) total depth, with no success in obtaining hot or even warm water. The thermal anomaly has been confirmed to be spurious with regard to the presence of underlying warm or hot ground water, or to the existence of anomalously high subsurface heat flow. No cold water was encountered at shallow depth (<80 feet) that could have contributed to the anomaly. Abundant cold water (12°C) was encountered at 100-150 feet (30-46 m) depth; this water may be associated with the intrusive contact zone between the late Cretaceous granite and the Helena Formation sediments penetrated by the well. There is no indication from the test well data that this well is connected in any way with the hot water system at Broadwater Hot Springs, or that deeper drilling at this site would tap into this system.

REFERENCE CITED:

Knopf, A., 1963. Geology of the Northern Part of the Boulder Bathylith and Adjacent area, Montana. U.S. Geological Survey Misc. Geologic Investigations, Map I-381 .

Table 1. Sample Lithologic Log: State Nursery Test No. 1

DEPTH	CUTTINGS DESCRIPTION	VISUAL ESTIMATES OF CONSTITUENTS		WEIGHT % CARBONATE
15-20'	Disaggregated quartz, fragments of quartzite and quartzite ls., minor granite fragments	quartz	40%	---
		quartzite	25	
		quartzitic limestone	15	
		granite fragments	10	
		white opalline silica	10	
20-25'	Quartz; quartzitic fragments; granite fragments; white opalline silica; minor ls. fragments	quartz	40%	---
		quartzite	25	
		granite	30	
		limestone	2	
		opalline silica	2	
25-28'	light gray and pink quartzitic ls.; dark gray quartzite; disaggregated quartz	light gray siliceous limestone	50%	3.0
		pink siliceous ls.	10	
		dark gray quartzite	20	
		quartz	20	
28-33'	light gray quartzite ls.; pink and clear quartzite fragments	light gray siliceous limestone	90%	3.0
		quartzite	10	
30-40'	light gray quartzitic ls.; buff quartzitic ls.; pink quartzite	light gray siliceous limestone	30%	2.8
		buff quartzitic ls.	50	
		pink quartzite	20	
40-50'	Fine grained white and light gray recrystallized siliceous limestone	lt. gray siliceous ls.	25%	3.4
		white siliceous ls.	25	
		dark gray finely crystalline argillaceous limestone	20	
		white quartzite	10	
		clear quartz	15	
50-60'	Fine grained white to light gray siliceous limestone and calcareous argillite, carbonate cement in fractures	light gray siliceous limestone	50%	3.1
		white quartzite	5	
		clear quartz	25	
		dark gray crystalline argillaceous ls.	20	
60-70'	Fine grained light gray siliceous limestone, clear quartzite and argillaceous limestone; calcareous cement in fractures	light gray siliceous limestone	60%	2.3
		white quartzite	20	
		dark gray argillaceous limestone	10	
		micaceous siltstone	10	
70-80'	Fine grained light gray siliceous limestone, white quartzite	light gray siliceous limestone	50%	[illegible]
		white quartzite	[illegible]	

Table 1 (continued)

DEPTH	CUTTINGS DESCRIPTION	VISUAL ESTIMATES OF CONSTITUENTS		WEIGHT % CARBONATE
80-100'	Fine grained lt., gray siliceous limestone, white and clear quartzite	clear quartz	30%	2.1
		white quartzite	30	
		light gray siliceous limestone	40	
110'	small fragments of quartz and biotite, very few small fragments of fine-grained granite; large cuttings of light gray siliceous limestone and clear quartzite	quartz	20%	2.3
		biotite	30	
		granite fragments	5	
		light gray limestone	35	
		clear quartzite	10	
		sparry clear calcite	trace	
120'	rounded granite fragments, small biotite and quartz fragments, large light gray siliceous limestone cuttings Fe-oxide stained granite cuttings	granite fragments	10%	1.4
		biotite	15	
		quartz	20	
		light gray siliceous limestone	45	
		clear quartz	5	
120-160'	angular and rounded granite fragments, disaggregated quartz and biotite, very minor limestone fragments	granite fragments	65%	1.1
		biotite	10	
		quartz	10	
		light gray limestone	10	
160-180'	angular and rounded granite fragments, disaggregated quartz and biotite, very minor limestone fragments	limestone	5%	1.3
		granite fragments	70	
		quartz	15	
		biotite	10	
180-280'	angular and rounded granite fragments, perthitic intergrowths in granite; disaggregated quartz and biotite, very minor limestone fragments	limestone	5%	1.3
		granite fragments	70	
		quartz	10	
		biotite	15	

Form No. 603 R10/79

File No. ____________

WELL LOG REPORT

State law requires that this form be filed by the water well driller within 60 days after completion of the well.

1. WELL OWNER
Name: Montana Bureau of Mines at State Nursery

2. CURRENT MAILING ADDRESS
Montana Tech College
Butte, Mt. 59701

3. WELL LOCATION

NW | NE | SW | SE

____ ¼ ____ ¼ ____ ¼ Section 22
Township 10 N/S Range 4 E/W
County L&C
Lot ____ Block ____
Subdivision ____
Well Elevation ____
Accuracy: ____ ± 10'; ____ ± 50'; ____ ± 100';

4. DRILLING METHOD ____ cable, ____ bored, ____ forward rotary, ____ reverse rotary, ____ jetted, X other (specify) Air Rotary

5. WELL CONSTRUCTION AND COMPLETION

Size of drilled hole	Size and weight of casing	From (feet)	To (feet)	Perforations and/or Screen: Kind Size	From (feet)	To (feet)
6"	6 5/8 17#	0	27			
"		27	280			

Was casing left open end? X Yes ____ No
Was a packer or seal used? ____ Yes X No
If so, what material ____
Was the well gravel packed? ____ Yes X No
Was the well grouted? ____ Yes X No
To what depth? ____
Material used in grouting ____
Well head completion: Pitless adapter ____
12 in. above grade ____, other ____
(if other, specify) ____
Pump horsepower [ ], pump type ____
Pump intake level ____ feet below land surface
Power (electric, diesel, etc.) ____

6. WATER LEVEL
Static water level [31] feet below land surface
If flowing, closed-in pressure ____ psi
____ gpm flow through ____ inch pipe
Controlled by: ____ valve, ____ reducers, ____ other
(if other, specify) ____

7. WELL TEST DATA ____ pump ____ bailer X other
(if other, specify) Air
Pumping level below land surface:
260 ft. after 1 hrs. pumping [100+] gpm
____ ft. after ____ hrs. pumping ____ gpm

8. WAS WELL PLUGGED OR ABANDONED? ____ Yes X No
If yes, how? ____

9. DATE STARTED 10-26-81
DATE COMPLETED 10-27-81

10. WELL LOG

Depth (ft.) From	To	Formation
0	27	rotten rock
27	110	limestone
110	130	granite
130	160	fault zone
160	280	granite

(use separate sheet if necessary)

11. DRILLER'S CERTIFICATION
This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

10-29-81
Date

Lindsay Drilling
Firm Name

Clancy, Mt
Address

Terry Lindsay 255
Signature License No.

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION DNRC
32 SOUTH EWING HELENA, MONTANA 59601 449-3634

DEPARTMENT COPY

WL - 5820

Tile - Book #163

DRILLING REPORT:

STATE NURSERY TEST WELL

NO. 1

Joseph Donovan
John Sonderegger

Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Montana 59701

Supported by
U. S. Department of Energy

CONTRACT NO. DE-FC07-79ID12033

TEST WELL NO. 1

INTRODUCTION

A geothermal test well was sited and drilled approximately 0.8 miles (1.3 km) east of Broadwater Hot Springs, near Helena, Montana. The site is on the property of the State Nursery, along the north side of Ten Mile Creek. The purpose of the drilling was to test a thermal infrared imagery anomaly and to evaluate whether a source of warm water for space heating of a series of new greenhouses could be developed to replace ones destroyed in the spring 1981 flooding of Ten Mile Creek.

SITING AND LOCATION

The test well was sited in T. 22 N., R. 4 W., section 22 CD. This location is on a small low-intensity thermal anomaly apparent on infrared imagery flown over the Broadwater Hot Springs area in September 1977. It is also near the contact between a late Cretaceous granite body and Belt sediments (Proterozoic) of the Helena Formation. The well was sited at the intersection of the projection of this contact with the long axis of a small colluvium-filled draw, which probably represents a fault or pronounced joint plane cutting through the Precambrian section. The exploration rationale was to investigate the infrared anomaly, assuming that hot water circulation is encouraged along the granite-limestone contact, particularly near an intersecting fault. The infrared anomaly was not the largest or the most intense in the vicinity, but was the only one which was located on State Nursery property.

LOCAL GEOLOGY

The test well site is located near the center of a gently-dipping anticlinal structure across which are exposed lower Belt sediments of the

Precambrian Helena, Empire, and Spokane Formations, as mapped at a scale of 1:48,000 by Knopf (1963) (Figure 1). The anticline is, according to Knopf's map, intruded by a late Cretaceous granite-adamellite stock associated with a late stage of the Boulder Batholith. In the field, a pre-drilling site investigation of the granite-limestone contact approximately 200 feet (65 m) from the test site was made. Chilled margins in the granite and obvious contact metamorphism in the sediments (viz., calc-silicates or argillic alteration products) were not evident at the outcrop. Therefore, it was tentatively interpreted that the contact could be either of fault or intrusive origin.

DRILLING SUMMARY

The test well was spudded with a churn drill operated by the Montana Department of Highways Core Drill Section on 10/19/81. 6" I.D. well casing was driven through poorly-sorted colluvial sand, clay, and cobbles derived from the rock outcrops immediately upslope, dominated by Helena Formation quartzite and limestone. Solid bedrock was encountered in the well at 27 feet (8.2 m) below ground surface, where the casing was set and the cable tool rig moved off the hole. A Failing 1500 air rotary rig was moved onto the hole on 10/21/81 to proceed into bedrock with a tungsten carbide chisel-tooth tricone bit. However, due to insufficient pull-down pressure on the rig, it was unable to penetrate deeper than 33 feet (10.1 m). A water well contractor (Lindsay Drilling of Clancy, MT) was mobilized on the hole on 10/26/81 with an Ingersoll-Rand TH-60 air rotary rig. Drilling proceeded rapidly with an air hammer to a depth of 280' (85.3 m) under open hole conditions.

No significant amount of water was obtained in the overburden

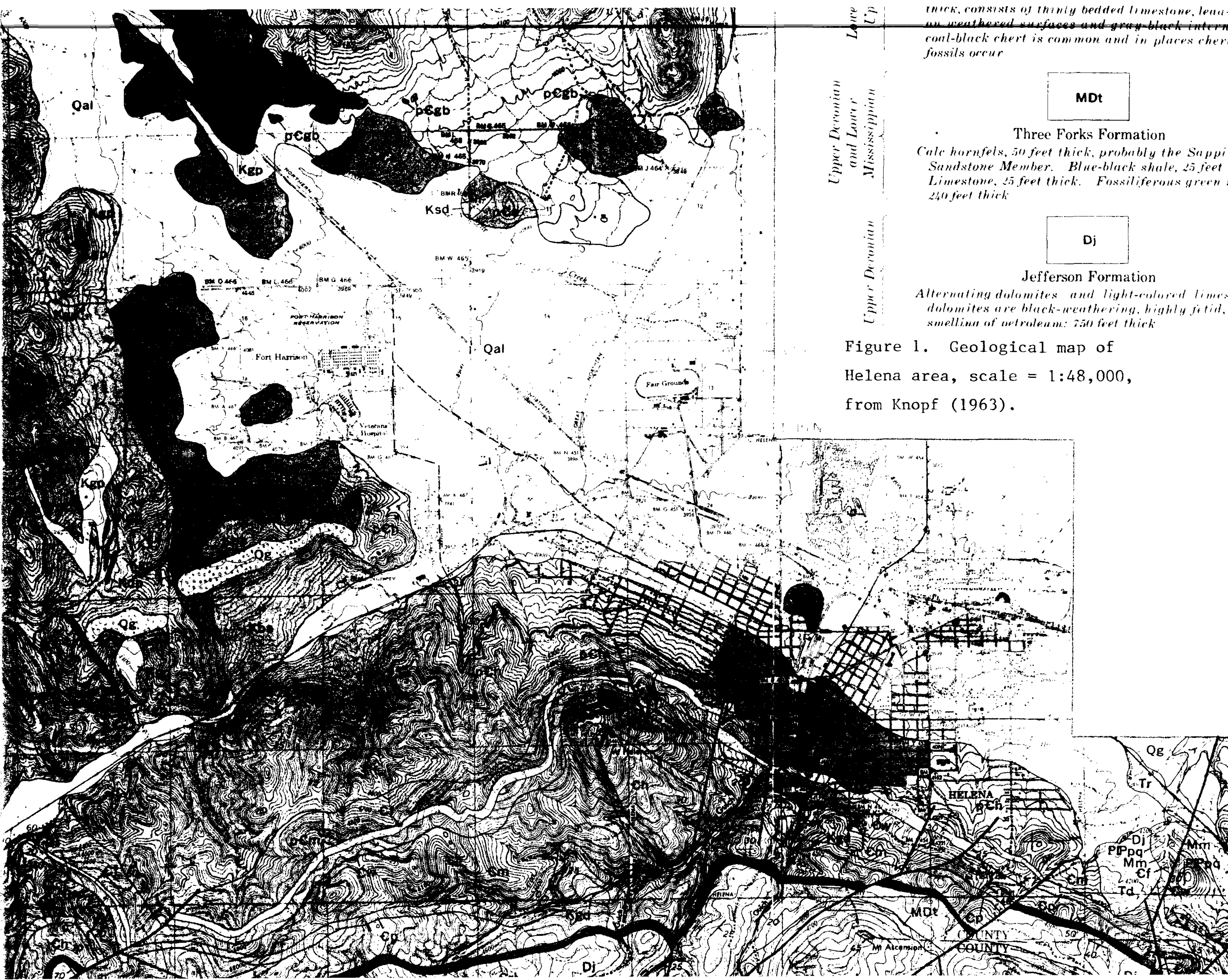

Figure 1. Geological map of Helena area, scale = 1:48,000, from Knopf (1963).

Td

Dacite

Kp

...est Pass Leucomonzonite

Ksd

...yenodiorite, d = 2.70-2.78

...wnite gabbro, d = 3.02-3.18

Ksk

Shonkinite, d = 2.86
West of Austin

Kgp

...anodiorite porphyry and related porphyries

Kgd

...ranodiorite, undivided

Kgr

...aphophyre, d = 2.67-2.70

Kog

...orthoclase gabbro and gabbro, undivided

...te porphyry, includes some that is synbathylithic

Gabbro, d = 2.97-3.06

Kal

Alaskite and aplite, d = 2.57-2.61

Muscovite-biotite granite, d = 2.61

Biotite adamellite, d = 2.65

Kpg

Porphyritic granodiorite, d = 2.65-2.71

Kng

Nonporphyritic granodiorite equigranular equivalent of the porphyritic granodiorite

Kc

Clancy Granodiorite, d = 2.67-2.75

Ku

Unionville Granodiorite (d = 2.78) including its basic facies granogabbro (d = 2.85)

Andesite, basalt, and rhyodacite Granodiorite undivided

CRETACEOUS

PRECAMBRIAN

Hasmark Dolomite
Upper part, light-colored dolomite. Lower part thick-bedded dark dolomite mottled in bizarre patterns. Density 2.81 to 2.86. Commonly is metamorphosed to white marble

Park Argillite
Dark compact rock (d = 2.72 to 2.80), locally fossiliferous. Thickness, 200 feet

Cm

Meagher Limestone
Upper part, massive pure limestone, 280 feet thick. Lower part, thin-bedded impure limestone, 360 feet thick

Wolsey Formation
Micaceous siltstone, largely detrital quartz, muscovite, and biotite, and possibly glauconite; phyllitic appearance on bedding surfaces; 200 feet thick

Cf

Flathead Quartzite
White, vitreous; almost 100 percent quartz; 90 to 170 feet thick

CAMBRIAN

Greenhorn Mountain Quartzite
Feldspathic quartzite with about 15 percent of clear limpid microcline. Upper third is well stratified in beds averaging 1 to 2 inches. Lower part, massively bedded, 1,800 feet thick. Density 2.58 to 2.62

Marsh Formation
Argillites, commonly deep-red, maroon, purple, and violet, with interbedded quartzite in belts as much as 500 feet thick, cross-bedded siltstones, and laminites containing casts of salt crystals; 3,000 feet thick

Helena Dolomite
Siliceous dolomite, buff-weathering, and subordinate limestone; 4,000 feet thick. Collenia bioherms are common. Density of dolomite 2.76 to 2.82

...re and Spokane Formations
... deep-red argillites (brick-red, maroon, ... lavender), and clear-green fine-grained feld-... quartzite, 1,000 feet thick

PRECAMBRIAN

Figure 1 (cont.). Map legend from Knopf (1963).

material. A good flow of water was obtained from permeable zones in the limestone from 90-120 feet (27-37 m) and from fractures associated with the granite-limestone contact and within the granite itself, from 120-150 feet (36-46 m). Yield by air lift was estimated by the driller at 100-150 gallons per minute, although this is by no means a precise value. The specific capacity of each producing zone is not known.

The water-producing zones were subject to caving and sloughing at several levels between 110-150 feet (34-46 m). For this reason the driller did not remove the drill string from the hole after water was encountered; to continue much deeper than 280 feet (85.3 m) a steel liner would have had to have been set to prevent the sloughing from endangering the drill string.

A temperature log (Figure 2) was run while the rig was still on the hole, running the thermistor down the inside of the drill steel to penetrate the sloughed zone. The water ranged from 9.8°-12.8°C from top to bottom. The ten foot spacing on the readings was inadequate to delineate water producing zones in detail, but does describe in general the zone from 120-140' (36-43 m) as being an aquifer. Temperature gradients in the bottom 80 feet (25 m) of the hole, which the driller had indicated had produced no additional water, ranged from 3.3°-16.4°C/km, with an average of about 9°C/km, far less than a 'normal' conductive geothermal gradient of 25°C/km. This was interpreted to indicate that (a) no warm water source (>30°C) was located within a few hundred feet of the bottom of the hole, and (b) the depressed gradient at the bottom of the well suggests an extensive cold water reservoir, either below or around the 280 foot (85 m) depth of the test well. For this reason, and due to the additional expense of the liner needed to pursue deepening of the well, the well was drilled no deeper than 280 feet and the rig demobilized on 10/27/81.

Geophysical logs (gamma, SP, and resistivity) were run on the hole after drilling (Figure 2). Water-bearing fractures in both the limestone and the granite can be recognized by a characteristic high SP-low resistivity signature. Unfractured dry granite is characterized by generally higher gamma values and a slightly higher frequency and amplitude of transient noise-like spikes in the gamma curve, probably due to gamma radiation from potassium in clots of biotite.

DRILL CUTTINGS

Both cable tool and rotary cuttings were fine, ranging from 0.1-5 mm in size, with rarely a few larger chips mixed in. Cuttings were sampled in the field and returned to the lab, where they were washed to remove the fine carbonate flour which coated many of them, sieved to obtain the coarser than 100 mesh fraction, and split. One split was saved for storage, while the other was used for microscopic examination and, for intervals for which there was sufficient sample, for carbonate determinations. Carbonates were determined using an acid digestion-pressure bomb technique, using the washed sieved fraction. Cuttings were pulverized in a Buehler puck mill prior to bomb carbonate determination, to assure complete digestion of carbonates.

The drill cuttings log (Table 1) indicate that the Helena Formation at this site is generally a weakly calcareous, well-crystallized siliceous limestone or calcareous quartzite, with secondary calcite precipitated along the fracture planes. The granite is of relatively homogenous composition: quartz, biotite, plagioclase, and potassium feldspar, in most cases relatively fresh, although the biotite in some zones has been strongly weathered and oxidized, staining the surrounding rock a bright orange with iron hydroxide weathering products. The biotite is fine-grained and subhedral to euhedral, sometimes occurring in euhedral subsequent hexagonal plates in the cuttings, characteristic of plutonic biotite.

The first trace of granite in the bedrock cuttings occurs at 110' (33.5 m). This sample is composed almost exclusively of granite cuttings (limestone <15%). The next deeper sample (120', 36.6 m) showed about 35% granite cuttings but was dominantly limestone fragments. The next deeper sample (120-140', 36-43 m)) was almost exclusively granite cuttings again (limestone <15%), with an amount of carbonate material that could be accounted for by contamination from the open-hole or sloughing portion of the hole above the drilling depth. It seems likely that about 8 feet (2.4 m) of granite was drilled through at 110-118 feet (33.5-36.0 m) then about 6 feet (1.8 m) of limestone, and finally back into granite from 123 feet (37.5 m) to total depth (see geophysical logs, Figure 2). This makes a fault block hypothesis for the igneous sedimentary contact seem unlikely; the contact is probably of intrusive origin despite the apparent lack of chilled margins in outcrop.

INTERPRETATION AND SUMMARY

The test well site was picked to investigate a thermal imagery anomaly located near a suspected fault. The well was drilled to 280 feet (85 m) total depth, with no success in obtaining hot or even warm water. The thermal anomaly has been confirmed to be spurious with regard to the presence of underlying warm or hot ground water, or to the existence of anomalously high subsurface heat flow. No cold water was encountered at shallow depth (<80 feet) that could have contributed to the anomaly. Abundant cold water (12°C) was encountered at 100-150 feet (30-46 m) depth; this water may be associated with the intrusive contact zone between the late Cretaceous granite and the Helena Formation sediments penetrated by the well. There is no indication from the test well data that this well is connected in any way with the hot water system at Broadwater Hot Springs, or that deeper drilling at this site would tap into this system.

REFERENCE CITED:

Knopf, A., 1963. Geology of the Northern Part of the Boulder Bathylith and Adjacent area, Montana. U.S. Geological Survey Misc. Geologic Investigations, Map I-381.

Table 1. Sample Lithologic Log: State Nursery Test No. 1

DEPTH	CUTTINGS DESCRIPTION	VISUAL ESTIMATES OF CONSTITUENTS		WEIGHT % CARBONATE
15-20'	Disaggregated quartz, fragments of quartzite and quartzite ls., minor granite fragments	quartz quartzite quartzitic limestone granite fragments white opalline silica	40% 25 15 10 10	---
20-25'	Quartz; quartzitic fragments; granite fragments; white opalline silica; minor ls. fragments	quartz quartzite granite limestone opalline silica	40% 25 30 2 2	---
25-28'	light gray and pink quartzitic ls.; dark gray quartzite; disaggregated quartz	light gray siliceous limestone pink siliceous ls. dark gray quartzite quartz	50% 10 20 20	3.0
28-33'	light gray quartzite ls.; pink and clear quartzite fragments	light gray siliceous limestone quartzite	90% 10	3.0
30-40'	light gray quartzitic ls.; buff quartzitic ls.; pink quartzite	light gray siliceous limestone buff quartzitic ls. pink quartzite	30% 50 20	2.8
40-50'	Fine grained white and light gray recrystallized siliceous limestone	lt. gray siliceous ls. white siliceous ls. dark gray finely crystalline argillaceous limestone white quartzite clear quartz	25% 25 20 10 15	3.4
50-60'	Fine grained white to light gray siliceous limestone and calcareous argillite, carbonate cement in fractures	light gray siliceous limestone white quartzite clear quartz dark gray crystalline argillaceous ls.	50% 5 25 20	3.1
60-70'	Fine grained light gray siliceous limestone, clear quartzite and argillaceous limestone, calcareous cement in fractures	light gray siliceous limestone white quartzite dark gray argillaceous limestone micaceous siltstone	60% 20 10 10	2.3
70-80'	Fine grained light gray siliceous limestone, white quartzite	light gray siliceous limestone white quartzite	50% 40	1.5

Table 1 (continued)

DEPTH	CUTTINGS DESCRIPTION	VISUAL ESTIMATES OF CONSTITUENTS		WEIGHT % CARBONATE
80-100'	Fine grained lt., gray siliceous limestone, white and clear quartzite	clear quartz	30%	2.1
		white quartzite	30	
		light gray siliceous limestone	40	
110'	small fragments of quartz and biotite, very few small fragments of fine-grained granite; large cuttings of light gray siliceous limestone and clear quartzite	quartz	20%	2.3
		biotite	30	
		granite fragments	5	
		light gray limestone	35	
		clear quartzite	10	
		sparry clear calcite	trace	
120'	rounded granite fragments, small biotite and quartz fragments, large light gray siliceous limestone cuttings Fe-oxide stained granite cuttings	granite fragments	10%	1.4
		biotite	15	
		quartz	20	
		light gray siliceous limestone	45	
		clear quartz	5	
120-160'	angular and rounded granite fragments, disaggregated quartz and biotite, very minor limestone fragments	granite fragments	65%	1.1
		biotite	10	
		quartz	10	
		light gray limestone	10	
160-180'	angular and rounded granite fragments, disaggregated quartz and biotite, very minor limestone fragments	limestone	5%	1.3
		granite fragments	70	
		quartz	15	
		biotite	10	
180-280'	angular and rounded granite fragments, perthitic intergrowths in granite; disaggregated quartz and biotite, very minor limestone fragments	limestone	5%	1.3
		granite fragments	70	
		quartz	10	
		biotite	15	

Form No. 603 R10/79

File No. ____________

WELL LOG REPORT

State law requires that this form be filed by the water well driller within 60 days after completion of the well.

1. WELL OWNER Name Montana Bureau of Mines at State Nursery

2. CURRENT MAILING ADDRESS
Montana Tech College
Butte, Mt. 59701

3. WELL LOCATION

NW NE SW SE

__ ¼ __ ¼ __ ¼ Section 22
Township 10 N/S Range 4 E/W
County L&C
Lot ______ Block ______
Subdivision ______
Well Elevation ______
Accuracy: ___ ± 10'; ___ ± 50'; ___ ± 100';

4. DRILLING METHOD ___ cable, ___ bored, ___ forward rotary, ___ reverse rotary, ___ jetted, X other (specify) Air Rotary

5. WELL CONSTRUCTION AND COMPLETION

Size of drilled hole	Size and weight of casing	From (feet)	To (feet)	Perforations and/or Screen: Kind Size	From (feet)	To (feet)
6"	6 5/8 17#	0	27			
"		27	280			

Was casing left open end? X Yes ___ No
Was a packer or seal used? ___ Yes X No

6. WATER LEVEL
Static water level 31 feet below land surface
If flowing, closed-in pressure ______ psi
______ gpm flow through ______ inch pipe
Controlled by: ___ valve, ___ reducers, ___ other
(if other, specify) ______

7. WELL TEST DATA ___ pump ___ bailer X other
(if other, specify) Air
Pumping level below land surface:
260 ft. after 1 hrs. pumping 100+ gpm
___ ft. after ___ hrs. pumping ___ gpm

8. WAS WELL PLUGGED OR ABANDONED? ___ Yes X No
If yes, how? ______

9. DATE STARTED 10-26-81
DATE COMPLETED 10-27-81

10. WELL LOG

Depth (ft.) From	To	Formation
0	27	rotten rock
27	110	limestone
110	130	granite
130	160	fault zone
160	280	granite

(use separate sheet if necessary)

If so, what material ______

Was the well gravel packed? ____ Yes X No

Was the well grouted? ____ Yes X No

To what depth? ______

Material used in grouting ______

Well head completion: Pitless adapter ______

12 in. above grade ______, other ______

(if other, specify) ______

Pump horsepower ______, pump type ______

Pump intake level ______ feet below land surface

Power (electric, diesel, etc.) ______

11. DRILLER'S CERTIFICATION

This well was drilled under my jurisdiction and this report is true to the best of my knowledge.

10-29-81
Date

Lindsay Drilling
Firm Name

Clancy, MT
Address

Terry Lindsay 255
Signature License No.

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION **DNRC**

32 SOUTH EWING HELENA, MONTANA 59601 449-3634

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Telephone: (303) 447-8850

See instruction sheet for deadlines and addresses

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1982 SECTION ABSTRACT FORM

Exact format shown on instruction sheet must be followed. Blue margins below are absolute limits.

CLASSIFICATION

You must specify one. If more than one category is appropriate, indicate your order of preference by numbers. Be specific.

- ☐ archaeological geology
- ☐ coal geology
- ☐ economic geology
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- ☐ environmental geology
- ☐ extraterrestrial geology
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- ☐ geochemistry
- ☐ geology education
- ☐ geomorphology
- ☐ geophysics
- ☐ geoscience information
- ☐ history of geology
- ☐ hydrogeology
- ☐ marine geology
- ☐ mathematical geology
- ☐ micropaleontology
- ☐ mineralogy/crystallography
- ☐ paleontology/paleobotany
- ☐ petrology, experimental
- ☐ petrology, igneous
- ☐ petrology, metamorphic
- ☐ petrology, sedimentary
- ☐ Precambrian geology
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- ☐ stratigraphy
- ☐ structural geology
- ☐ tectonics
- ☐ volcanology
- ☐ other—describe below
- ☒ GEOTHERMAL

Title, Author(s) Affiliation

SUBSURFACE INVESTIGATIONS AT BOZEMAN HOT SPRINGS

DONOVAN, Joseph J., STICKNEY, Michael C., and SONDEREGGER, John L., Montana Bureau of Mines and Geology, Butte, MT 59701; and PAGE, Charles, Bozeman Hot Springs, Bozeman, MT 59715.

Body of Abstract

Recent drilling activities have investigated the subsurface geology directly beneath Bozeman Hot Springs. Beneath 470 ft. of valley fill sand, clay, and gravel, there is a 30-40 ft. thick caving zone, dry during drilling, which yields large subangular cobbles but little sand. This zone is either fractured bedrock (pre-Belt gneiss) or monolithologic "rubble" of uncertain origin directly overlying bedrock. Fractured gneiss from 525-680 ft. produced >2000 gpm during drilling, later decreasing to 1510 gpm due to massive caving in the rubble zone. Aquifer testing yielded initial transmissivity estimates of 190,000 gpd/ft followed by a boundary condition value of 26,000 gpd/ft encountered after eight hours. Two possible interpretations are: (a) the very permeable fractured aquifer is of limited extent, (b) the dry "rubble" zone fills with water when the well is shut in and causes the initial high-T values. Long-term sustained yield is 790 gpm; temperature is 54° C, very close to that of the spring. Hotter temperatures occur elsewhere in the system at shallow depth: temperature of water seeping from a Tertiary sand bed at depth 125 ft. is 59° C. Aqueous silica-quartz and cation geothermometers yield temperatures from 114°-130°C, thought to be estimates of temperature at the greatest depth of circulation. Under normal gradient conditions this would be about 5 km.

Gravity measurements taken near the springs at half mile intervals with a Lacoste-Romberg gravimeter define a broad NE-trending anomaly, corresponding to that shown by Davis et al. (1965), extending nearly across the Gallatin Valley. This anomaly reflects a bedrock high beneath valley fill that is probably fault-bounded. The faulted SE margin of the anomaly may be part of the geothermal system. In a detailed survey near the springs, precise (0.1 mgal) Bouguer anomalies were determined for stations with 300 ft. spacing, revealing a subtle elongate gravity high of several milligal amplitude, trending about N 60° E, subparallel to the broad high. This anomaly is about 0.3 mi. north of the springs and represents either a buried bedrock ridge or a zone of hydrothermal mineralization in alluvial gravels along the axis of a relict flow system.

☒ Oral ☐ Poster ☐ Either

☐ Symposium ______________________
(title of symposium for which abstract was invited)

PLEASE NOTE: All invited symposium abstracts (original plus two copies) must be sent to the organizers of the respective symposia according to deadlines established by symposium organizers.

Speaker's name Joseph J. Donovan

Address Montana Bureau of Mines and Geology
Montana Tech College

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7/81

STRUCTURE OF THE CENTENNIAL AND MADISON VALLEYS BASED ON GRAVITATIONAL INTERPRETATION

by
James Dean Schofield[1]

ABSTRACT

Major structural elements in the Centennial-Madison region of Southwestern Montana and adjoining Idaho are revealed by examination of the gravity maps of the area. The gravity anomaly of the eastern Centennial Valley is almost 40 m/gals. and the southern Madison Valley has a comparable anomaly; whereas the Henrys Lake basin has a 25 milligal anomaly.

Modeling suggests there exists approximately 3500 feet of Cenozoic deposits in the Henrys Lake basin, less than half the depth of Cenozoic sediments estimated for the Centennial and Madison Valleys. A gravity low extends from the eastern end of the Centennial Valley toward the Madison Valley. The low is interpreted as a valley that previously connected the two valleys but is now hidden beneath several hundred feet of volcanic flows. The buried valley is aligned with the O'dell Creek fault, and appears to be controlled by the fault. The east side of the O'dell Creek fault has been uplifted. The sediment thickness below the Upper Red Rock Lake is just 2000 feet, significantly less than the remainder of the Centennial Valley. Both the Centennial and Madison faults are normal faults that can be traced into the Henry Lake Basin.

INTRODUCTION

Gravity data for the Centennial and Madison Valleys (see Fig. 1) has been examined in an attempt to delineate the major faults of the region and to estimate the thickness of the low density Cenozoic fill of the valleys. Gravity measurements can reveal structural elements not visible on the surface. Density contrasts cause variations in the local gravitational acceleration; therefore, those structures that juxtapose materials of different densities, such as faults, can be detected. The geologic map shown in Fig. 1 has been simplified because differences in density may not correspond to differences in age or lithology.

Most of the major topographic units of southwestern Montana, including the Centennial and Madison Valleys and surrounding mountain ranges, are related to Cenozoic block faulting. The faulting took place in a regime of crystalline rock. The two faults with the largest displacement in this area are the Centennial Fault and the Madison Range Fault. These are the bounding faults of the valleys investigated. The Centennial Mountains are controlled by the normal fault to the north. The southern flank is buried by volcanic rocks of the plain.

On Fig. 1 are the sources of gravity data for this paper. With 179 gravity stations in the Henrys Lake area, 175 stations in the eastern Centennial Valley, and nearly two hundred stations in the northern portion of the Madison Valley, the station density is adequate. There is data across the Upper and Lower Red Rock Lakes. The coverage is sparse in the mountains near Hidden Lake.

METHOD OF INTERPRETATION

The interpretations of the gravity data in Figs. 4 and 6 are based on 2-D modeling using Talwani-type programs (Talwani and others, 1959). The emphasis of this paper is on the eastern Centennial Valley. Ten profiles of the area were modeled in detail (Schofield, 1980); three additional profiles were modeled for the Madison Valley interpretation, and another for Henrys Lake Basin. The models consisted of a simplified geologic cross section having a single density contrast with the observed and calculated gravity for the profile plotted above (Fig. 2). The basement interpretation of Fig. 4 was constructed by plotting the structures portrayed on the 2-D models in their proper location, and then using the gravity map to guide the interpolation between cross sections.

The density contrasts used for the Centennial profiles ranged from -0.6 g/cc to -0.35 g/cc. The density contrasts picked are the differences between the estimated bedrock density and the traditional 2.25 g/cc for Cenozoic valley fill in southwestern Montana (Burfeind, 1967). These density contrast values used may be large and may not reflect the true amount of compaction and lithification. The density contrast used for the Madison Valley and Henrys Lake Basin profiles was -0.3 g/cc. Gary (1980) used a -0.5 g/cc contrast (2.8 g/cc for Precambrian metamorphic rocks, 2.3 g/cc for Cenozoic

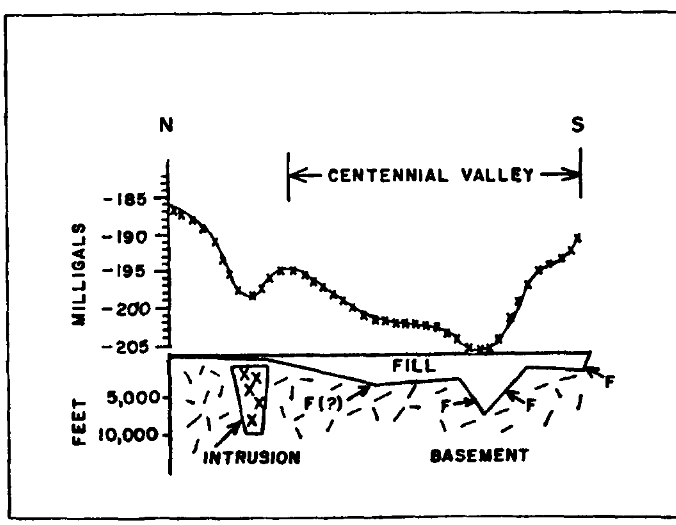

Figure 2. A 2D gravity model of a north-south profile across the lower Red Rock Lake showing the Murphy Creek stock, the fill in Centennial Valley, the faults (F) controlling the shape of the valley, and the north dipping block associated with anomaly H or Fig. 3. The density contrast between both the intrusion and the fill with the basement is -0.564 2/cc. The X's represent the observed gravity; the solid line, the calculated gravity.

[1]Amoco Oil Company, Denver, Colorado 80202

sediments and volcanic tuffs).

In general, gravity highs are associated with mountainous areas and gravity lows with valleys. Large gravity gradients are associated with major faults that juxtapose materials with different densities. Small highs within the low of the valley may be interpreted as uplifted basement blocks. but there is no unique structural interpretation for any given gravity anomaly. The expression of a particular body will broaden as it is buried deeper and deeper; thus, gravity anomalies of small areal extent are assumed to be near surface.

CENTENNIAL VALLEY

Fig. 3 is the complete Bouguer gravity map of the eastern Centennial Valley. There is a broad east-trending gravity low in conjunction with the Centennial Valley. The gravity anomaly across the valley is 20 milligals. The complete gravitational expression of the Centennial and Madison Valleys is not known because very few gravity stations are setup in the mountina.s The map of the basement of the valley (Fig. 4) shows a complex structure which is concealed beneath the nearly flat surface. The depth to basement is

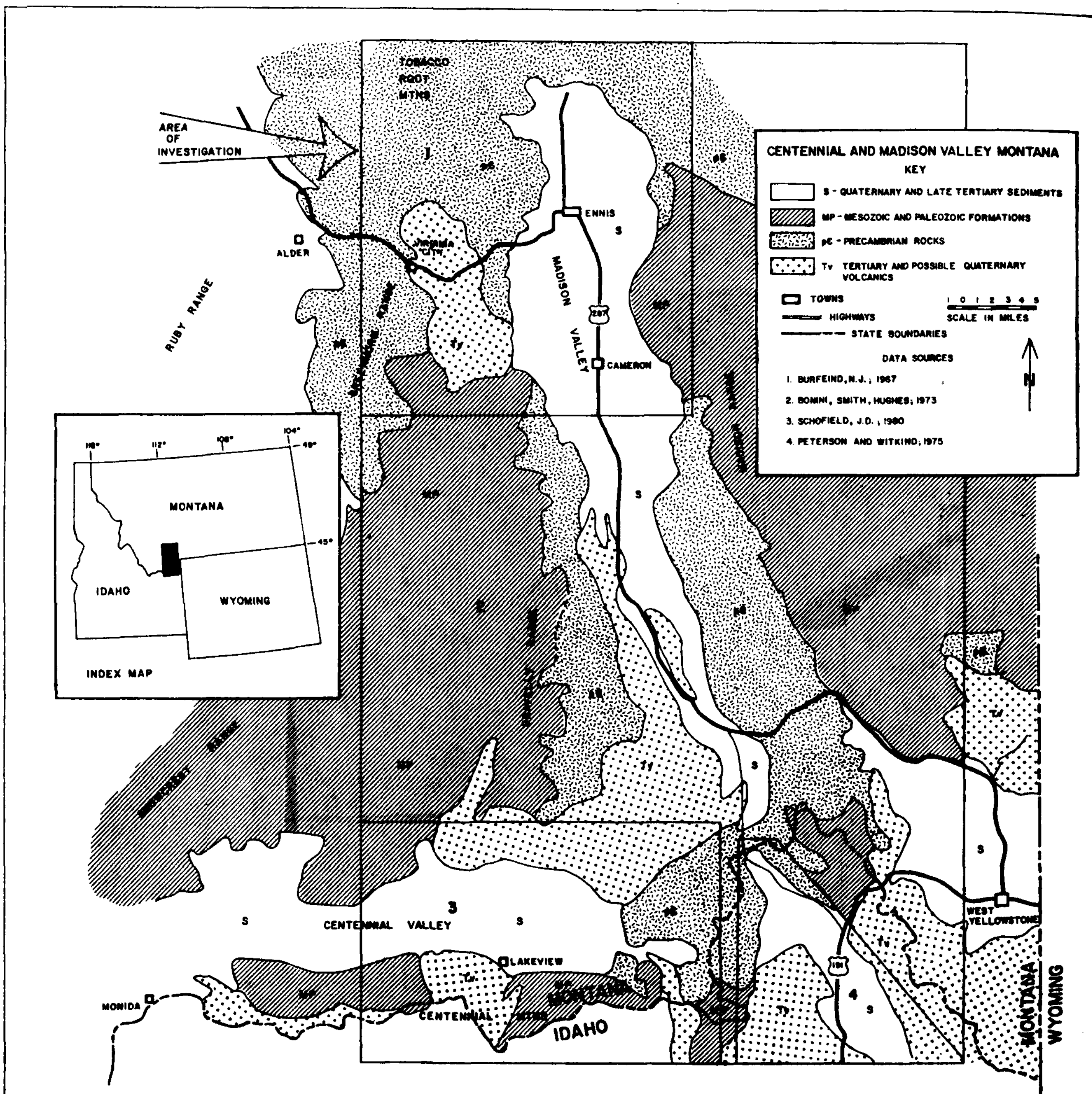

Figure 1. Index map. Generalized geology map (after Egbert, 19600 with bibliographic index for gravity data.

probably too conservative because of large density contrasts used. The maximum thickness of Cenozoic sediments, based on the 2-D model's 7000 feet of fill, may be as much as 3000 feet too small. The smaller anomalous gravity features are marked with letters, and are:

A. The steep gravity gradient with variable contour spacing between the Centennial Mountains and the Lower Red Rock Lake.
B. The south pointing indentation of the gravity contours where Odell Creek emerges from the Centennial Mountains;
C. The steep gradient between the Centennial Mountains and the Upper Red Rock Lake;
D. The nose in the gravity contours at the Upper Red Rock Lake;
E. The closed gravity low at Alaska Basin;
F. The narrow gravity low paralleling the trend of Elk and Hidden Lakes;
G. The south pointing nose at Teepee Creek;
H. The bend in the gravity contours north of the Lower Red Rock Lake; and
I. The closed gravity low near Murphy Creek.

CENTENNIAL FAULT

Modeling of the gravity data suggests that the Centennial Fault should actually be thought of as a fault system rather than a single fault. The Centennial Fault is broken into a number of segments, and in the eastern half of the valley there are two major branches to the Fault: a branch beneath the sediments as well as the high angle normal fault mapped on the surface. South of the Lower Red Rock Lake the displacement of the Centennial Fault has taken place in two large steps, and perhaps several smaller steps below the resolution of the data. The basement elevations south of the lower lake increases from sea level to +5000 feet at the top of a fault block which dips south into the surface branch of the Centennial Fault (Fig. 4). The south dipping blocks are the cause of the widening of the contours at gravity anomaly **A** of Fig. 3. A dip to the south would conform in direction with the dip of the Mesozoic formations (20° - 30° S) south of the lower lake (Pardee, 1950). Pardee states that the Tertiary lavas on the summits also dip to the south, though less steeply. It should be noted that Witkind (1975) mapped the Centennial Mountains east of Odell Creek as the southwest limb of a southeast-plunging anticline. At Odell Creek, the Centennial Fault appears to be a single unit that ends against the Odell Creek Fault (anomaly **B**).

The Centennial Fault bifurcates east of the Odell Creek Fault and forms an upraised platform beneath the Upper Red Rock Lake (nose **D**). The north branch of the Centennial Fault lifts the bedrock more than 4000 feet. The surface of the platform is inclined to the northwest. The unexpected existence of a shallow basement below the Upper Red Rock Lake helps explain the warm water discovered by the Montana Bureau of Mines and Geology in the Upper Red Rock Lake. Metoric water probably circulates along the north Centennial Fault which forms the north face of the platform. The path of the warm water for the final few hundred feet to the surface is not known uniquely, but the most probable route is the suspected fault along the northern border of the upper lake. The fault was not detected on the gravity map; however, small vertical offsets would not be detected and the fault need not be large to trigger depositional infilling of the older lake of which Swan Lake, Upper Red Rock Lake, and the surrounding swamps are but remnants. Such a fault could easily serve as a conduit for the warm water.

The imposing front of the Centennial Mountains, where the elevation changes 3000 feet in a mile, coincides with the large gravity gradient marked **C** on Fig. 3. At least 10,000 feet of vertical displacement has occurred along the Centennial Fault system, and the movement has probably taken place in the last ten million years. An average rate of displacement of 0.3 mm/yr is easily accepted in view of present rates of uplift and subsidence. Recent releveling has revealed that the eastern Centennial Valley is being uplifted by 5 mm/yr (Reilinger and other, 1977) and rates of uplift as high as 14 mm/yr have been measured at the center of the Yellowstone Caldera (Smith and Christiansen, 1980). Curiously, the Centennial Fault has an obvious scarp in the western half of the valley where the rate of uplift is only a fifth of that on the eastern end, yet the eastern scarp is lost beneath till, landslides, and alluvial fans. That the Pliocene (?) volcanics at the southern rim of the Centennial Valley were probably once continuous with the volcanics near the Continental Divide in the Centennial Mountains (Witkind, 1975) illustrates the magnitude of movement of the bounding fault of the valley.

ODELL CREEK FAULT

The most important conclusion formed about the Centennial Valley is that the gravity low trending northeast from the eastern end of the valley (gravity anomaly **F**) is caused by the Cenozoic sediment fill of a valley which has been concealed by a layer of volcanics several hundred feet thick. This buried valley is a direct connection between the eastern Centennial and the southern Madison Valleys. Before the valley was covered by rhyolitic flows, it probably served as the drainage for the eastern Centennial Valley. The approximate width of the valley hidden by the volcanics is from Teepee Creek to Elk Lake. It would seem the western border is a north-trending fault east of Teepee Creek (anomaly **G**). The eastern boundary of the valley is more clearly defined. Gravity anomaly **F** is interpreted as a segment of the Odell Creek Fault; this segment is the bounding fault of the buried valley. The mapped portion of Odell Creek Fault has a strike of N.30°E. which is similar to the western flank of gravity anomaly **D**. The Elk Lake segment (Fig. 4) has the same N.30°E. strike as the series of lakes and ponds connecting the Centennial and Madison Valleys. High seismicity was noted along a N.35°E. trend from Cliff Lake into the Madison Valley during a recent investigation (Bailey, 1977).

The Odell Creek Fault has "an estimated stratigraphic throw of 4,500 feet and a displacement of 3,000 feet" in the Centennial Mountains (Honkala, 1949, p. 104). This high angle normal fault has a general strike of N.30°E. The western edge of the platform of bedrock below the upper Red Rock Lake is formed by a segment of the Odell Creek Fault which has vertical displacement in excess of 2,000 feet (Fig. 4). The Odell Fault has been offset by movement on the younger Centennial Fault. Basement may have been dropped as much as 6,000 feet on the west side of the Elk Lake segment of the Odell Creek Fault. The movements indicated by gravity modeling are comparable to the measured movement of the fault.

ALASKA BASIN

A simple downdropped block, bounded on one side by a

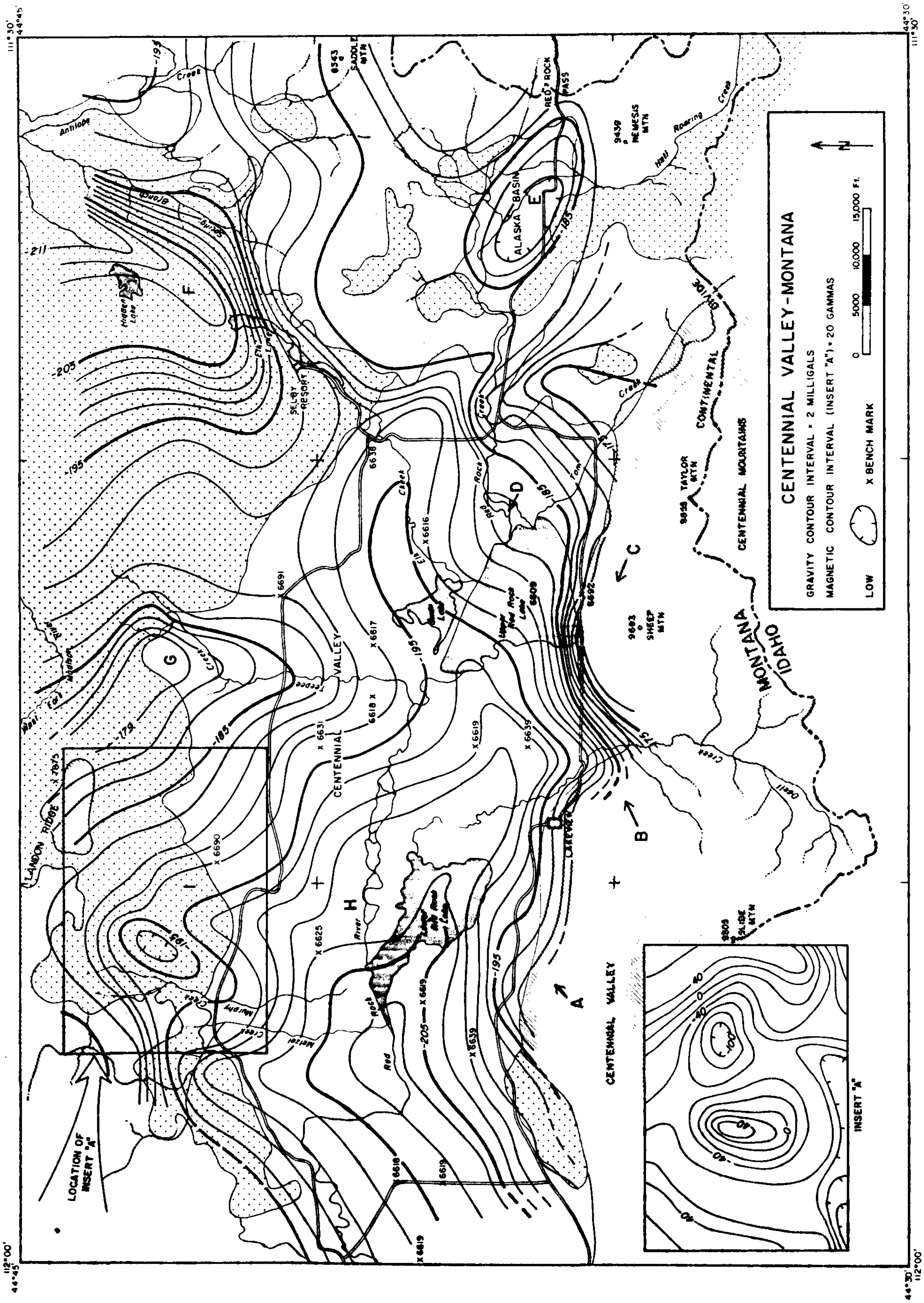

Figure 3. Complete Bouguer gravity map of the eastern Centennial Valley with an insert showing the ground magnetics for the Murphy Creek area. The large letters mark significant features on the gravity map.

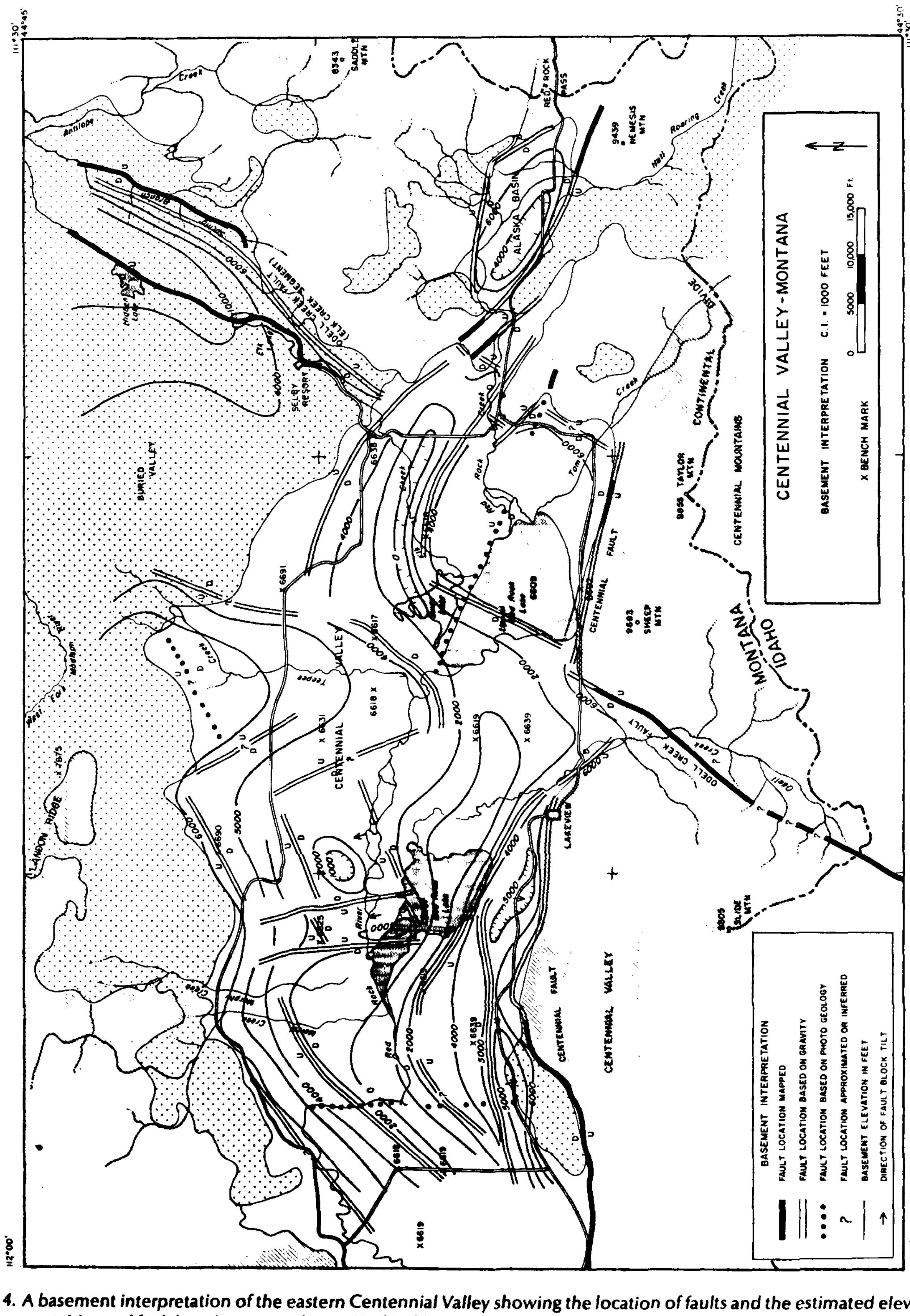

Figure 4. A basement interpretation of the eastern Centennial Valley showing the location of faults and the estimated elevation of the basement. Mapped fault locations according to Witkind (1976, Witkind and Prostka (1980) and Sonderegger and others (1980).

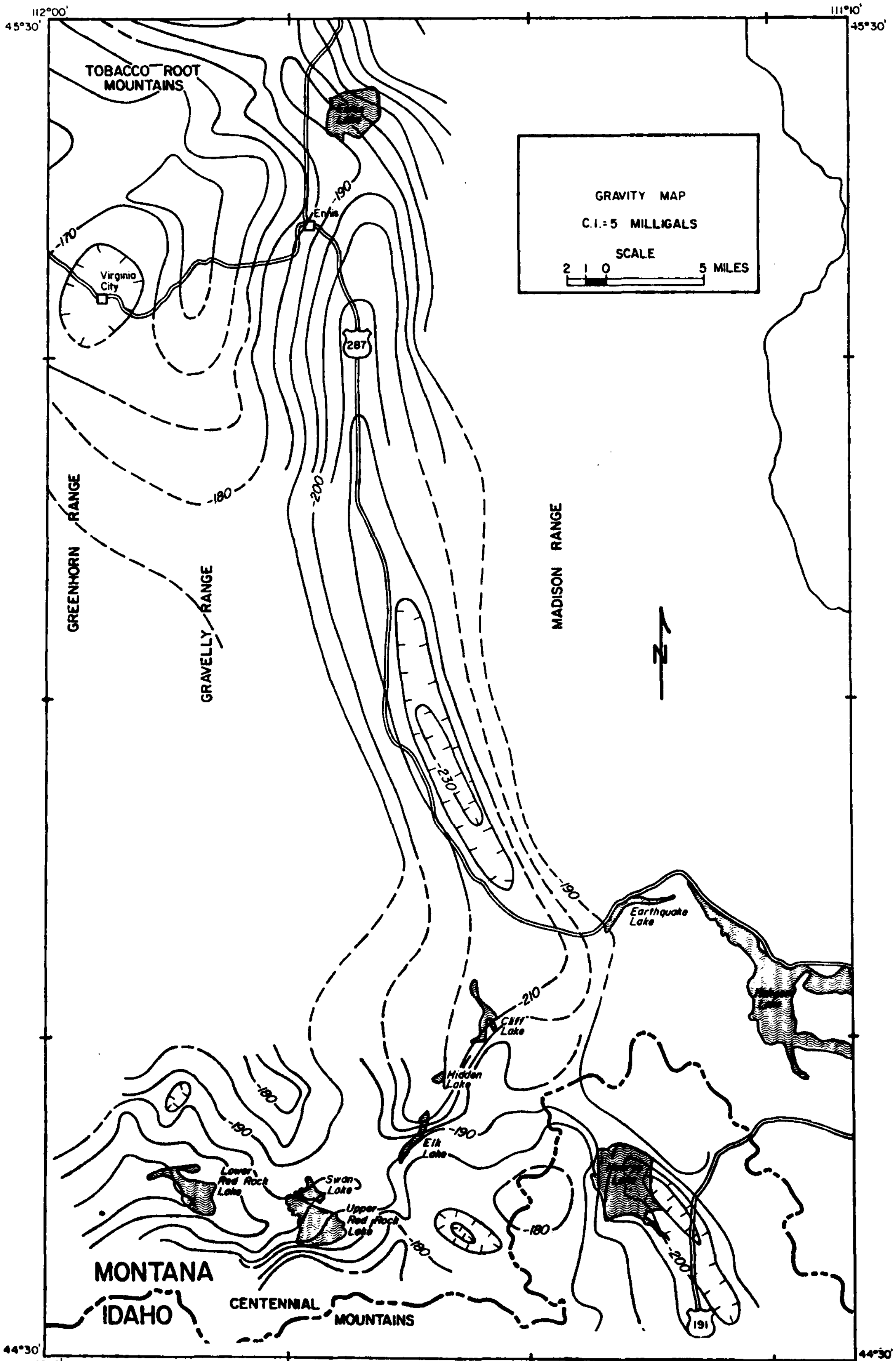

Figure 5. Complete Bouguer gravity map of the eastern Centennial Valley, Madison Valley, and Henrys Lake basin.

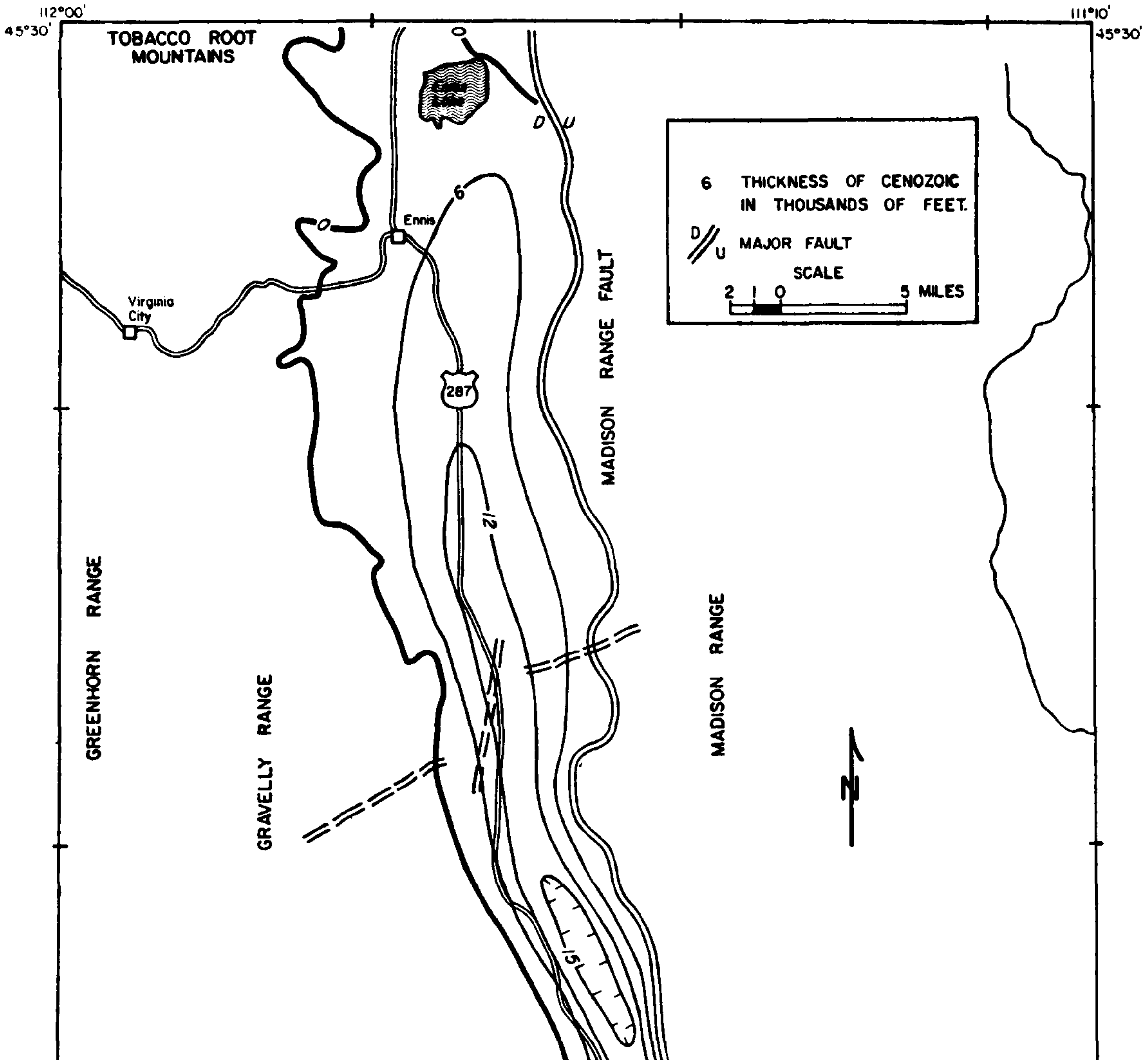

Figure 6. Map of the estimated thickness of Cenozoic fill for the eastern Centennial Valley, the Buried Valley, Madison Valley, and Henrys Lake basin.

single major normal fault and on the other by a series of normal faults of small displacement, with a valley floor which dipped toward the large boundary fault would produce an asymmetric anomaly like that of the Alaska Basin (**E**, Fig. 3). On the gravity map of Fig. 3, Centennial Valley and Alaska Basin appear as separate structures. The gravitational high between the valley and the basin coincides with a mapped horst. The horst is breached at the surface by Red Rock Creek. The small structural depression of Alaska Basin has more than 3,000 feet of relief.

MURPHY CREEK STOCK

The source of the gravity low near Murphy Creek (anomaly **I** of Fig. 3) not only has a low density but also a high susceptibility, as demonstrated by the results of a grond magnetic survey shown in Insert A (Schofield, 1980). The dipolar magnetic anomaly suggests the source is an intrustion. In southwestern Montana, gravity lows are often associated with intrustions. The gravity map of Montana (Bonini and other, 1973) has a low in conjunction with the Boulder Batholith and another over the Tobacco Root Batholith.

A seven milligal residual anomaly was modeled as a sphere. The calculations reveal a depth of 6,000 feet to the center of the anomalous mass, which is 4.3 billion tons lighter than a uniform bedrock section would be. Such a small intrustion would cool quickly, and indeed the strong magnetic anomaly means the body is below its Curie point (Curie point for magnetite is 578° C). A steeply dipping cylinder is a good approximation of the shape of the stock.

MADISON VALLEY

A gravity map of the Madison Valley is provided in Fig. 5, and an estimation of the thickness of Cenozoic sediments is given in Fig. 6. The magnitude of the gravity anomaly, in excess of 40 milligals, associated with the Madison Valley is unusual in view of the narrowness of the valley. The maximum thickness of valley fill for the Madison Valley is 15,000 feet based on models with a density contrast of -0.3 g/cc. Gary (1980), using a -0.5 g/cc. density contrast, predicts a miximum thickness of sediment in the valley of 10,000 feet. Gary's work also indicated the valley dips east into the Madison Range Fault, the bounding fault. A fault with northeast trend cuts the valley at approximately 45°05′ (Gary, 1980). According to Gary, the fault may be a reactivated zone of weakness, for a lineament shows up on the topographic, gravity, and aeromagnetic maps of the area. Textbook quality alluvial fans line the eastern edge of the Madison Valley, which attests to the magnitude of the displacement that has produced the Madison Range. Although the Madison Range Fault is defined as a normal fault, the fault plane solution calculated by Gary shows left-lateral relative movement along the fault, which he relates to the differential spreading rates along the Sanke River Plain. Last minute alterations were made to reflect the work of Gary in the Madison Valley.

Only a thin veneer of sediment covers Precambrian rocks at Raynolds Pass on the Idaho-Montana border where the Madison Valley ends and Henrys Lake Basin begins. The Madison Range Fault continues south of the Madison Valley into Henrys Lake Basin where it forms the eastern border of the basin. The Madison Range east of the basin has less relief than the mountains east of the Madison Valley, and the thickness of Cenozoic fill in the basin is substantially less than the fill in the Madison Valley. The maximum depth of fill predicted by modeling was 4000 feet. Peterson and Witking (1975) estimated 3600 feet using a model with two density contrasts (-0.6 g/cc betwen sediments and bedrock, -0.3 g/cc between volcanics and bedrock) rather than the single contrast of -0.3 g/cc used for Fig. 6. The deepest part of the basin appears to parallel the Madison Range Fault and to be east of the center of the basin. Henrys Lake Basin narrows where the Centennial Fault enters, but the gravity does not show the fault crossing the basin. If the fault actually does continue to the Madison Range the present displacement must be too small to detect with available gravity data.

SUMMARY

A small stock exists east of Murphy Creek. The Cenozoic fill in the Centennial Valley is at least 7,000 feet thick and may be as much as 10,000 feet thick. Gravity modeling suggests the narrow Madison Valley has a maximum of 15,000 feet of fill. Henrys Lake Basin is bounded by the same fault as the Madison Valley but there is only 4000 feet of fill within the basin. There are 3000 feet of sediments in the small, separate structure of Alaska Basin. The Odell Creek Fault extends north of the Centennial Fault under the Upper Red Rock Lake and northeast to the Madison Valley. The Elk Lake segment of the Odell Creek Fault bounds a valley buried by volcanics. The Centennial Fault is broken into several segments and into two main branchs. One branch of the Centennial Fault is covered by the fill in the valley. The basement of the Centennial Valley is divided into a number of separate blocks.

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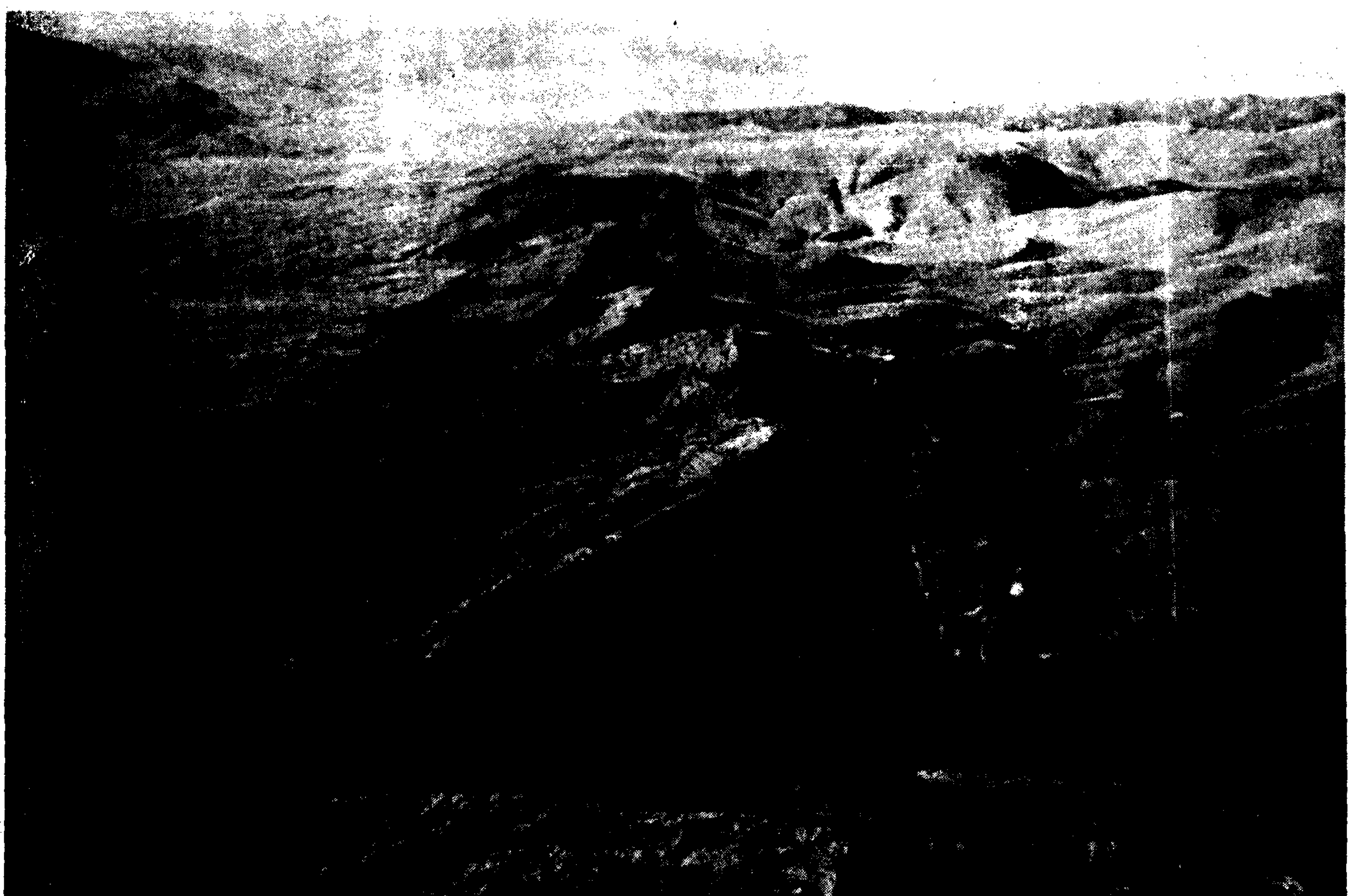


View northward across Camp Creek, east of Melrose, of the west-dipping Cambrian to Mississippian Sequence. The massive dark cliff in the middle of the slope on the far side of Camp Creek is Meagher dolomite which has been thrust eastward over the underlying Wolsey shale and Flathead sandstone to rest on the Precambrian schists. A later, north-striking normal fault has dropped the Meagher down on the east.

GEOLOGY AND GEOTHERMAL RESOURCES OF THE EASTERN CENTENNIAL VALLEY

by
John L. Sonderegger[1]

INTRODUCTION

The upper Centennial Valley graben was selected for geothermal evaluation in 1976 because this area contains the most areally extensive exposure of Quaternary igneous rock known within the state. Witkind's Open-File Report on known and suspected active faults in western Montana (1975) provided documentation that the southern side of the valley still had an active fault system. With rocks that were believed to be correlative to the Yellowstone Group volcanics exposed on both the north and south sides of the graben, it was logical to speculate on the thickness of young volcanic rocks within the graben itself. The absence of detailed geologic mapping north of the lakes made it impossible to estimate the thickness of volcanics which might be preserved within the graben.

Warm water occurrences were found to be restricted to the north side of the Centennial Valley (figure 1). A total of seven springs were located in sections 17 and 18, T. 13 S., R. 2 W. They have a combined discharge of about sis cubic per second (2700 gallons per minute) and an average temperature of 27°C. Also a zone of water approximately 5°C above the background temperature was depicted along the western half of the north side of Upper Red Rock Lake and along the marshy channel connecting it with the Lower Red Rock Lake. The boundaries of this zone were established by airborne heat sensing imagery.

Location of the spring discharge appears to be controlled by both Laramide and Tertiary structures. The springs occur along the axial plane and on the west limb of the Metzel Creek anticline (Honkala, 1949, 1960) where it is cut by late (?) Cenozoic age, normal, basin margin faults.

GEOLOGIC FRAMEWORK

This investigation was conducted in the basement province of McMannis (1965) which is typified by the absence of Belt strata, a generally thin Paleozoic and Mesozoic sequence, abundant Cenozoic basin deposits and volcanic ejecta, and extensive exposures of pre-Belt metamorphic rock. The study area is bounded to the west by the Tendoy Mountains, and the Snowcrest Range, the easternmost ranges with proven thrust faulting as the dominant Laramide structural mechanism. Late Cenozoic mountain formation is due to block faulting. To the north, south and east, the Gravelly, and Centennial ranges, and the Henry's Lake Mountains, respectively, are believed to be formed by block faulting. Most of the structural grain has been previously ascribed to the Laramide orogeny. The Laramide stresses from the west have deformed the Paleozoic and Mesozoic rocks into broad gentle folds in most areas. Valleys between the mountains have been infilled with Tertiary sediments and sedimentary rocks which normally appear undeformed, although highly deformed slump structures can be found in the Madison Valley. The thickness of valley fill varies, but up to 6,600 feet are believed to be present in the Centennial Valley (Schofield, this publication). Possibly 9,000 feet may exist under the Missouri Flats area of the Madison Valley (Steve Gary, 1979, oral comm.). Volcanic ash-flow tuffs of early Pleistocene age cover much of the valley margins. Glacial outwash and tills are preserved along the valley margins, while in the lower portions of the valleys lacustrine deposits sand dunes and alluvium are found.

The Cambrian through Mississippian section in the study area consists of carbonates interbedded with minor shale. Younger Paleozoic rocks become more clastic, containing nearly equal amounts of sandstone, shale and carbonate (cherts included). The Mesozoic strata are nearly all clastic, with minor carbonate and a preponderance of shale, siltstone, and sandstone, with minor coal reported nearby. The preserved Tertiary strata consist of basalt, limestone and sandstone, in that order of abundance. The Quaternary section includes 16 units of which 7 are volcanic.

The Paleozoic strata in the study area do not consitute the complete stratigraphic section. Faulting near Landon Camp (along the West Fork) has juxtaposed the upper Jefferson Formation against the Precambrian. A small block of what is believed to be Meagher Limestone (Middle Cambrian) is preserved along the creek bottom, just west of the fault contolling the West Fork drainage, but the intervening strata, if present, are covered by Pliocene basalt and Pleistocene tuff. The description below uses the nomenclature of Sloss (1966) for the major depositional cycles of the Paleozoic and Mesozoic Eras.

The study area is east of the Greenhorn fault, and while part of the "stable" craton, this area has a thinner Cambrian section preserved and no identifiable Ordovician age rocks. This suggests that the southern Gravelly Range was, to some extent, a positive element during Sauk sequence deposition. There are no preserved rocks from the Tippecanoe sequence, and Kaskaskia deposition starts with the Jefferson Formation of of Middle (?) and Late Devonian age. The area received Kaskaskian sequence sediments representative of those found in southwestern Montana, except for the Big Snowy Group, which, due to poor exposures, could have been missed in mapping. Erosion at the end of the Kaskaskia Sequence was severe to the north where Christie (1961, p. 40) notes erosional channels 200 feet deep in the Mission Canyon Formation.

Absaroka sequence rocks are thicker in this area than in most of southwestern Montana due to crustal downwarping. Armstrong and Oriel (1965) attribute the basin development southwest of the study area to the migration of the miogeosyncline toward the eastern portion of Idaho. The study area was on the shoulder or flexure of this structure and contains

[1]Montana Bureau of Mines & Geology, Butte, Montana; financial support by the U.S. Department of Energy under Contract No. EY-76-S-06-2426

only two recognized unconformities within this sequence. Erosion following the deposition of the Kaskaskian sequence was accompanied by southward tilting of the strata by the time the Ellis Group was deposited at the start of the Zuni sequence (McMannis, 1965).

The Zuni sequence starts with 300 to 400 feet of Jurassic rocks, mainly the Morrison Formation, unconformably overlain by the Cretaceous Kootenai Formation. Local angularity of the unconformity (Christie, 1961, p. 89) suggests additional tilting of the strata. Deposition following the Kootenai includes a thin shale and the Aspen Formation, a predominantly non-marine unit.

The Laramide orogeny deformed the sedimentary rocks, with the major structure in the area being the Metzel Creek anticline (Honkala, 1949). The northwesterly trend and asmmetry of the anticline (cross section A-A', figures 2 and 3) suggest that compressional force was directed from the west-southwest. Surficial mapping does not require that the anticline be faulted; however, so little of the east limb is exposed that the western limb may be locally detached and thrust over the eastern limb. This is compatible with Scholten's (1967) overview of the Laramide tectonics of this region. Culmination of this oroglenic event included the thrust faulting west of the study area to which Scholten (1967) and Ryder (1967) attribute the origin of much of the Beaverhead Formation, which unconformably overlies the pre-Laramide rocks in the western part of the study area. Scholten (1967), however, believes that the Blacktail-Snowcrest and Gravelly "arches" contributed significant volumes of clastics to the Centennial Valley. Thus, as the compressional forces of the

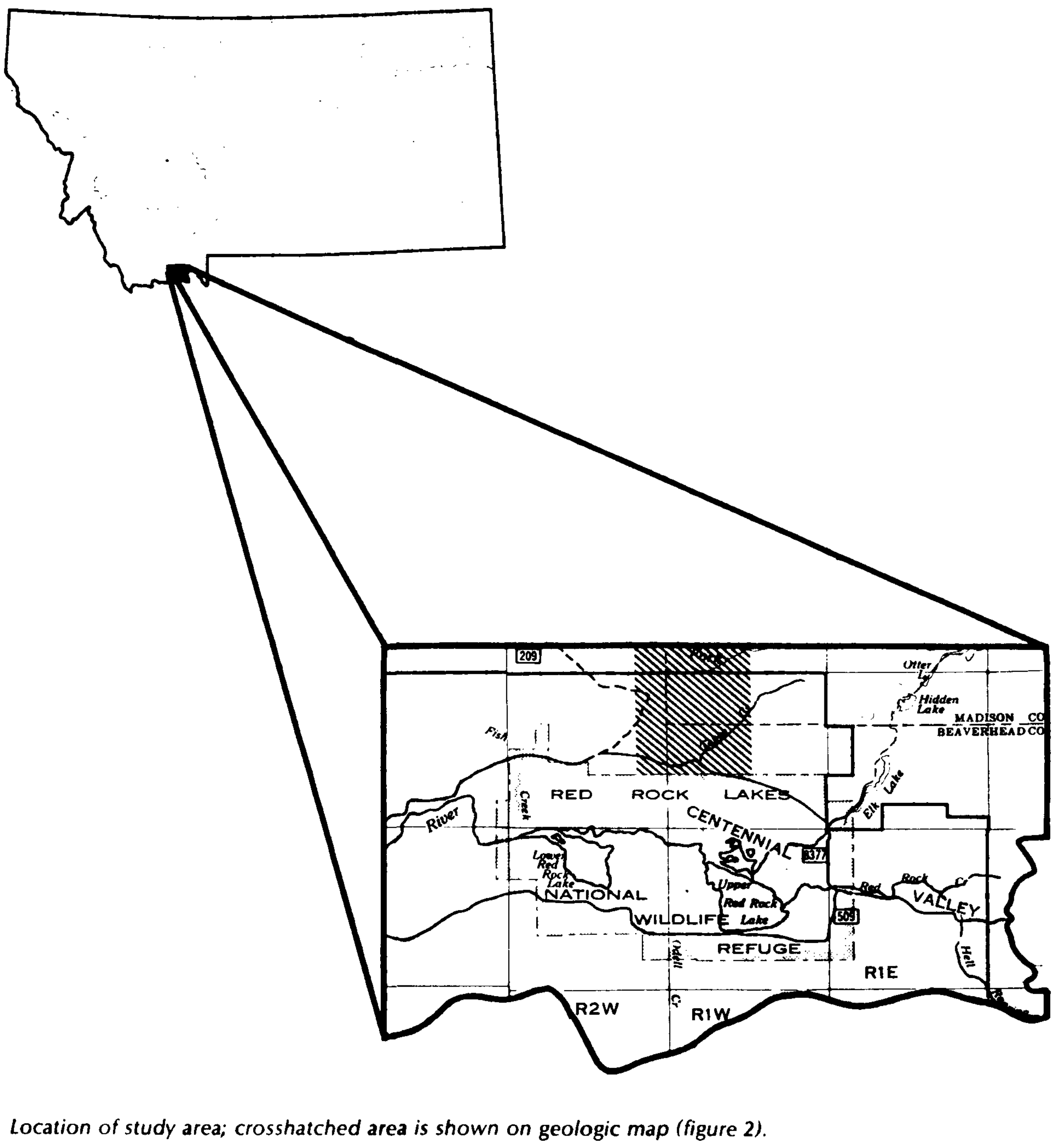


Figure 1. Location of study area; crosshatched area is shown on geologic map (figure 2).

Laramide were waning, renewed (?) block fault uplifting must have occurred north of the study area, probably in the Paleocene time.

From the end of Beaverhead deposition, presumably in late Paleocene or early Eocene time, there is no exposed rock record until the extrusion of the older Tertiary basalt at about the beginning of late Oligocene time. The basalt is overlain by lower (?) Miocene sandstone and limestone believed to be of continental origin. These units dip gently into the Centennial Valley from the north at about three degrees. Erosion followed and only remnants of these strata are preserved.

Within the study area, the Cenozoic history may be interpreted as follows:

(1) Doming occurred along the northwest-southeast trend on the east, as evidenced by the erosion of pre-Pleistocene rocks in the eastern portion of the study area. Faulting along the trend appears to be fairly local as evidenced by the

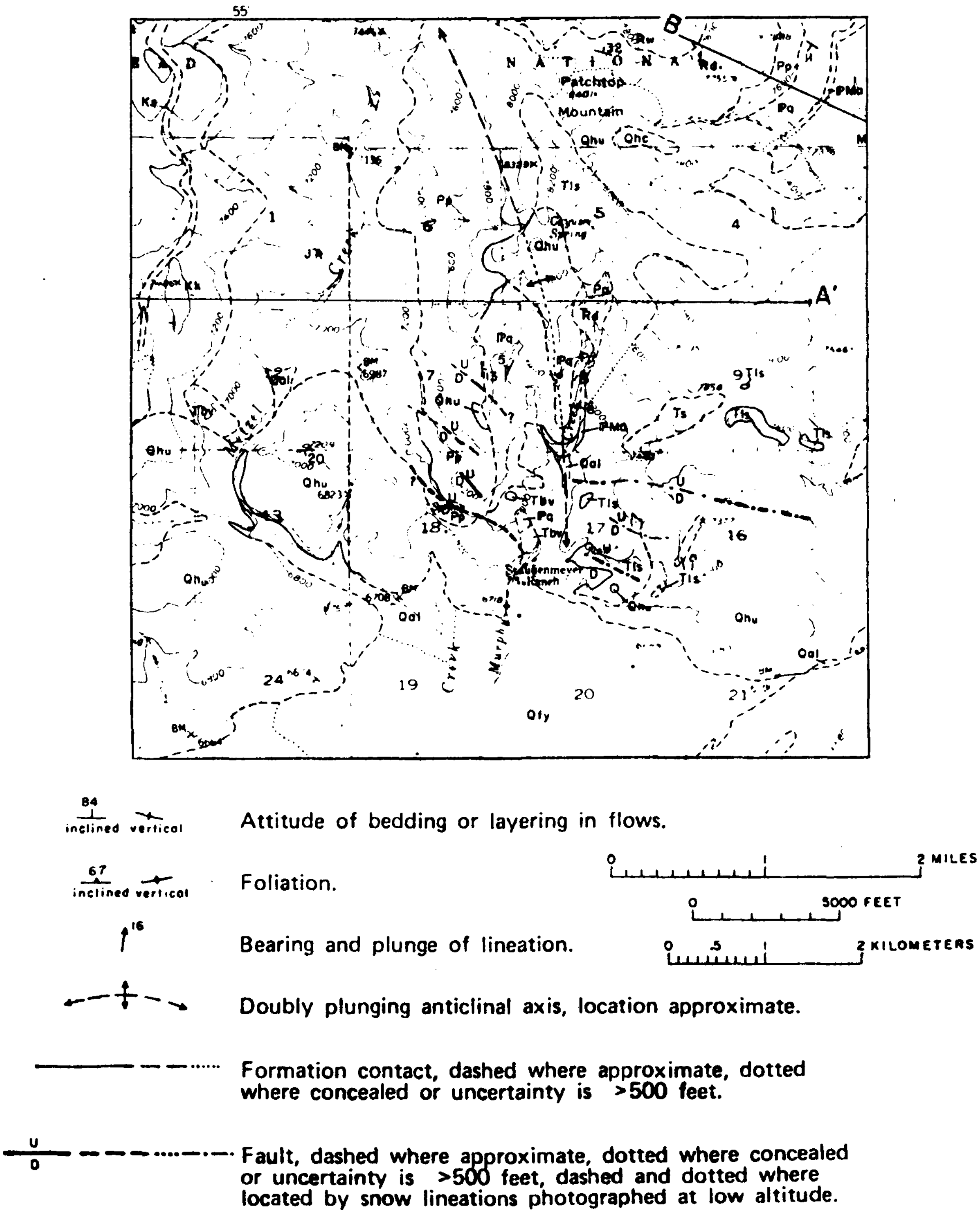


Figure 2. Geologic map in the vicinity of the warm springs.

juxtaposition of Devonian and Precambrian strata south of Landon Camp and the normal transgressive sequence which is preserved outside the study area along the West Fork of the Madison, roughly two miles to the northwest (Christie, 1961).

(2) Fluvial sedimentation and erosion were ongoing processes during Paleocene time. Sedimentation may have continued until the Early Eocene, with the major unit deposited being the Beaverhead Formation. An ancestral Centennial Range probably existed further south (Ryder and Scholten, 1973, Figure 10 and discussion of Pinyon-Harebell Conglomerate in Wyoming), which later foundered into the Snake River trough. The Gravelly Range was probably the major souce of sediment at this time. The near absence of limestone clasts in the Beaverhead suggests that drainage off the Gravelly block was to the west, or that the materials from the ancestral Centennial Range uplift were the volumetrically dominent influx. These two factors suggest the lack of a western source during Paleocene time. Drainage may have been to the east-southeast, as depicted by Ryder and Scholten (1973, fig. 10).

(3) Erosion locally reduced the land surface to a virtual plain during the rest of Eocene and early and middle Oligocene time, as evidenced by the flat basal nature fo the Oligocene basalt flow near Cayuse Spring. The western part of the study area was probably a pediment. To the north, a structurally active, upland erosional area must have been maintained. This interpretation is based upon Christie's (1961) contact between the Tertiary basalt and underlying pre-Tertiary formations and preexisting normal faults.

(4) Fluvial deposition of the unnamed Tertiary sandstone probably occurred during the early Miocene. The influx of clastics was sufficient to disrupt existing drainage, as this unit is overlain by a limestone believed to be of fresh-water origin. Consequently, moderate uplift of the Gravelly block during the late Oligocene-early Miocene interval followed by a period of relative tectonic quiescence is envisioned.

(5) Pliocene age units have not been recognized in outcrop within the study area. It is believed that tectonic quiescence continued throughout most of this time. Renewed uplift and erosion probably began near the end of the Pliocene as evidenced by volcanic flows and reworked Beaverhead Formation south of the map area (Witkind and Prostka, 1980), scattered patches of reworked gravels in the vicinity of Two Drink Springs, and the topographic relief formed on the Tertiary limestone and sandstone units before deposition of the overlying early Pleistocene age ash-flow tuffs.

(6) During the early Pleistocene a moderate amount of relief must have existed, based upon the outcrop pattern of the oldest Pleistocene volcanic unit compared to underlying older strata (Witkind, 1976; Witkind and Prostka, 1980; Sonderegger and others, in prep.). It is believed that the Huckleberry Ridge ash-flow tuff erupted from the Island Park Caldera, passing over the then-low ancestral Centennial Mountains, across the Centennial Valley and up against the southern margin of the Gravelly Range (Christianson, 1979; Mannick, 1980). On the northwest side of Deer Mountain, northeast of the Upper Red Rock Lake, a minimum of 500 feet of preexisting relief is indicated by the Huckleberry Ridge-Precambrian contact. Movement along the Centennial fault continued throughout the Quaternary, displacing the Huckleberry Ridge Tuff a minimum of 1500 to 1800 meters (5,000 to 6,000 feet) in the last 2.0 million years. The Centennial Range was sufficiently high 1.2 million years ago to block the passage of the Mesa Falls ash flow into the upper Centennial Valley from the Island Park Caldera. The only portions of the ash flow to enter the valley crossed the divide through low passes such as one near Hell Roaring Canyon (Witkind, 1976). Major volcanism occurred in the Yellowstone caldera region 0.6 million years ago producing the Lava Creek Tuff. This ash flow was entirely blocked from the upper Centennial Valley and is exposed along the lower southeastern slopes of the Centennial Range.

(7) Normal faulting on the north side of the valley is well exposed in the Phosphoria Formation outcrop west of the Metzel Creek anticline, where displacement is on the order of 40 feet. Lineations representing unmelted snow were noted during a low altitude over flight the area. They are believed to represent minor fault scarps, unrecognizable on the ground, which have less than five feet of displacement and which cut the Huckleberry Ridge Tuff. If this interpretation is correct, the

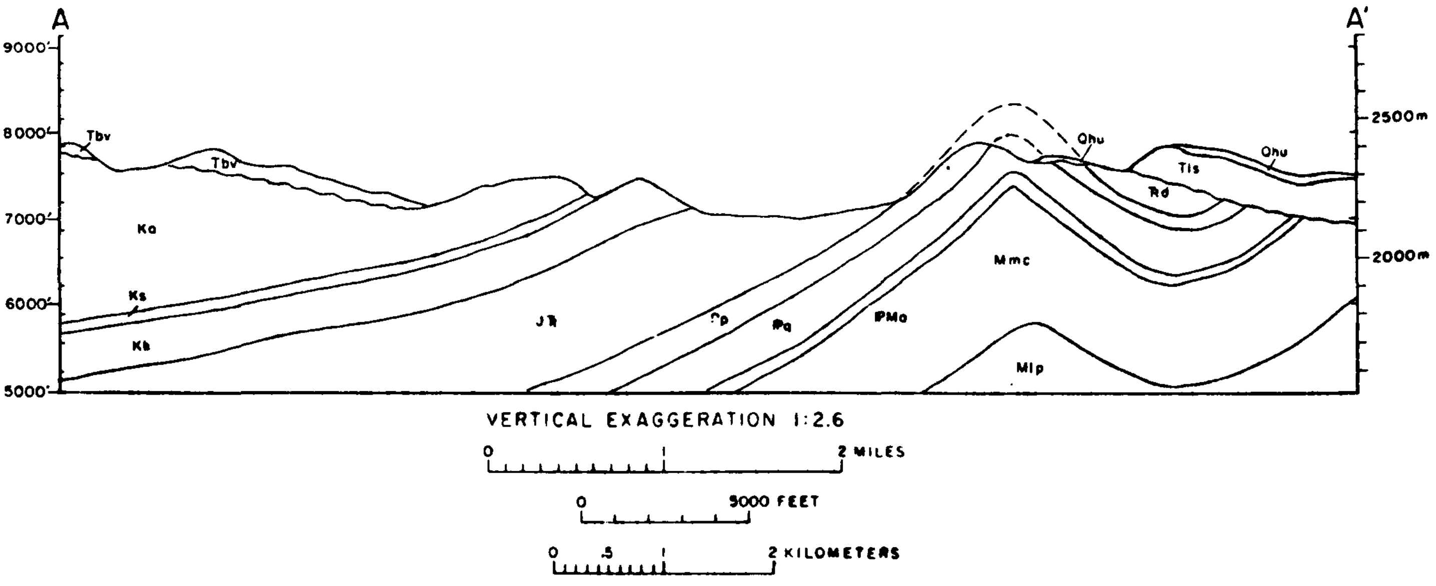
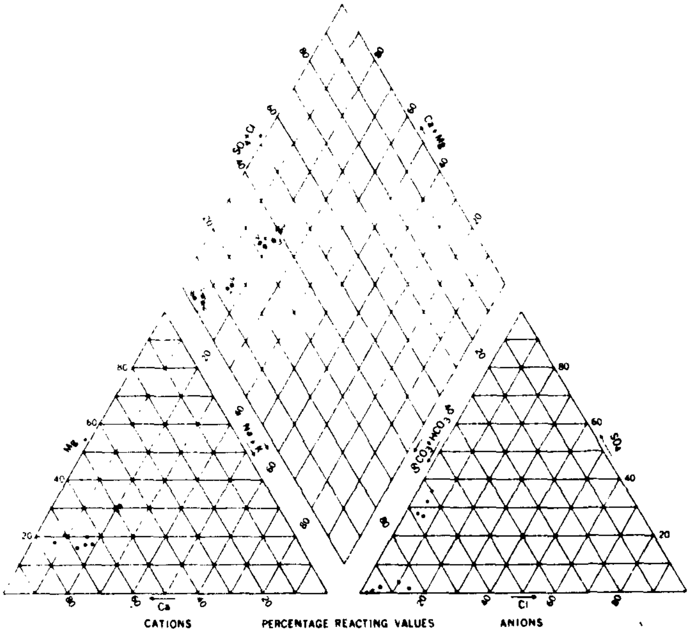


Figure 3. Geologic cross section nearly normal to the Metzel Creek anticline.



No.	TDS	Source
1	394	Anderson Springs
2	401	Staudenmeyer Springs
3	519	Staudenmeyer House Well
4	376	Anderson House Well
5	347	Anderson Stock Well
6	128	Smith Boxcar Well
7	184	Refuge Stock Well
8	176	Staudenmeyer Stock SE
9	313	Staudenmeyer Stock SW
10	184	Staudenmeyer Stock NW

Figure 4. Trilinear diagram of water chemistry from wells and warm springs.

faults must be less than two million years old and may be considerably younger. The warm springs occur just below the fault trace on the downdropped side of the faults.
faults.

(8) Alpine glaciers eroded the mountain ranges surrounding the Centennial Vally at different times throughout the Pleistocene. Deposits of pre-Bull Lake, Bull Lake and Pinedale glaciations indicate that the ice originated in high cirques and traveled downward, cutting U-shaped valleys which, in many instances, reached the larger valley floors such as the Madison Valley (Weinheimer, 1979). Glacial meltwater accumulated in the Centennial Valley to form a large lake which drained at several locations including a stream situated in the Cliff Lake Fault trench. The West Fork of the Madison River began to cut a valley approximately along the Huckleberry Ridge Tuff-Precambrian contact (Gravelly fault) during late Pleistocene-early Holocene time. The Centennial Valley glacial lake eventually receded to form the Upper and Lower Red Rock Lakes and associated ponds and marshes. As the lake receded, the drainage along the Cliff Lake fault trench was dammed by mass wasting to create Elk, Hidden, Goose, Otter, Cliff, and Wade lakes.

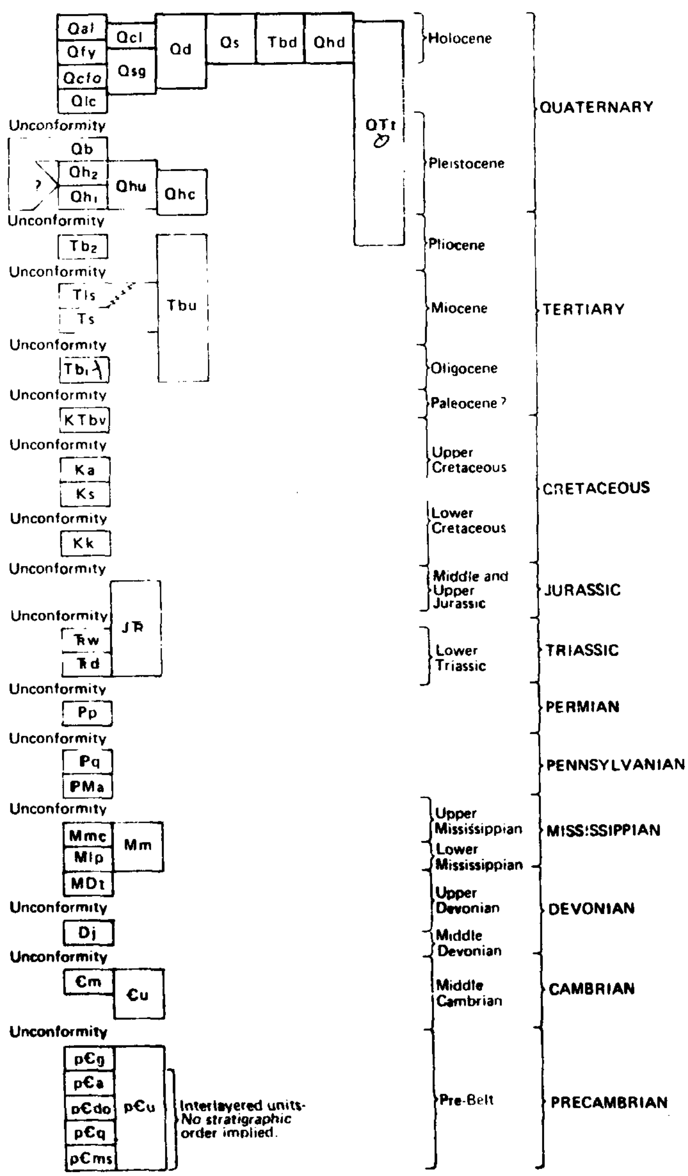
(9) It appears that the rate of movement along the Centennial fault has increased since Pinedale time to over an inch per year. The Centennial, Cliff Lake, and southern Madison faults continue to be seismically active today.

WATER CHEMISTRY ASPECTS

The types of water chemistry exhibited by springs and wells on the north side of the Centennial Valley are fairly similar: (1) bicarbonate is the dominant anion; (2) calcium is the dominant cation; (3) magnesium is generally the second most abundant cation (based upon milliequivalents per liter). North of Upper Red Rock Lake, where the Huckleberry Ridge Tuff is thicker, springs with a shallow, local flow system commonly have a total dissolved solids (TDS) content of less than 100 milligrams per liter (mg/L). Wells south and east of the warm springs have TDS values ranging from 128 to 519 mg/L. Figure 4 depicts chemical characteristics of these wells in the valley Quaternary deposits. Two subgroups can be characterized. The low TDS wells have smaller percentages (on a milliequivalent per liter bases; Hem, 1970, p. 268-270) of magnesium and sulfate. There is a distinct hiatus of sulfate values betwen 7 and 24 percent. The high sulfate waters are restricted to wells and springs along the northern margin of the valley.

The major sources for sulfate in ground water are the dissolution of sulfate minerals such as gypsum and andydrite, and the oxidation of sulfide minerals such as pyrite. Warm springs issuing from the Madison Group (such as Anderson's, Bearmouth, Bridger Canyon, Brooks, Carter's Bridge, Durfee

CORRELATION OF MAP UNITS



Creek, LaDuke, Landusky, Little Warm, Lodgepole, McMenomey, Plunkets, Toston, and Vigilante; Sonderegger and Bergantino, 1981) have a relatively high sulfate content. Hot springs believed to be derived from the Madison (LaDuke, New Biltmore, and Warm Springs State Hospital; ibid.) have the anion content of their water dominated by sulfate. The generally accepted explanation for this phenomena is the dissolution of sulfate minerals from the upper portion of the Madison Group.

The other shift associated with the high TDS and thermal waters is a change toward higher Mg/Ca ratios. The Madison Group is a dolomitic limestone; both dolomite and calcite will be dissolved by undersaturated waters. Both the dissolution and precipitation of dolomite are retarded relative to calcite, probably by larger necessary activation energies. Consequently, one expects to see calcite and dolomite dissolution occur in recharge areas (equations 1 and 2, respectively)

(1) $CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3$

(2) $CaMG(CO_3)_2 + 2H_2CO_3 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3$

As water descends to greater depth, temperatures increase and the water becomes supersaturated with respect to both minerals. However, calcite precipitates much more easily than dolomite and the fluid phase becomes enriched with magnesium.

If the thermal water is not diluted the water chemistry can be used to calculate values commonly referred to as "reservoir temperatures." The methodology varies; the silica thermometers compare the silica content of the thermal water with that believed to be in equilibrium (laboratory data) for solid phases such as quartz, chalcedony, a or b cristobalite, or amorphous silica, while the cation geothermometers use atomic ratios of the elements Na, K, and Ca, and equivalent ratios of the elements Mg, Ca, and K.

In the Centennial Valley, the thermal springs have water chemistry with a definite limestone signature. Quartz and chalcedony geothermometers yield reservoir temperatures of 66° and 34°C, respectively. The Na-K-Ca geothermometer yields a temperature of 52°C, due mainly to the Na/K ratio of 6.4. The high Mg and Ca content of the water suggests that it has never been very hot (Mg/Ca ratio of 0.59).

The magnesium correction is not applied to waters which yield a Na-K-Ca temperature of less than 70°C (Fournier and Potter, 1979), so this correction is not made to the Centennial Valley thermal waters. Based upon the data available, and assuming no dilution, the reservoir temperature is believed to be 45°C or less, with 40°C probably being a reasonable estimate of the maximum reservoir temperature. The highest chalcedony temperature calculated from these springs is 37°C. Chloride content varies from 9.0 to 10.0 mg/L, and silica from 20.1 to 23.3 mg/L. These data prohibit the use of most dilution models for the spring data.

If the water from the Staudenmeyer ranch house well (T= 10.2°C) is considered, due to its high dissolved solids content, to represent the "best" water sample, chalcedony and Na-K-Ca temperatures of 48° and 62°C, respectively are calculated. The silica content may be elevated due to contact with detrital volcanic material, and the maximum temperature for the thermal system is still about 45°C if no significant mixing or precipitation has occurred.

The silica geothermometry becomes almost useless when water interacts with glass-rich acidic rocks such as the Huckleberry Ridge Tuff. Samples of this rock and the Mesa Falls Tuff were ground to medium- to fine-sand size and leached with distilled water in the laboratory at different temperatures. Within three months, the silica content in the water plotted between the α and β cristobalite curves for laboratory temperatures of 27° and 57°C.

CONCLUSIONS

A lake temperature survey showed warmer water along the northern side of Upper Red Rock Lake. Heat sensing imagery was flown over the northern side of the valley during the fall of 1977. An intense rain storm the afternoon before the flight resulted in ponding of water in almost all areas except the sand dunes. Air temperature was slightly below freezing between 3:00 and 5:30 a.m. while ground truth data was collected and the overflight occurred. Water temperatures on the lakes and river were considered to be the only reliable values under these conditions. Temperatures ranged from 8.5° to 15.5°C. A warm zone was identified from the computer printout of the digital data.

The alignment of the thermal water zone southeast of the thermal springs is subparallel to Quaternary age faults identified by low altitude aerial reconnaissance. These features are interpreted to be small scale step faults on the southernmost margin of the Gravelly Range. These faults are beilieved to aid in localizing the ascent of warm water from the Madison Group limestones near the axis of the doubly-plunging Metzel Creek anticline. The heat source could be either p postulated intrusive (Schofield, this publication) or deep circulation. Based upon the small size of the postulated body and the rapid cooling which it would undergo, it appears more probable to assign the source of the heat to the deep circulation of meteoric water.

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Tight S-shaped fold in Lodgepole beds adjacent to Jefferson Canyon fault (large draw to the left), Jefferson Canyon (looking south). Photo by Rich Aram.

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SUBSURFACE INVESTIGATIONS AT BOZEMAN HOT SPRINGS

DONOVAN, Joseph J., STICKNEY, Michael C., and SONDEREGGER, John L., Montana Bureau of Mines and Geology, Butte, MT 59701; and PAGE, Charles, Bozeman Hot Springs, Bozeman, MT 59715.

Body of Abstract

Recent drilling activities have investigated the subsurface geology directly beneath Bozeman Hot Springs. Beneath 470 ft. of valley fill sand, clay, and gravel, there is a 30-40 ft. thick caving zone, dry during drilling, which yields large subangular cobbles but little sand. This zone is either fractured bedrock (pre-Belt gneiss) or monolithologic "rubble" of uncertain origin directly overlying bedrock. Fractured gneiss from 525-680 ft. produced >2000 gpm during drilling, later decreasing to 1510 gpm due to massive caving in the rubble zone. Aquifer testing yielded initial transmissivity estimates of 190,000 gpd/ft followed by a boundary condition value of 26,000 gpd/ft encountered after eight hours. Two possible interpretations are: (a) the very permeable fractured aquifer is of limited extent, (b) the dry "rubble" zone fills with water when the well is shut in and causes the initial high-T values. Long-term sustained yield is 790 gpm; temperature is 54° C, very close to that of the spring. Hotter temperatures occur elsewhere in the system at shallow depth: temperature of water seeping from a Tertiary sand bed at depth 125 ft. is 59° C. Aqueous silica-quartz and cation geothermometers yield temperatures from 114°-130°C, thought to be estimates of temperature at the greatest depth of circulation. Under normal gradient conditions this would be about 5 km.

Gravity measurements taken near the springs at half mile intervals with a Lacoste-Romberg gravimeter define a broad NE-trending anomaly, corresponding to that shown by Davis et al. (1965), extending nearly across the Gallatin Valley. This anomaly reflects a bedrock high beneath valley fill that is probably fault-bounded. The faulted SE margin of the anomaly may be part of the geothermal system. In a detailed survey near the springs, precise (0.1 mgal) Bouguer anomalies were determined for stations with 300 ft. spacing, revealing a subtle elongate gravity high of several milligal amplitude, trending about N 60° E, subparallel to the broad high. This anomaly is about 0.3 mi. north of the springs and represents either a buried bedrock ridge or a zone of hydrothermal mineralization in alluvial gravels along the axis of a relict flow system.

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STRUCTURE OF THE CENTENNIAL AND MADISON VALLEYS BASED ON GRAVITATIONAL INTERPRETATION

by
James Dean Schofield[1]

ABSTRACT

Major structural elements in the Centennial-Madison region of Southwestern Montana and adjoining Idaho are revealed by examination of the gravity maps of the area. The gravity anomaly of the eastern Centennial Valley is almost 40 m/gals. and the southern Madison Valley has a comparable anomaly; whereas the Henrys Lake basin has a 25 milligal anomaly.

Modeling suggests there exists approximately 3500 feet of Cenozoic deposits in the Henrys Lake basin, less than half the depth of Cenozoic sediments estimated for the Centennial and Madison Valleys. A gravity low extends from the eastern end of the Centennial Valley toward the Madison Valley. The low is interpreted as a valley that previously connected the two valleys but is now hidden beneath several hundred feet of volcanic flows. The buried valley is aligned with the O'dell Creek fault, and appears to be controlled by the fault. The east side of the O'dell Creek fault has been uplifted. The sediment thickness below the Upper Red Rock Lake is just 2000 feet, significantly less than the remainder of the Centennial Valley. Both the Centennial and Madison faults are normal faults that can be traced into the Henry Lake Basin.

INTRODUCTION

Gravity data for the Centennial and Madison Valleys (see Fig. 1) has been examined in an attempt to delineate the major faults of the region and to estimate the thickness of the low density Cenozoic fill of the valleys. Gravity measurements can reveal structural elements not visible on the surface. Density contrasts cause variations in the local gravitational acceleration; therefore, those structures that juxtapose materials of different densities, such as faults, can be detected. The geologic map shown in Fig. 1 has been simplified because differences in density may not correspond to differences in age or lithology.

Most of the major topographic units of southwestern Montana, including the Centennial and Madison Valleys and surrounding mountain ranges, are related to Cenozoic block faulting. The faulting took place in a regime of crystalline rock. The two faults with the largest displacement in this area are the Centennial Fault and the Madison Range Fault. These are the bounding faults of the valleys investigated. The Centennial Mountains are controlled by the normal fault to the north. The southern flank is buried by volcanic rocks of the plain.

On Fig. 1 are the sources of gravity data for this paper. With 179 gravity stations in the Henrys Lake area, 175 stations in the eastern Centennial Valley, and nearly two hundred stations in the northern portion of the Madison Valley, the station density is adequate. There is data across the Upper and Lower Red Rock Lakes. The coverage is sparse in the mountains near Hidden Lake.

METHOD OF INTERPRETATION

The interpretations of the gravity data in Figs. 4 and 6 are based on 2-D modeling using Talwani-type programs (Talwani and others, 1959). The emphasis of this paper is on the eastern Centennial Valley. Ten profiles of the area were modeled in detail (Schofield, 1980); three additional profiles were modeled for the Madison Valley interpretation, and another for Henrys Lake Basin. The models consisted of a simplified geologic cross section having a single density contrast with the observed and calculated gravity for the profile plotted above (Fig. 2). The basement interpretation of Fig. 4 was constructed by plotting the structures portrayed on the 2-D models in their proper location, and then using the gravity map to guide the interpolation between cross sections.

The density contrasts used for the Centennial profiles ranged from -0.6 g/cc to -0.35 g/cc. The density contrasts picked are the differences between the estimated bedrock density and the traditional 2.25 g/cc for Cenozoic valley fill in southwestern Montana (Burfeind, 1967). These density contrast values used may be large and may not reflect the true amount of compaction and lithification. The density contrast used for the Madison Valley and Henrys Lake Basin profiles was -0.3 g/cc. Gary (1980) used a -0.5 g/cc contrast (2.8 g/cc for Precambrian metamorphic rocks, 2.3 g/cc for Cenozoic

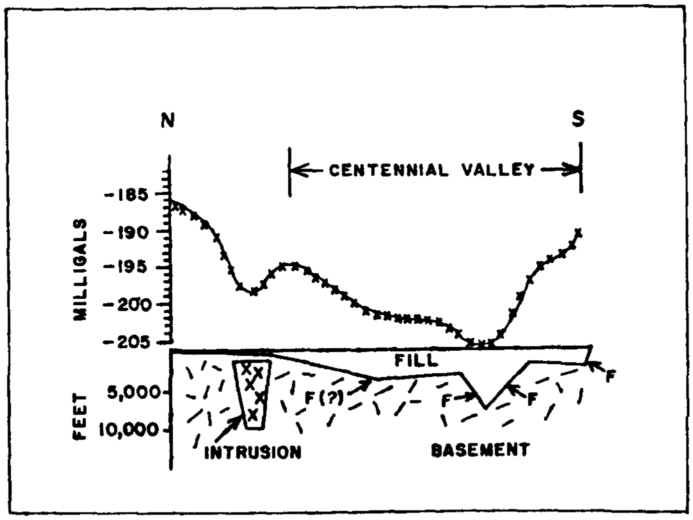

Figure 2. A 2D gravity model of a north-south profile across the lower Red Rock Lake showing the Murphy Creek stock, the fill in Centennial Valley, the faults (F) controlling the shape of the valley, and the north dipping block associated with anomaly H or Fig. 3. The density contrast between both the intrusion and the fill with the basement is -0.564 2/cc. The X's represent the observed gravity; the solid line, the calculated gravity.

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sediments and volcanic tuffs).

In general, gravity highs are associated with mountainous areas and gravity lows with valleys. Large gravity gradients are associated with major faults that juxtapose materials with different densities. Small highs within the low of the valley may be interpreted as uplifted basement blocks. but there is no unique structural interpretation for any given gravity anomaly. The expression of a particular body will broaden as it is buried deeper and deeper, thus, gravity anomalies of small areal extent are assumed to be near surface.

CENTENNIAL VALLEY

Fig. 3 is the complete Bouguer gravity map of the eastern Centennial Valley. There is a broad east-trending gravity low in conjunction with the Centennial Valley. The gravity anomaly across the valley is 20 milligals. The complete gravitational expression of the Centennial and Madison Valleys is not known because very few gravity stations are setup in the mountina.s The map of the basement of the valley (Fig. 4) shows a complex structure which is concealed beneath the nearly flat surface. The depth to basement is

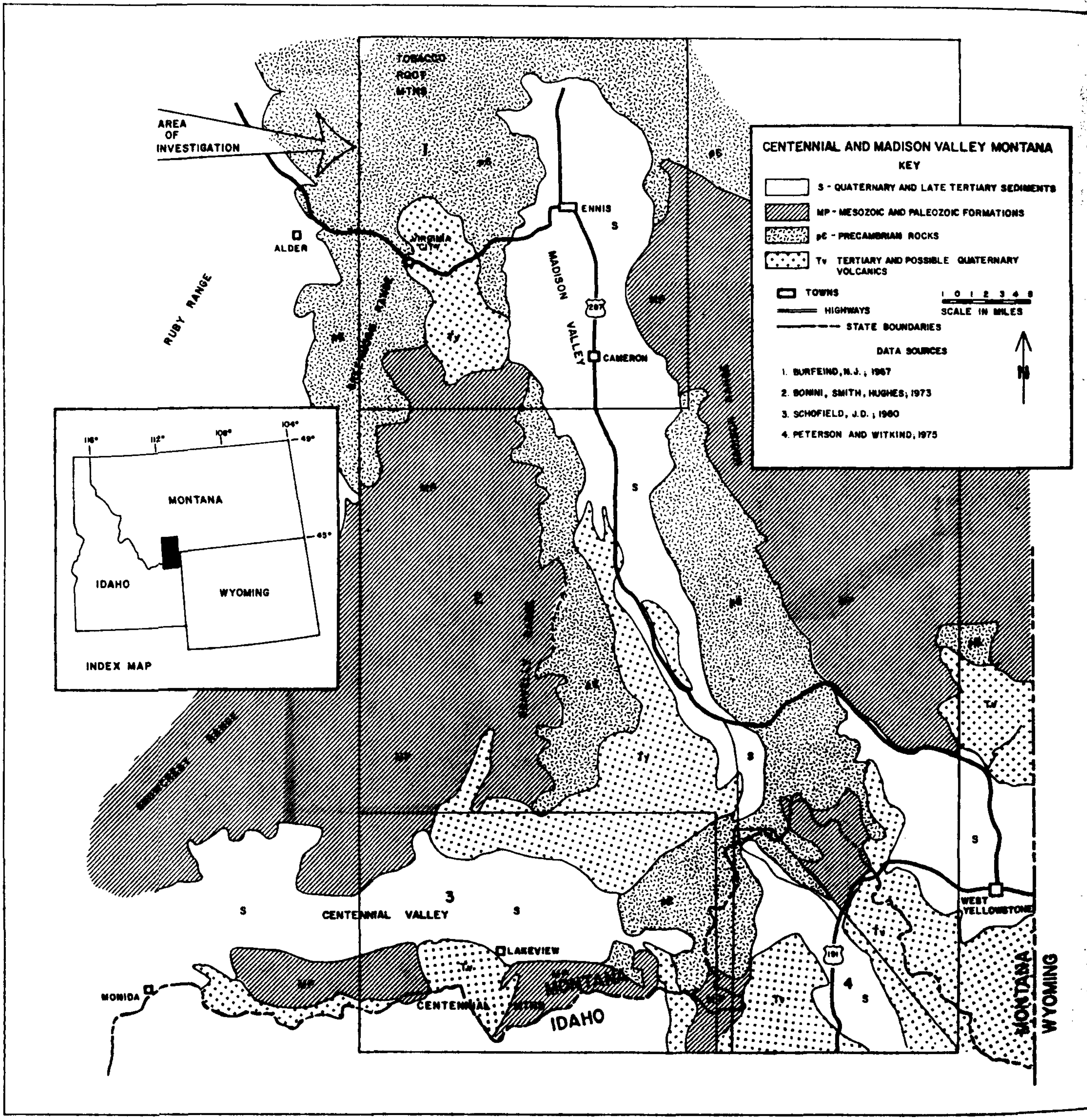

Figure 1. Index map. Generalized geology map (after Egbert, 19600 with bibliographic index for gravity data.

probably too conservative because of large density contrasts used. The maximum thickness of Cenozoic sediments, based on the 2-D model's 7000 feet of fill, may be as much as 3000 feet too small. The smaller anomalous gravity features are marked with letters, and are:

A. The steep gravity gradient with variable contour spacing between the Centennial Mountains and the Lower Red Rock Lake.
B. The south pointing indentation of the gravity contours where Odell Creek emerges from the Centennial Mountains;
C. The steep gradient between the Centennial Mountains and the Upper Red Rock Lake;
D. The nose in the gravity contours at the Upper Red Rock Lake;
E. The closed gravity low at Alaska Basin;
F. The narrow gravity low paralleling the trend of Elk and Hidden Lakes;
G. The south pointing nose at Teepee Creek;
H. The bend in the gravity contours north of the Lower Red Rock Lake; and
I. The closed gravity low near Murphy Creek.

CENTENNIAL FAULT

Modeling of the gravity data suggests that the Centennial Fault should actually be thought of as a fault system rather than a single fault. The Centennial Fault is broken into a number of segments, and in the eastern half of the valley there are two major branches to the Fault: a branch beneath the sediments as well as the high angle normal fault mapped on the surface. South of the Lower Red Rock Lake the displacement of the Centennial Fault has taken place in two large steps, and perhaps several smaller steps below the resolution of the data. The basement elevations south of the lower lake increases from sea level to +5000 feet at the top of a fault block which dips south into the surface branch of the Centennial Fault (Fig. 4). The south dipping blocks are the cause of the widening of the contours at gravity anomaly **A** of Fig. 3. A dip to the south would conform in direction with the dip of the Mesozoic formations (20° - 30° S) south of the lower lake (Pardee, 1950). Pardee states that the Tertiary lavas on the summits also dip to the south, though less steeply. It should be noted that Witkind (1975) mapped the Centennial Mountains east of Odell Creek as the southwest limb of a southeast-plunging anticline. At Odell Creek, the Centennial Fault appears to be a single unit that ends against the Odell Creek Fault (anomaly **B**).

The Centennial Fault bifurcates east of the Odell Creek Fault and forms an upraised platform beneath the Upper Red Rock Lake (nose **D**). The north branch of the Centennial Fault lifts the bedrock more than 4000 feet. The surface of the platform is inclined to the northwest. The unexpected existence of a shallow basement below the Upper Red Rock Lake helps explain the warm water discovered by the Montana Bureau of Mines and Geology in the Upper Red Rock Lake. Metoric water probably circulates along the north Centennial Fault which forms the north face of the platform. The path of the warm water for the final few hundred feet to the surface is not known uniquely, but the most probable route is the suspected fault along the northern border of the upper lake. The fault was not detected on the gravity map; however, small vertical offsets would not be detected and the fault need not be large to trigger depositional infilling of the older lake of which Swan Lake, Upper Red Rock Lake, and the surrounding swamps are but remnants. Such a fault could easily serve as a conduit for the warm water.

The imposing front of the Centennial Mountains, where the elevation changes 3000 feet in a mile, coincides with the large gravity gradient marked **C** on Fig. 3. At least 10,000 feet of vertical displacement has occurred along the Centennial Fault system, and the movement has probably taken place in the last ten million years. An average rate of displacement of 0.3 mm/yr is easily accepted in view of present rates of uplift and subsidence. Recent releveling has revealed that the eastern Centennial Valley is being uplifted by 5 mm/yr (Reilinger and other, 1977) and rates of uplift as high as 14 mm/yr have been measured at the center of the Yellowstone Caldera (Smith and Christiansen, 1980). Curiously, the Centennial Fault has an obvious scarp in the western half of the valley where the rate of uplift is only a fifth of that on the eastern end, yet the eastern scarp is lost beneath till, landslides, and alluvial fans. That the Pliocene (?) volcanics at the southern rim of the Centennial Valley were probably once continuous with the volcanics near the Continental Divide in the Centennial Mountains (Witkind, 1975) illustrates the magnitude of movement of the bounding fault of the valley.

ODELL CREEK FAULT

The most important conclusion formed about the Centennial Valley is that the gravity low trending northeast from the eastern end of the valley (gravity anomaly **F**) is caused by the Cenozoic sediment fill of a valley which has been concealed by a layer of volcanics several hundred feet thick. This buried valley is a direct connection between the eastern Centennial and the southern Madison Valleys. Before the valley was covered by rhyolitic flows, it probably served as the drainage for the eastern Centennial Valley. The approximate width of the valley hidden by the volcanics is from Teepee Creek to Elk Lake. It would seem the western border is a north-trending fault east of Teepee Creek (anomaly **G**). The eastern boundary of the valley is more clearly defined. Gravity anomaly **F** is interpreted as a segment of the Odell Creek Fault; this segment is the bounding fault of the buried valley. The mapped portion of Odell Creek Fault has a strike of N.30°E. which is similar to the western flank of gravity anomaly **D**. The Elk Lake segment (Fig. 4) has the same N.30°E. strike as the series of lakes and ponds connecting the Centennial and Madison Valleys. High seismicity was noted along a N.35°E. trend from Cliff Lake into the Madison Valley during a recent investigation (Bailey, 1977).

The Odell Creek Fault has "an estimated stratigraphic throw of 4,500 feet and a displacement of 3,000 feet" in the Centennial Mountains (Honkala, 1949, p. 104). This high angle normal fault has a general strike of N.30°E. The western edge of the platform of bedrock below the upper Red Rock Lake is formed by a segment of the Odell Creek Fault which has vertical displacement in excess of 2,000 feet (Fig. 4). The Odell Fault has been offset by movement on the younger Centennial Fault. Basement may have been dropped as much as 6,000 feet on the west side of the Elk Lake segment of the Odell Creek Fault. The movements indicated by gravity modeling are comparable to the measured movement of the fault.

ALASKA BASIN

A simple downdropped block, bounded on one side by a

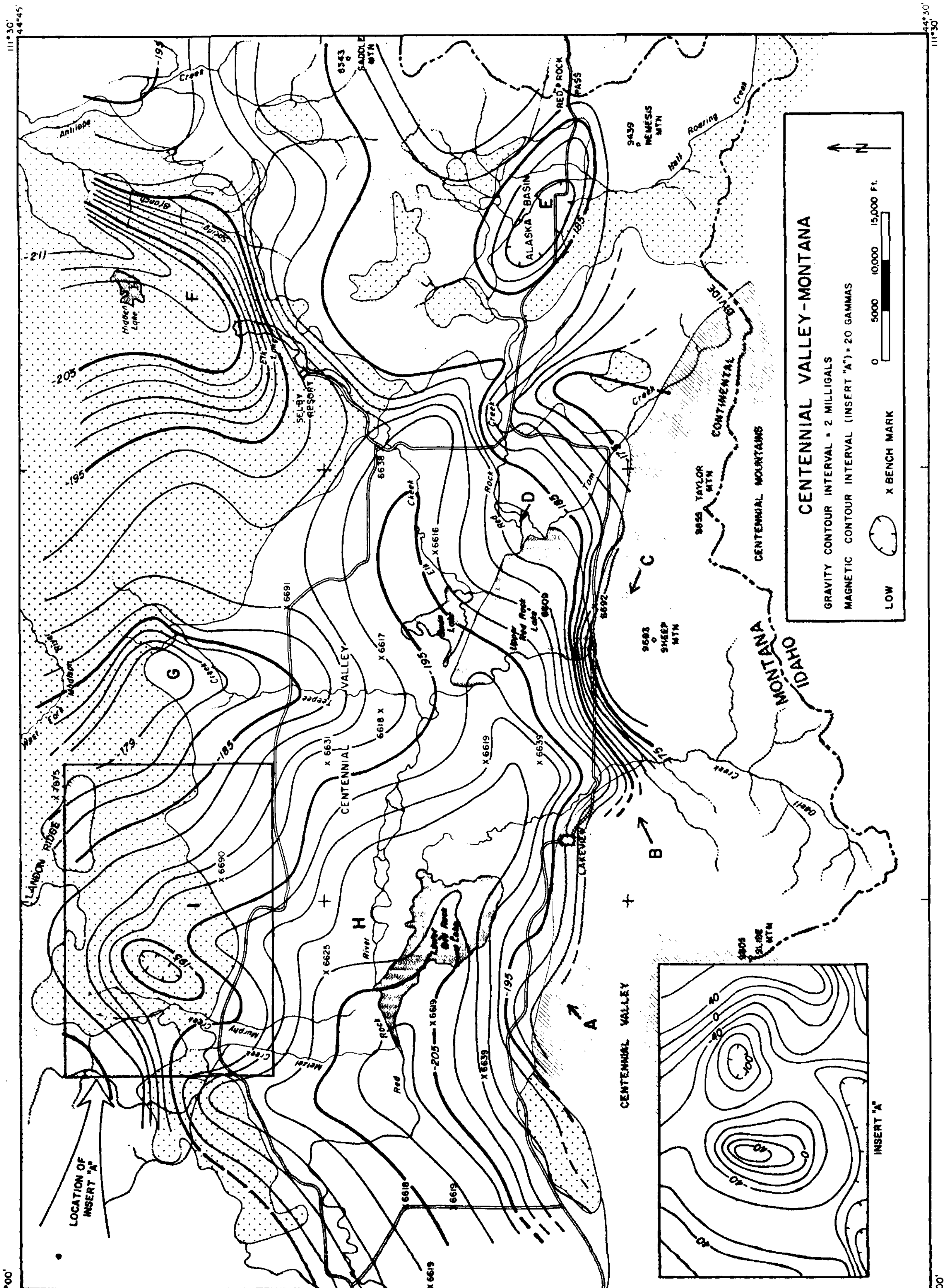

Figure 3. Complete Bouguer gravity map of the eastern Centennial Valley with an insert showing the ground magnetics for the Murphy Creek area. The large letters mark significant features on the gravity map.

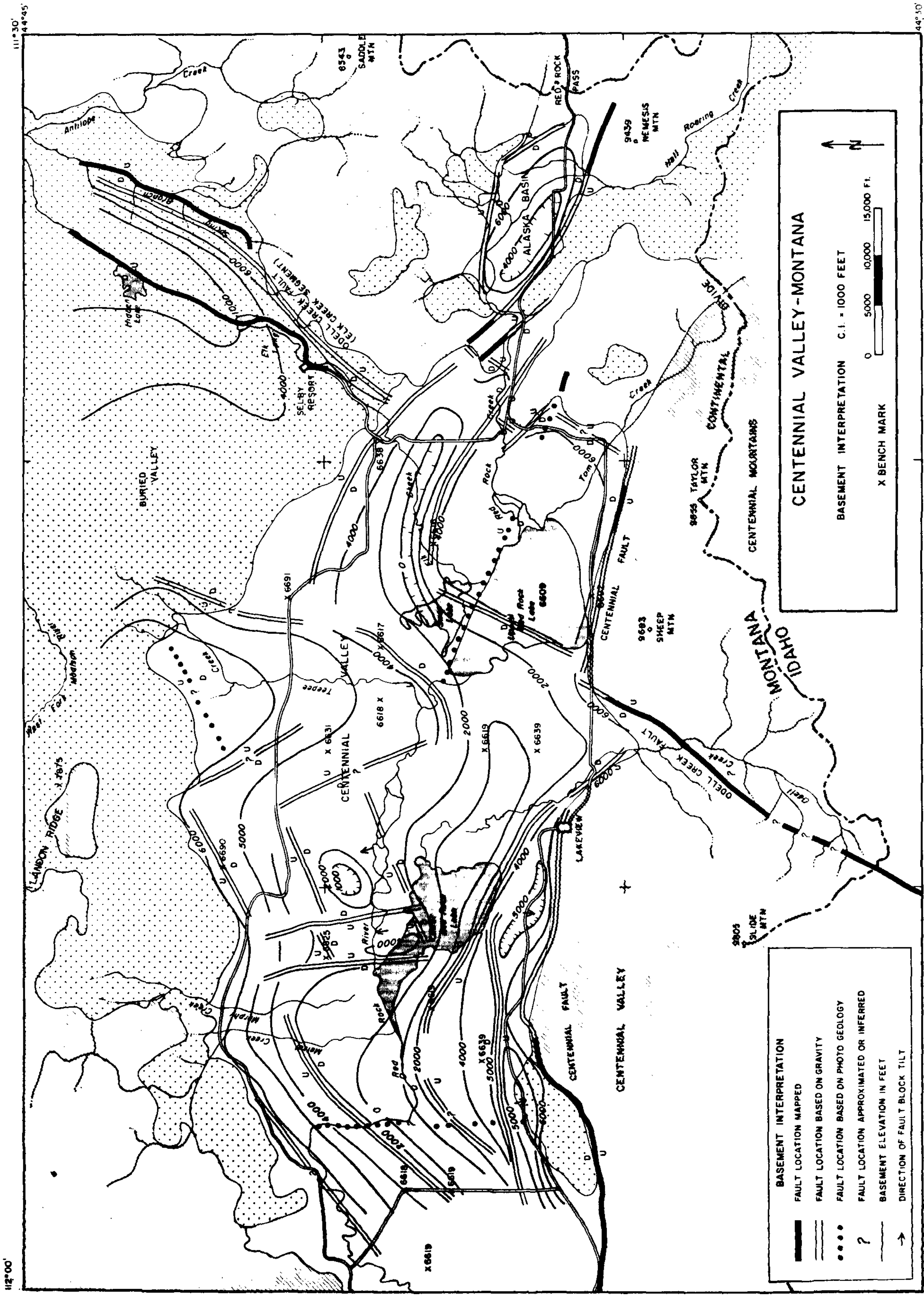

Figure 4. A basement interpretation of the eastern Centennial Valley showing the location of faults and the estimated elevation of the basement. Mapped fault locations according to Witkind (1976, Witkind and Prostka (1980) and Sonderegger and others (1980).

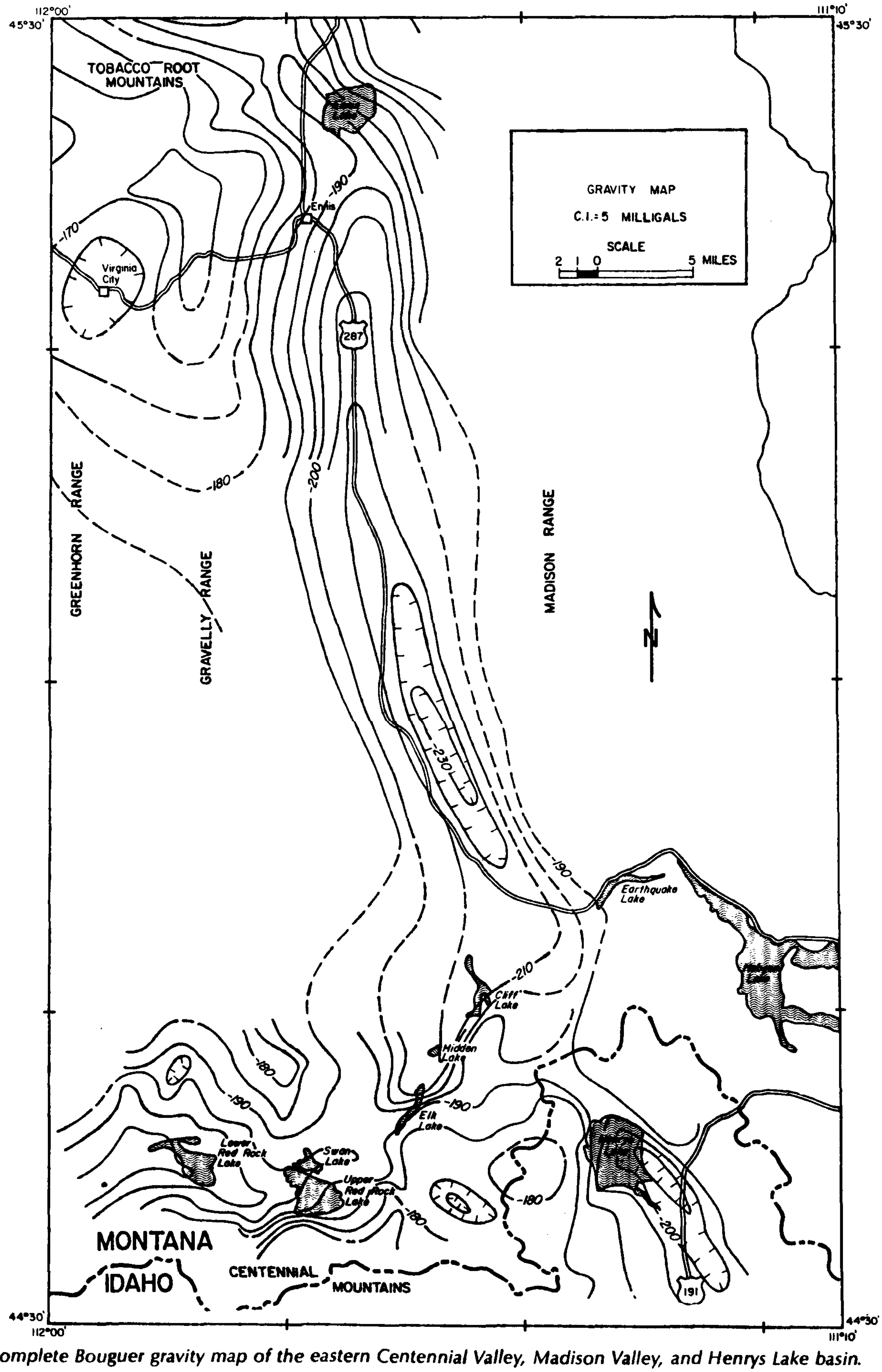

Figure 5. Complete Bouguer gravity map of the eastern Centennial Valley, Madison Valley, and Henrys Lake basin.

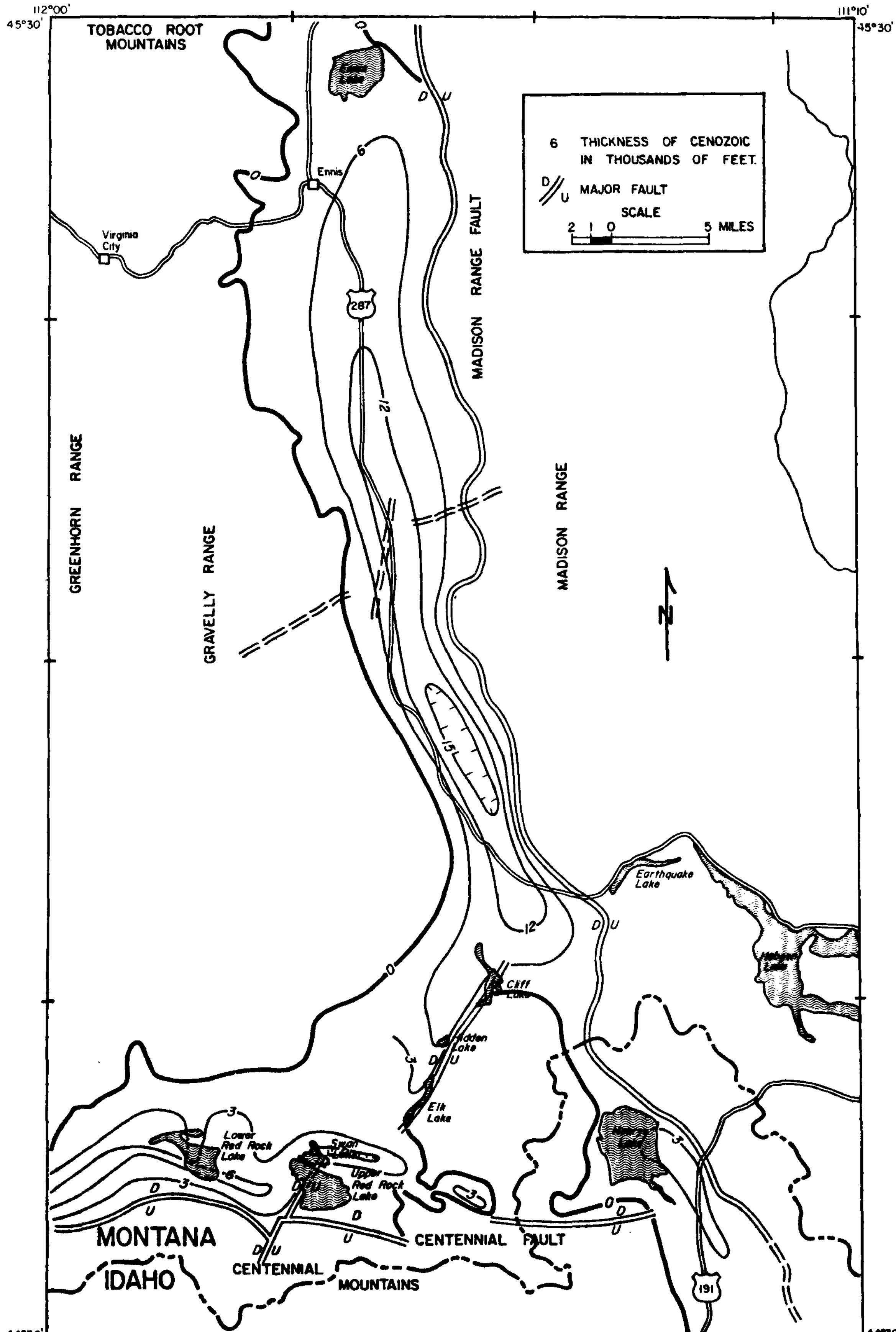

Figure 6. Map of the estimated thickness of Cenozoic fill for the eastern Centennial Valley, the Buried Valley, Madison Valley, and Henrys Lake basin.

single major normal fault and on the other by a series of normal faults of small displacement, with a valley floor which dipped toward the large boundary fault would produce an asymmetric anomaly like that of the Alaska Basin (**E**, Fig. 3). On the gravity map of Fig. 3, Centennial Valley and Alaska Basin appear as separate structures. The gravitational high between the valley and the basin coincides with a mapped horst. The horst is breached at the surface by Red Rock Creek. The small structural depression of Alaska Basin has more than 3,000 feet of relief.

MURPHY CREEK STOCK

The source of the gravity low near Murphy Creek (anomaly **I** of Fig. 3) not only has a low density but also a high susceptibility, as demonstrated by the results of a grond magnetic survey shown in Insert A (Schofield, 1980). The dipolar magnetic anomaly suggests the source is an intrustion. In southwestern Montana, gravity lows are often associated with intrustions. The gravity map of Montana (Bonini and other, 1973) has a low in conjunction with the Boulder Batholith and another over the Tobacco Root Batholith.

A seven milligal residual anomaly was modeled as a sphere. The calculations reveal a depth of 6,000 feet to the center of the anomalous mass, which is 4.3 billion tons lighter than a uniform bedrock section would be. Such a small intrustion would cool quickly, and indeed the strong magnetic anomaly means the body is below its Curie point (Curie point for magnetite is 578° C). A steeply dipping cylinder is a good approximation of the shape of the stock.

MADISON VALLEY

A gravity map of the Madison Valley is provided in Fig. 5, and an estimation of the thickness of Cenozoic sediments is given in Fig. 6. The magnitude of the gravity anomaly, in excess of 40 milligals, associated with the Madison Valley is unusual in view of the narrowness of the valley. The maximum thickness of valley fill for the Madison Valley is 15,000 feet based on models with a density contrast of -0.3 g/cc. Gary (1980), using a -0.5 g/cc. density contrast, predicts a miximum thickness of sediment in the valley of 10,000 feet. Gary's work also indicated the valley dips east into the Madison Range Fault, the bounding fault. A fault with northeast trend cuts the valley at approximately 45°05′ (Gary, 1980). According to Gary, the fault may be a reactivated zone of weakness, for a lineament shows up on the topographic, gravity, and aeromagnetic maps of the area. Textbook quality alluvial fans line the eastern edge of the Madison Valley, which attests to the magnitude of the displacement that has produced the Madison Range. Although the Madison Range Fault is defined as a normal fault, the fault plane solution calculated by Gary shows left-lateral relative movement along the fault, which he relates to the differential spreading rates along the Sanke River Plain. Last minute alterations were made to reflect the work of Gary in the Madison Valley.

Only a thin veneer of sediment covers Precambrian rocks at Raynolds Pass on the Idaho-Montana border where the Madison Valley ends and Henrys Lake Basin begins. The Madison Range Fault continues south of the Madison Valley into Henrys Lake Basin where it forms the eastern border of the basin. The Madison Range east of the basin has less relief than the mountains east of the Madison Valley, and the thickness of Cenozoic fill in the basin is substantially less than the fill in the Madison Valley. The maximum depth of fill predicted by modeling was 4000 feet. Peterson and Witking (1975) estimated 3600 feet using a model with two density contrasts (-0.6 g/cc betwen sediments and bedrock, -0.3 g/cc between volcanics and bedrock) rather than the single contrast of -0.3 g/cc used for Fig. 6. The deepest part of the basin appears to parallel the Madison Range Fault and to be east of the center of the basin. Henrys Lake Basin narrows where the Centennial Fault enters, but the gravity does not show the fault crossing the basin. If the fault actually does continue to the Madison Range the present displacement must be too small to detect with available gravity data.

SUMMARY

A small stock exists east of Murphy Creek. The Cenozoic fill in the Centennial Valley is at least 7,000 feet thick and may be as much as 10,000 feet thick. Gravity modeling suggests the narrow Madison Valley has a maximum of 15,000 feet of fill. Henrys Lake Basin is bounded by the same fault as the Madison Valley but there is only 4000 feet of fill within the basin. There are 3000 feet of sediments in the small, separate structure of Alaska Basin. The Odell Creek Fault extends north of the Centennial Fault under the Upper Red Rock Lake and northeast to the Madison Valley. The Elk Lake segment of the Odell Creek Fault bounds a valley buried by volcanics. The Centennial Fault is broken into several segments and into two main branchs. One branch of the Centennial Fault is covered by the fill in the valley. The basement of the Centennial Valley is divided into a number of separate blocks.

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View northward across Camp Creek, east of Melrose, of the west-dipping Cambrian to Mississippian Sequence. The massive dark cliff in the middle of the slope on the far side of Camp Creek is Meagher dolomite which has been thrust eastward over the underlying Wolsey shale and Flathead sandstone to rest on the Precambrian schists. A later, north-striking normal fault has dropped the Meagher down on the east.

GEOLOGY AND GEOTHERMAL RESOURCES OF THE EASTERN CENTENNIAL VALLEY

by
John L. Sonderegger[1]

INTRODUCTION

The upper Centennial Valley graben was selected for geothermal evaluation in 1976 because this area contains the most areally extensive exposure of Quaternary igneous rock known within the state. Witkind's Open-File Report on known and suspected active faults in western Montana (1975) provided documentation that the southern side of the valley still had an active fault system. With rocks that were believed to be correlative to the Yellowstone Group volcanics exposed on both the north and south sides of the graben, it was logical to speculate on the thickness of young volcanic rocks within the graben itself. The absence of detailed geologic mapping north of the lakes made it impossible to estimate the thickness of volcanics which might be preserved within the graben.

Warm water occurrences were found to be restricted to the north side of the Centennial Valley (figure 1). A total of seven springs were located in sections 17 and 18, T. 13 S., R. 2 W. They have a combined discharge of about sis cubic per second (2700 gallons per minute) and an average temperature of 27°C. Also a zone of water approximately 5°C above the background temperature was depicted along the western half of the north side of Upper Red Rock Lake and along the marshy channel connecting it with the Lower Red Rock Lake. The boundaries of this zone were established by airborne heat sensing imagery.

Location of the spring discharge appears to be controlled by both Laramide and Tertiary structures. The springs occur along the axial plane and on the west limb of the Metzel Creek anticline (Honkala, 1949, 1960) where it is cut by late (?) Cenozoic age, normal, basin margin faults.

GEOLOGIC FRAMEWORK

This investigation was conducted in the basement province of McMannis (1965) which is typified by the absence of Belt strata, a generally thin Paleozoic and Mesozoic sequence, abundant Cenozoic basin deposits and volcanic ejecta, and extensive exposures of pre-Belt metamorphic rock. The study area is bounded to the west by the Tendoy Mountains, and the Snowcrest Range, the easternmost ranges with proven thrust faulting as the dominant Laramide structural mechanism. Late Cenozoic mountain formation is due to block faulting. To the north, south and east, the Gravelly, and Centennial ranges, and the Henry's Lake Mountains, respectively, are believed to be formed by block faulting. Most of the structural grain has been previously ascribed to the Laramide orogeny. The Laramide stresses from the west have deformed the Paleozoic and Mesozoic rocks into broad gentle folds in most areas. Valleys between the mountains have been infilled with Tertiary sediments and sedimentary rocks which normally appear undeformed, although highly deformed slump structures can be found in the Madison Valley. The thickness of valley fill varies, but up to 6,600 feet are believed to be present in the Centennial Valley (Schofield, this publication). Possibly 9,000 feet may exist under the Missouri Flats area of the Madison Valley (Steve Gary, 1979, oral comm.). Volcanic ash-flow tuffs of early Pleistocene age cover much of the valley margins. Glacial outwash and tills are preserved along the valley margins, while in the lower portions of the valleys lacustrine deposits sand dunes and alluvium are found.

The Cambrian through Mississippian section in the study area consists of carbonates interbedded with minor shale. Younger Paleozoic rocks become more clastic, containing nearly equal amounts of sandstone, shale and carbonate (cherts included). The Mesozoic strata are nearly all clastic, with minor carbonate and a preponderance of shale, siltstone, and sandstone, with minor coal reported nearby. The preserved Tertiary strata consist of basalt, limestone and sandstone, in that order of abundance. The Quaternary section includes 16 units of which 7 are volcanic.

The Paleozoic strata in the study area do not consitute the complete stratigraphic section. Faulting near Landon Camp (along the West Fork) has juxtaposed the upper Jefferson Formation against the Precambrian. A small block of what is believed to be Meagher Limestone (Middle Cambrian) is preserved along the creek bottom, just west of the fault contolling the West Fork drainage, but the intervening strata, if present, are covered by Pliocene basalt and Pleistocene tuff. The description below uses the nomenclature of Sloss (1966) for the major depositional cycles of the Paleozoic and Mesozoic Eras.

The study area is east of the Greenhorn fault, and while part of the "stable" craton, this area has a thinner Cambrian section preserved and no identifiable Ordovician age rocks. This suggests that the southern Gravelly Range was, to some extent, a positive element during Sauk sequence deposition. There are no preserved rocks from the Tippecanoe sequence, and Kaskaskia deposition starts with the Jefferson Formation of of Middle (?) and Late Devonian age. The area received Kaskaskian sequence sediments representative of those found in southwestern Montana, except for the Big Snowy Group, which, due to poor exposures, could have been missed in mapping. Erosion at the end of the Kaskaskia Sequence was severe to the north where Christie (1961, p. 40) notes erosional channels 200 feet deep in the Mission Canyon Formation.

Absaroka sequence rocks are thicker in this area than in most of southwestern Montana due to crustal downwarping. Armstrong and Oriel (1965) attribute the basin development southwest of the study area to the migration of the miogeosyncline toward the eastern portion of Idaho. The study area was on the shoulder or flexure of this structure and contains

[1] Montana Bureau of Mines & Geology, Butte, Montana; financial support by the U.S. Department of Energy under Contract No. EY-76-S-06-2426

only two recognized unconformities within this sequence. Erosion following the deposition of the Kaskaskian sequence was accompanied by southward tilting of the strata by the time the Ellis Group was deposited at the start of the Zuni sequence (McMannis, 1965).

The Zuni sequence starts with 300 to 400 feet of Jurassic rocks, mainly the Morrison Formation, unconformably overlain by the Cretaceous Kootenai Formation. Local angularity of the unconformity (Christie, 1961, p. 89) suggests additional tilting of the strata. Deposition following the Kootenai includes a thin shale and the Aspen Formation, a predominantly non-marine unit.

The Laramide orogeny deformed the sedimentary rocks, with the major structure in the area being the Metzel Creek anticline (Honkala, 1949). The northwesterly trend and asmmetry of the anticline (cross section A-A', figures 2 and 3) suggest that compressional force was directed from the west-southwest. Surficial mapping does not require that the anticline be faulted; however, so little of the east limb is exposed that the western limb may be locally detached and thrust over the eastern limb. This is compatible with Scholten's (1967) overview of the Laramide tectonics of this region. Culmination of this oroglenic event included the thrust faulting west of the study area to which Scholten (1967) and Ryder (1967) attribute the origin of much of the Beaverhead Formation, which unconformably overlies the pre-Laramide rocks in the western part of the study area. Scholten (1967), however, believes that the Blacktail-Snowcrest and Gravelly "arches" contributed significant volumes of clastics to the Centennial Valley. Thus, as the compressional forces of the

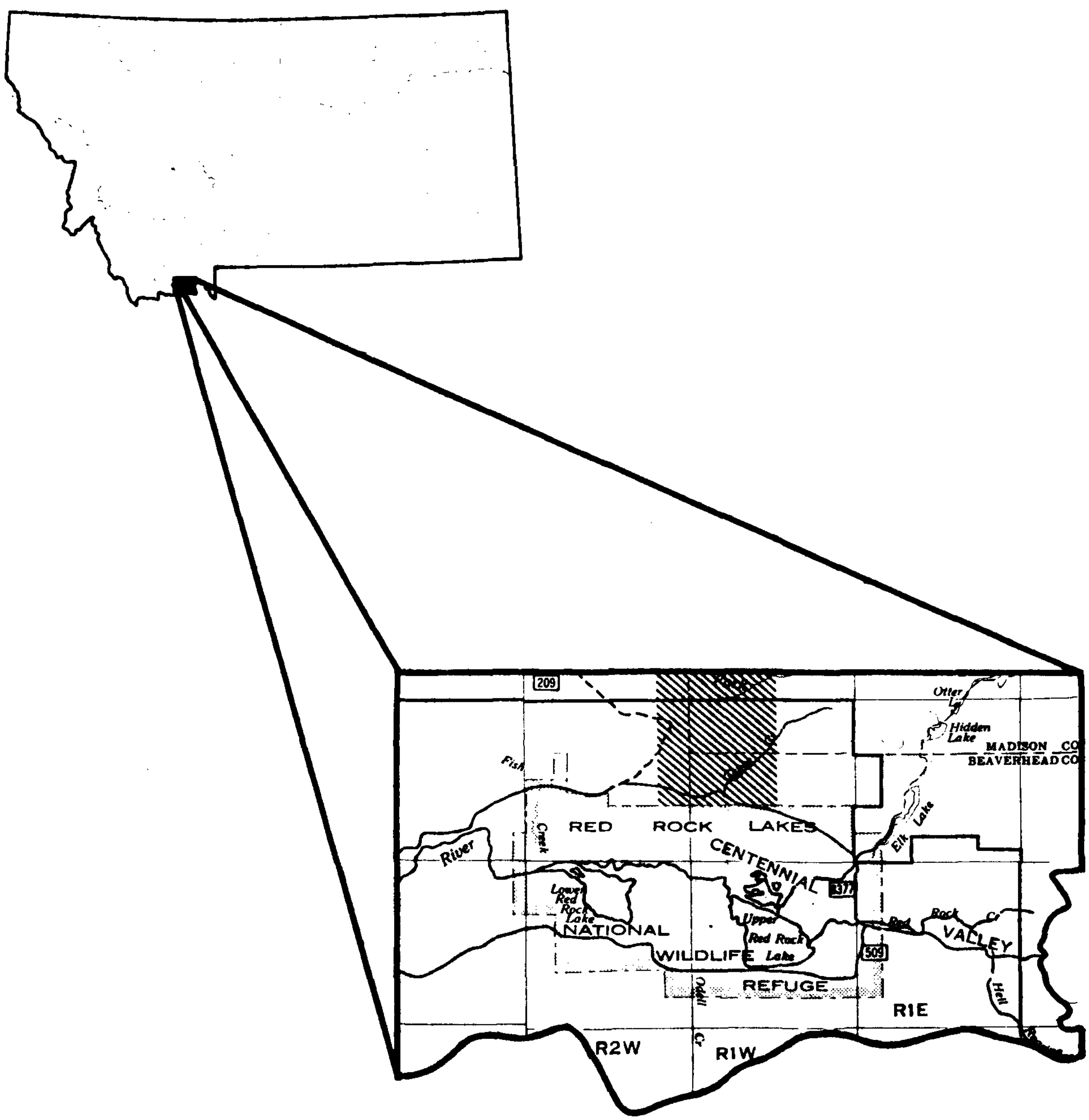


Figure 1. Location of study area; crosshatched area is shown on geologic map (figure 2).

Laramide were waning, renewed (?) block fault uplifting must have occurred north of the study area, probably in the Paleocene time.

From the end of Beaverhead deposition, presumably in late Paleocene or early Eocene time, there is no exposed rock record until the extrusion of the older Tertiary basalt at about the beginning of late Oligocene time. The basalt is overlain by lower (?) Miocene sandstone and limestone believed to be of continental origin. These units dip gently into the Centennial Valley from the north at about three degrees. Erosion followed and only remnants of these strata are preserved.

Within the study area, the Cenozoic history may be interpreted as follows:

(1) Doming occurred along the northwest-southeast trend on the east, as evidenced by the erosion of pre-Pleistocene rocks in the eastern portion of the study area. Faulting along the trend appears to be fairly local as evidenced by the

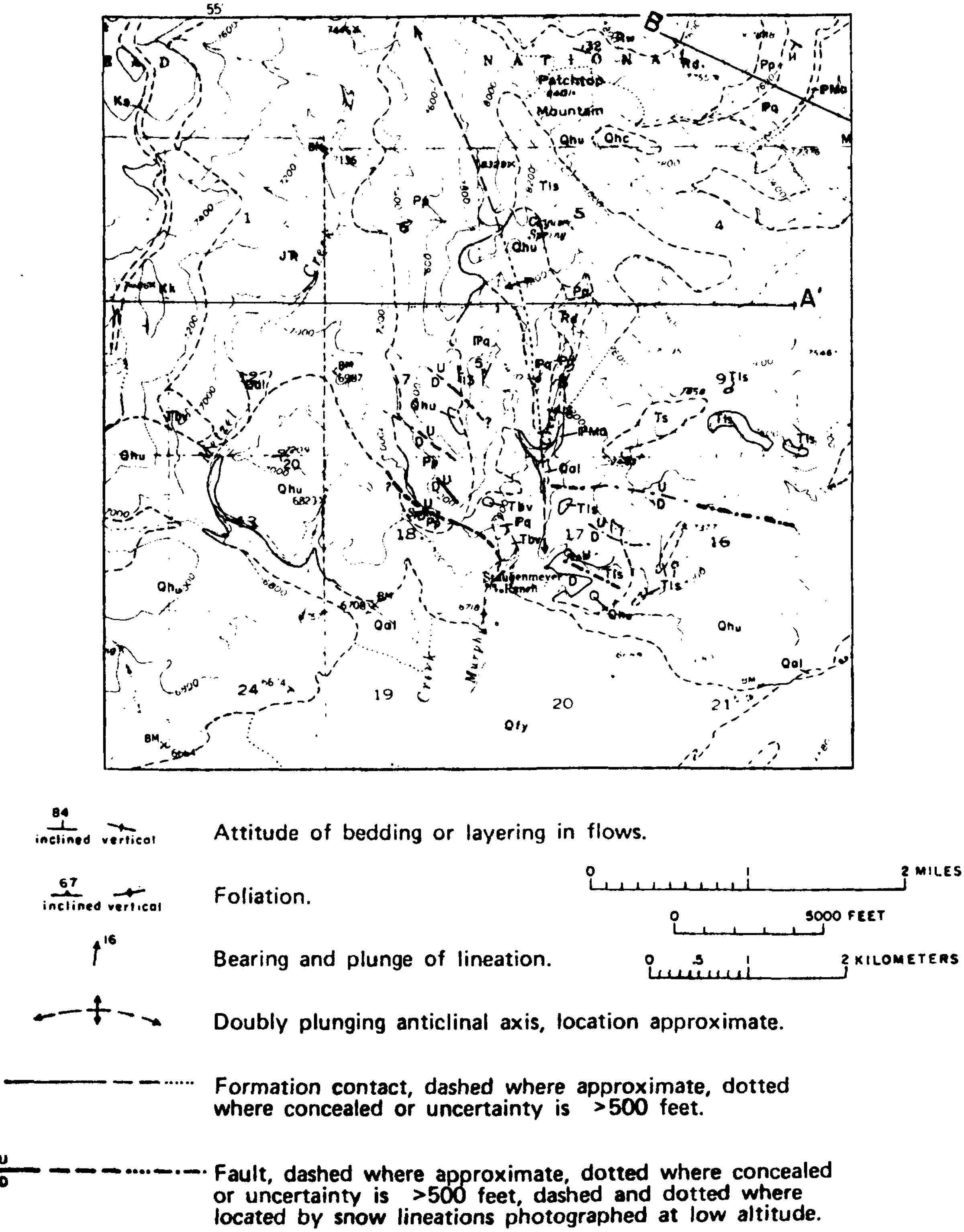


Figure 2. Geologic map in the vicinity of the warm springs.

juxtaposition of Devonian and Precambrian strata south of Landon Camp and the normal transgressive sequence which is preserved outside the study area along the West Fork of the Madison, roughly two miles to the northwest (Christie, 1961).

(2) Fluvial sedimentation and erosion were ongoing processes during Paleocene time. Sedimentation may have continued until the Early Eocene, with the major unit deposited being the Beaverhead Formation. An ancestral Centennial Range probably existed further south (Ryder and Scholten, 1973, Figure 10 and discussion of Pinyon-Harebell Conglomerate in Wyoming), which later foundered into the Snake River trough. The Gravelly Range was probably the major souce of sediment at this time. The near absence of limestone clasts in the Beaverhead suggests that drainage off the Gravelly block was to the west, or that the materials from the ancestral Centennial Range uplift were the volumetrically dominent influx. These two factors suggest the lack of a western source during Paleocene time. Drainage may have been to the east-southeast, as depicted by Ryder and Scholten (1973, fig. 10).

(3) Erosion locally reduced the land surface to a virtual plain during the rest of Eocene and early and middle Oligocene time, as evidenced by the flat basal nature fo the Oligocene basalt flow near Cayuse Spring. The western part of the study area was probably a pediment. To the north, a structurally active, upland erosional area must have been maintained. This interpretation is based upon Christie's (1961) contact between the Tertiary basalt and underlying pre-Tertiary formations and preexisting normal faults.

(4) Fluvial deposition of the unnamed Tertiary sandstone probably occurred during the early Miocene. The influx of clastics was sufficient to disrupt existing drainage, as this unit is overlain by a limestone believed to be of fresh-water origin. Consequently, moderate uplift of the Gravelly block during the late Oligocene-early Miocene interval followed by a period of relative tectonic quiescence is envisioned.

(5) Pliocene age units have not been recognized in outcrop within the study area. It is believed that tectonic quiescence continued throughout most of this time. Renewed uplift and erosion probably began near the end of the Pliocene as evidenced by volcanic flows and reworked Beaverhead Formation south of the map area (Witkind and Prostka, 1980), scattered patches of reworked gravels in the vicinity of Two Drink Springs, and the topographic relief formed on the Tertiary limestone and sandstone units before deposition of the overlying early Pleistocene age ash-flow tuffs.

(6) During the early Pleistocene a moderate amount of relief must have existed, based upon the outcrop pattern of the oldest Pleistocene volcanic unit compared to underlying older strata (Witkind, 1976; Witkind and Prostka, 1980; Sonderegger and others, in prep.). It is believed that the Huckleberry Ridge ash-flow tuff erupted from the Island Park Caldera, passing over the then-low ancestral Centennial Mountains, across the Centennial Valley and up against the southern margin of the Gravelly Range (Christianson, 1979; Mannick, 1980). On the northwest side of Deer Mountain, northeast of the Upper Red Rock Lake, a minimum of 500 feet of preexisting relief is indicated by the Huckleberry Ridge-Precambrian contact. Movement along the Centennial fault continued throughout the Quaternary, displacing the Huckleberry Ridge Tuff a minimum of 1500 to 1800 meters (5,000 to 6,000 feet) in the last 2.0 million years. The Centennial Range was sufficiently high 1.2 million years ago to block the passage of the Mesa Falls ash flow into the upper Centennial Valley from the Island Park Caldera. The only portions of the ash flow to enter the valley crossed the divide through low passes such as one near Hell Roaring Canyon (Witkind, 1976). Major volcanism occurred in the Yellowstone caldera region 0.6 million years ago producing the Lava Creek Tuff. This ash flow was entirely blocked from the upper Centennial Valley and is exposed along the lower southeastern slopes of the Centennial Range.

(7) Normal faulting on the north side of the valley is well exposed in the Phosphoria Formation outcrop west of the Metzel Creek anticline, where displacement is on the order of 40 feet. Lineations representing unmelted snow were noted during a low altitude over flight the area. They are believed to represent minor fault scarps, unrecognizable on the ground, which have less than five feet of displacement and which cut the Huckleberry Ridge Tuff. If this interpretation is correct, the

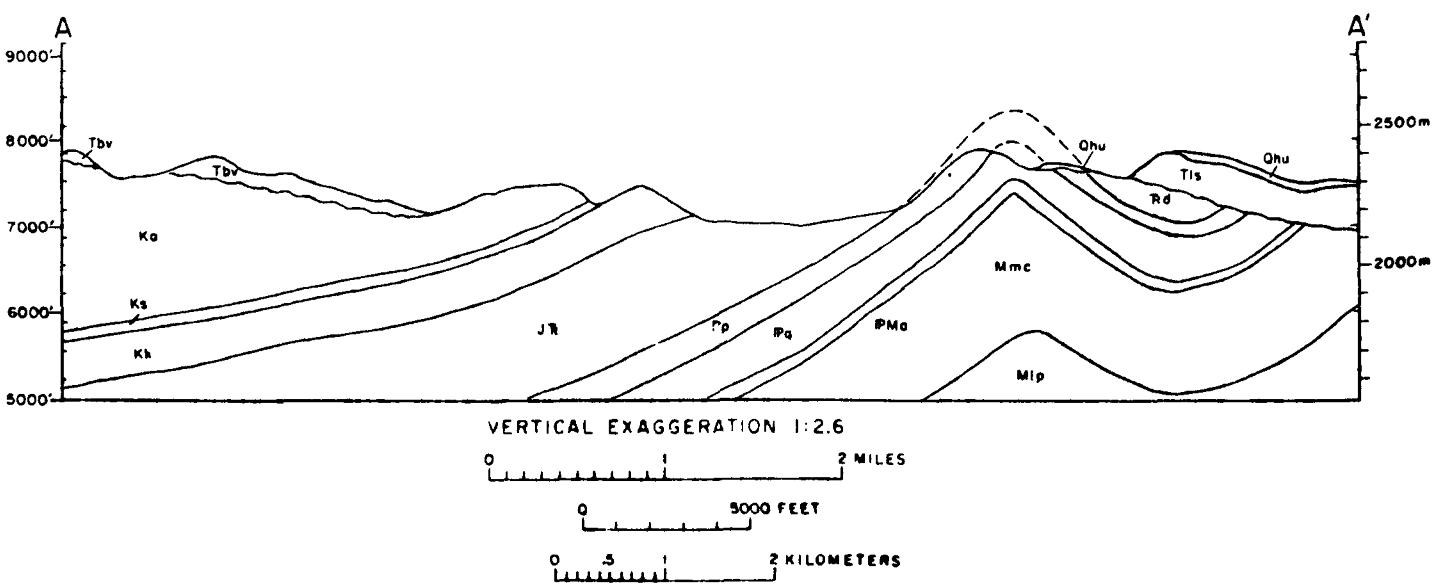
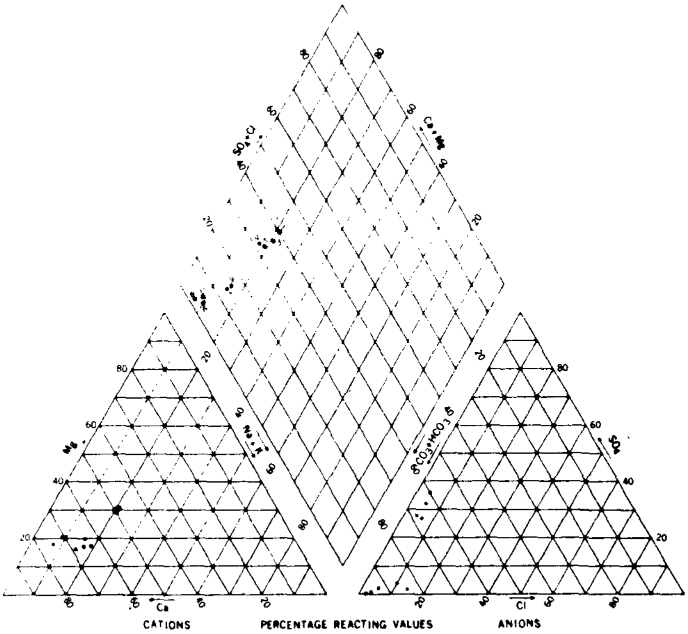


Figure 3. Geologic cross section nearly normal to the Metzel Creek anticline.



No.	TDS	Source
1	394	Anderson Springs
2	401	Staudenmeyer Springs
3	519	Staudenmeyer House Well
4	376	Anderson House Well
5	347	Anderson Stock Well
6	128	Smith Boxcar Well
7	184	Refuge Stock Well
8	176	Staudenmeyer Stock SE
9	313	Staudenmeyer Stock SW
10	184	Staudenmeyer Stock NW

Figure 4. Trilinear diagram of water chemistry from wells and warm springs.

faults must be less than two million years old and may be considerably younger. The warm springs occur just below the fault trace on the downdropped side of the faults.

faults.

(8) Alpine glaciers eroded the mountain ranges surrounding the Centennial Vally at different times throughout the Pleistocene. Deposits of pre-Bull Lake, Bull Lake and Pinedale glaciations indicate that the ice originated in high cirques and traveled downward, cutting U-shaped valleys which, in many instances, reached the larger valley floors such as the Madison Valley (Weinheimer, 1979). Glacial meltwater accumulated in the Centennial Valley to form a large lake which drained at several locations including a stream situated in the Cliff Lake Fault trench. The West Fork of the Madison River began to cut a valley approximately along the Huckleberry Ridge Tuff-Precambrian contact (Gravelly fault) during late Pleistocene-early Holocene time. The Centennial Valley glacial lake eventually receded to form the Upper and Lower Red Rock Lakes and associated ponds and marshes. As the lake receded, the drainage along the Cliff Lake fault trench was dammed by mass wasting to create Elk, Hidden, Goose, Otter, Cliff, and Wade lakes.

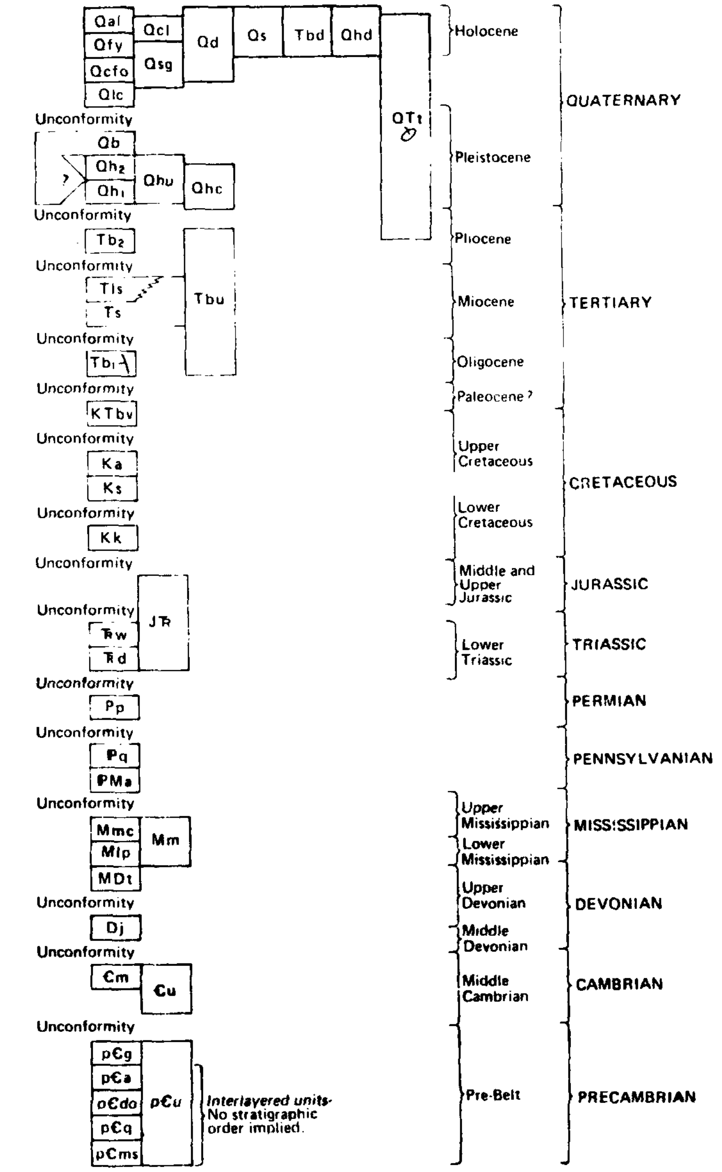
(9) It appears that the rate of movement along the Centennial fault has increased since Pinedale time to over an inch per year. The Centennial, Cliff Lake, and southern Madison faults continue to be seismically active today.

WATER CHEMISTRY ASPECTS

The types of water chemistry exhibited by springs and wells on the north side of the Centennial Valley are fairly similar: (1) bicarbonate is the dominant anion; (2) calcium is the dominant cation; (3) magnesium is generally the second most abundant cation (based upon milliequivalents per liter). North of Upper Red Rock Lake, where the Huckleberry Ridge Tuff is thicker, springs with a shallow, local flow system commonly have a total dissolved solids (TDS) content of less than 100 milligrams per liter (mg/L). Wells south and east of the warm springs have TDS values ranging from 128 to 519 mg/L. Figure 4 depicts chemical characteristics of these wells in the valley Quaternary deposits. Two subgroups can be characterized. The low TDS wells have smaller percentages (on a milliequivalent per liter bases; Hem, 1970, p. 268-270) of magnesium and sulfate. There is a distinct hiatus of sulfate values betwen 7 and 24 percent. The high sulfate waters are restricted to wells and springs along the northern margin of the valley.

The major sources for sulfate in ground water are the dissolution of sulfate minerals such as gypsum and andydrite, and the oxidation of sulfide minerals such as pyrite. Warm springs issuing from the Madison Group (such as Anderson's, Bearmouth, Bridger Canyon, Brooks, Carter's Bridge, Durfee

CORRELATION OF MAP UNITS



Creek, LaDuke, Landusky, Little Warm, Lodgepole, McMenomey, Plunkets, Toston, and Vigilante; Sonderegger and Bergantino, 1981) have a relatively high sulfate content. Hot springs believed to be derived from the Madison (LaDuke, New Biltmore, and Warm Springs State Hospital; ibid.) have the anion content of their water dominated by sulfate. The generally accepted explanation for this phenomena is the dissolution of sulfate minerals from the upper portion of the Madison Group.

The other shift associated with the high TDS and thermal waters is a change toward higher Mg/Ca ratios. The Madison Group is a dolomitic limestone; both dolomite and calcite will be dissolved by undersaturated waters. Both the dissolution and precipitation of dolomite are retarded relative to calcite, probably by larger necessary activation energies. Consequently, one expects to see calcite and dolomite dissolution occur in recharge areas (equations 1 and 2, respectively)

(1) $CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3$

(2) $CaMG(CO_3)_2 + 2H_2CO_3 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3$

As water descends to greater depth, temperatures increase and the water becomes supersaturated with respect to both minerals. However, calcite precipitates much more easily than dolomite and the fluid phase becomes enriched with magnesium.

If the thermal water is not diluted the water chemistry can be used to calculate values commonly referred to as "reservoir temperatures." The methodology varies; the silica thermometers compare the silica content of the thermal water with that believed to be in equilibrium (laboratory data) for solid phases such as quartz, chalcedony, a or b cristobalite, or amorphous silica, while the cation geothermometers use atomic ratios of the elements Na, K, and Ca, and equivalent ratios of the elements Mg, Ca, and K.

In the Centennial Valley, the thermal springs have water chemistry with a definite limestone signature. Quartz and chalcedony geothermometers yield reservoir temperatures of 66° and 34°C, respectively. The Na-K-Ca geothermometer yields a temperature of 52°C, due mainly to the Na/K ratio of 6.4. The high Mg and Ca content of the water suggests that it has never been very hot (Mg/Ca ratio of 0.59).

The magnesium correction is not applied to waters which yield a Na-K-Ca temperature of less than 70°C (Fournier and Potter, 1979), so this correction is not made to the Centennial Valley thermal waters. Based upon the data available, and assuming no dilution, the reservoir temperature is believed to be 45°C or less, with 40°C probably being a reasonable estimate of the maximum reservoir temperature. The highest chalcedony temperature calculated from these springs is 37°C. Chloride content varies from 9.0 to 10.0 mg/L, and silica from 20.1 to 23.3 mg/L. These data prohibit the use of most dilution models for the spring data.

If the water from the Staudenmeyer ranch house well (T= 10.2°C) is considered, due to its high dissolved solids content, to represent the "best" water sample, chalcedony and Na-K-Ca temperatures of 48° and 62°C, respectively are calculated. The silica content may be elevated due to contact with detrital volçanic material, and the maximum temperature for the thermal system is still about 45°C if no significant mixing or precipitation has occurred.

The silica geothermometry becomes almost useless when water interacts with glass-rich acidic rocks such as the Huckleberry Ridge Tuff. Samples of this rock and the Mesa Falls Tuff were ground to medium- to fine-sand size and leached with distilled water in the laboratory at different temperatures. Within three months, the silica content in the water plotted between the α and β cristobalite curves for laboratory temperatures of 27° and 57°C.

CONCLUSIONS

A lake temperature survey showed warmer water along the northern side of Upper Red Rock Lake. Heat sensing imagery was flown over the northern side of the valley during the fall of 1977. An intense rain storm the afternoon before the flight resulted in ponding of water in almost all areas except the sand dunes. Air temperature was slightly below freezing between 3:00 and 5:30 a.m. while ground truth data was collected and the overflight occurred. Water temperatures on the lakes and river were considered to be the only reliable values under these conditions. Temperatures ranged from 8.5° to 15.5°C. A warm zone was identified from the computer printout of the digital data.

The alignment of the thermal water zone southeast of the thermal springs is subparallel to Quaternary age faults identified by low altitude aerial reconnaissance. These features are interpreted to be small scale step faults on the southernmost margin of the Gravelly Range. These faults are beilieved to aid in localizing the ascent of warm water from the Madison Group limestones near the axis of the doubly-plunging Metzel Creek anticline. The heat source could be either p postulated intrusive (Schofield, this publication) or deep circulation. Based upon the small size of the postulated body and the rapid cooling which it would undergo, it appears more probable to assign the source of the heat to the deep circulation of meteoric water.

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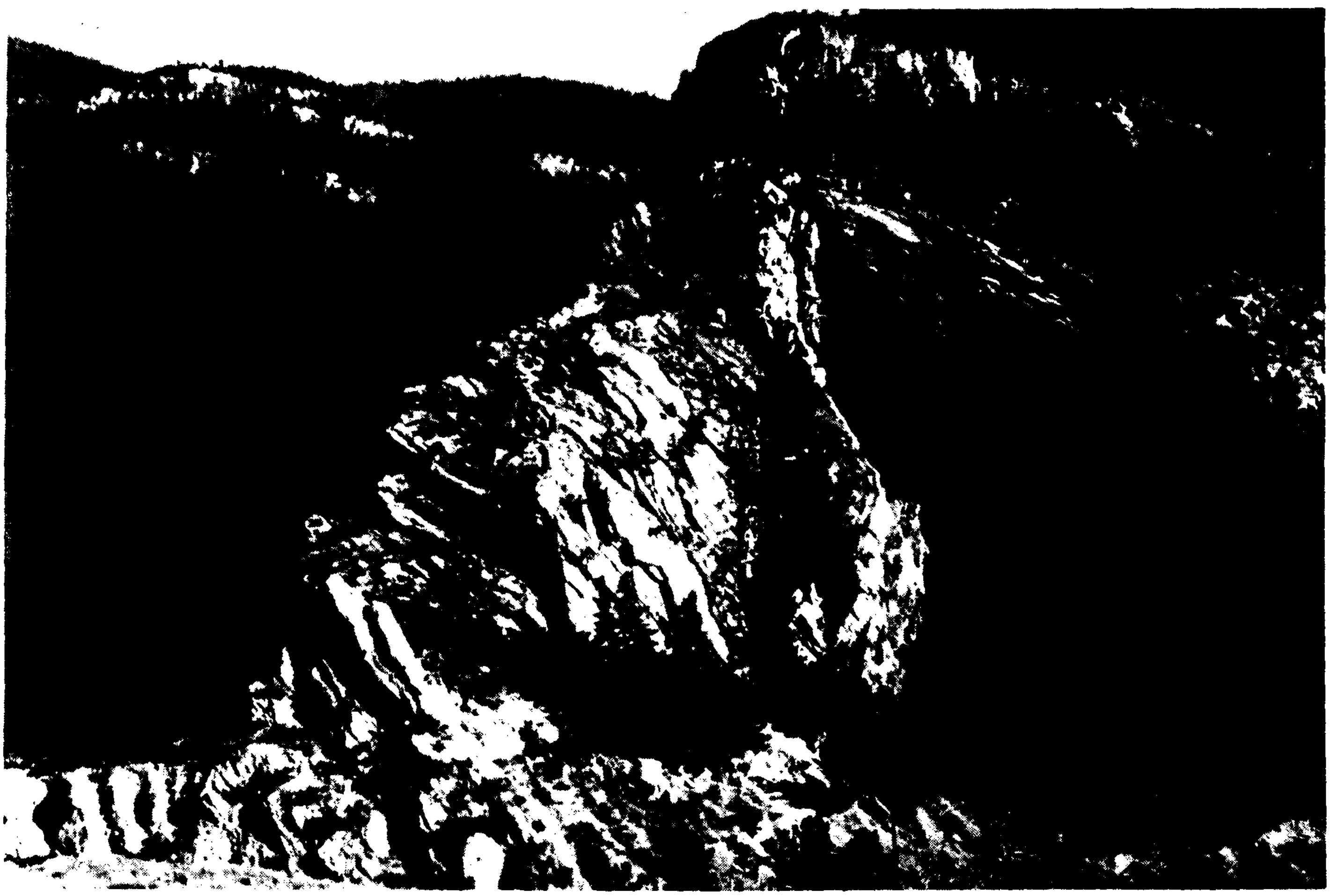

Tight S-shaped fold in Lodgepole beds adjacent to Jefferson Canyon fault (large draw to the left), Jefferson Canyon (looking south). Photo by Rich Aram.

GEOTHERMAL RESOURCES IN MONTANA

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ABSTRACT

This paper summarizes information concerning thermal springs and wells in Montana. New and previously unpublished data are included for thermal wells. Btu calculations for these sources are presented and a preliminary map depicting areas favorable for space heating with heat pumps is included.

Introduction

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 1970s when predictions of energy shortfalls began appearing. In Montana, previous work consisted of cataloguing by G. A. Waring (1965), and "while passing through" studies by S. L. Groff (results summarized in Balster and Groff, 1971).

Recent research was initiated by the U.S. Geological Survey in the early seventies from their Menlo Park regional office. The formation of first ERDA and then 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: Jeff Birkby and Michael Chapman - user assistance and grants.

3. Montana University System

   a. U of M, Missoula: Tony Quamar - resource evaluation

   b. MSU, Bozeman: Robert Chadwick - resource evaluation

   c. MT Tech, 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).

<u>Thermal Springs</u>

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 70s was that adequate measurement 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^{o}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^{o}C or less is, in the majority of cases, related to springs issuing from the Madison Group. However, 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 is grossly biased, i.e., that we have only included the high discharge springs with temperatures of less than 25°C. 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 lower temperatures and small discharge values, it is possible for solar and biological factors to increase the measured temperature enough to cause a spuriously anomalous spring temperature. 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 (Lawson and Sonderegger, 1978). 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 1,000 gpm (Bergantino and Sonderegger, 1978). By comparison, only two of the seven springs with temperatures of 65°C or greater have 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 Sonderegger and others, 1977) 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 2,500 square feet, the generally available heat pumps now being produced

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

Name	Temp. (^oC)	Flow (gpm)	H_1 (25^oC) (10^9 Btu/yr)	H_2 (18^oC) (10^9 Btu/yr)	H_3 (10^oC) (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	1,100		17.4	86.9
Beaverhead Rock	27	100	1.58	7.11	13.4
Bedford	23.6	1,500		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	72,000		1,080	5,630

Browns	23.7	1,100		49.5	119
Camas	45	24	3.79	5.12	6.64
Carter Bridge[1]	26.5	1,500	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	2,300		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	1,300	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	3,100		73.5	269
Landusky Plunge	24	2,900		137	321
Little Warm	22	5,000		160	474
Lodgepole	30	2,700	107	256	427
Lolo	44	180	27.0	37.0	48.3
Lovells	19.4	3,500		38.7	260
McMenomey Ranch	19	7,300		57.7	519
Medicine	46	100	16.6	22.1	28.4
New Biltmore	53	26	5.75	7.19	8.83
Nimrod	20.5	3,200		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	4,000			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	1,800	42.7	142	256
Sun River	30.4	710	30.3	69.5	114
Targhee Sulfur[2]	18	55			3.46
Toston	15.2	20,000			822
Trudau	22.7	175		6.50	17.6
Vigilante	23.5	2,200		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.

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.

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 (Chadwick and Leonard, 1979). Dates on the age of igneous rocks in Montana range for very ancient to 0.11 million years before present (Daniel and others, 1980). Known rocks younger than 2.0 million years are very few, extrusive, and of very limited extent; consequently, they are not believed to represent a significant thermal resource. Thus, the known geothermal system in eastern Montana are believed to result from deep circulation of meteoric ground water with fracture control (Sonderegger and others, 1977).

The best summary to date of all available water chemistry is by Leonard and others (1978) 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 70 springs and wells. Also, an annotated bibliography of geothermal studies in Montana, current through January of 1980, has just been published (Rautio and Sonderegger, 1980).

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 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 (McRae and others, 1980; Christopherson and others, 1979; Long and Senterfit, 1979a). Studies at other sites such as: (1) Warm Springs State Hospital (Halverson and Wideman, 1980); (2) Silver Star (Abdul-Malik, 1977; Long and Senterfit, 1979b); (3) Norris and Hunters hot springs (Chadwick and others, 1978); and the Little Bitterroot Valley (Camas area, work in progress; Hawe, 1974) 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 catagories: (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 (Leonard, 1979, oral 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 (Dunn, 1978, unpublished). 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, 1979, oral 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 would not produce enough water to warrant installing a pump.

The Marysville "hot dry rock" well was drilled because of very high heat flow values in that area. Unfortunately, the 6,790 foot deep well encountered water bearing zones with a maximum temperature of 204°F (96°C; McSpadden, 1975).

By comparison, the 600 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; Leonard, 1980, oral 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 1,498 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 4/9/80 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, especially if the well has silted in to the top of the perforations. 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 (Leonard and others, 1978). The Saco well, now used by the Sleeping Buffalo Resort produces a reported 290 gpm of 41°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 (Spencer and Cohen, 1980).

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 (6-8°C). Figure 4 shows seven areas which appear to have ground-water temperatures above 10°C, and may 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.

Favorable areas B, C, and D are in suburban areas where problems of water disposal are greater. The reported "warm" temperatures for these areas constitute a smaller percentage of the total number of temperatures. The water is almost entirely from shallow (<300 feet deep) wells and may show considerable seasonal variation. In these 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 (Gass, 1980).

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 around January 1981.

Area E, northeast of Pryor, is tentative at this time. A drilling report indicates that wells drilled into the Kootenai Formation should be abnormally warm in this area. Area F, southeast of Ashland has not been thoroughly checked but numerous warm stock wells are reported in this vicinity.

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 (Spencer and Cohen, 1980). 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. It is clear that some of the more ambitious projects to develop geothermal resources have fallen considerably short of their projected goals. But, as we learn more about the resource and as application technology improves, the risk factor is bound to be reduced and wider utilization of lower temperature resources will become commonplace.

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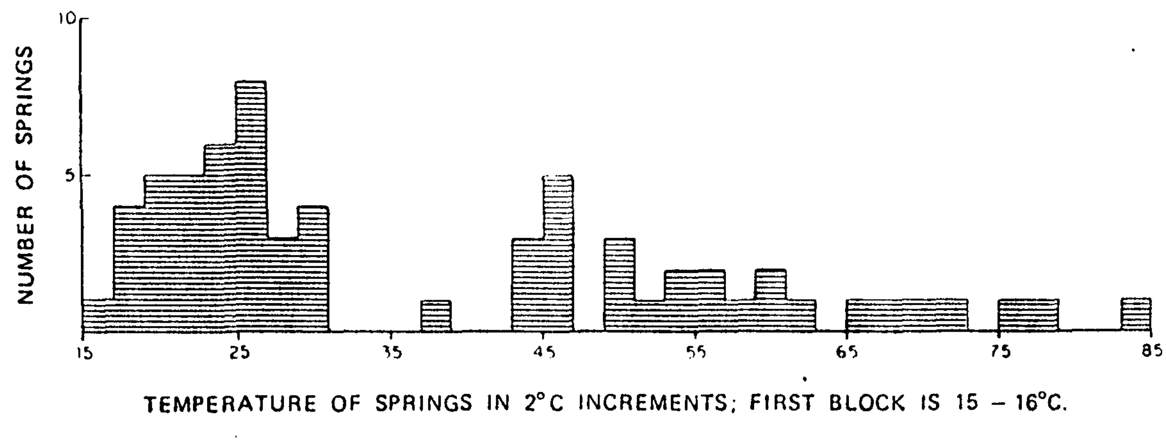

Figure 1. Histogram depicting the frequency of thermal spring temperatures.

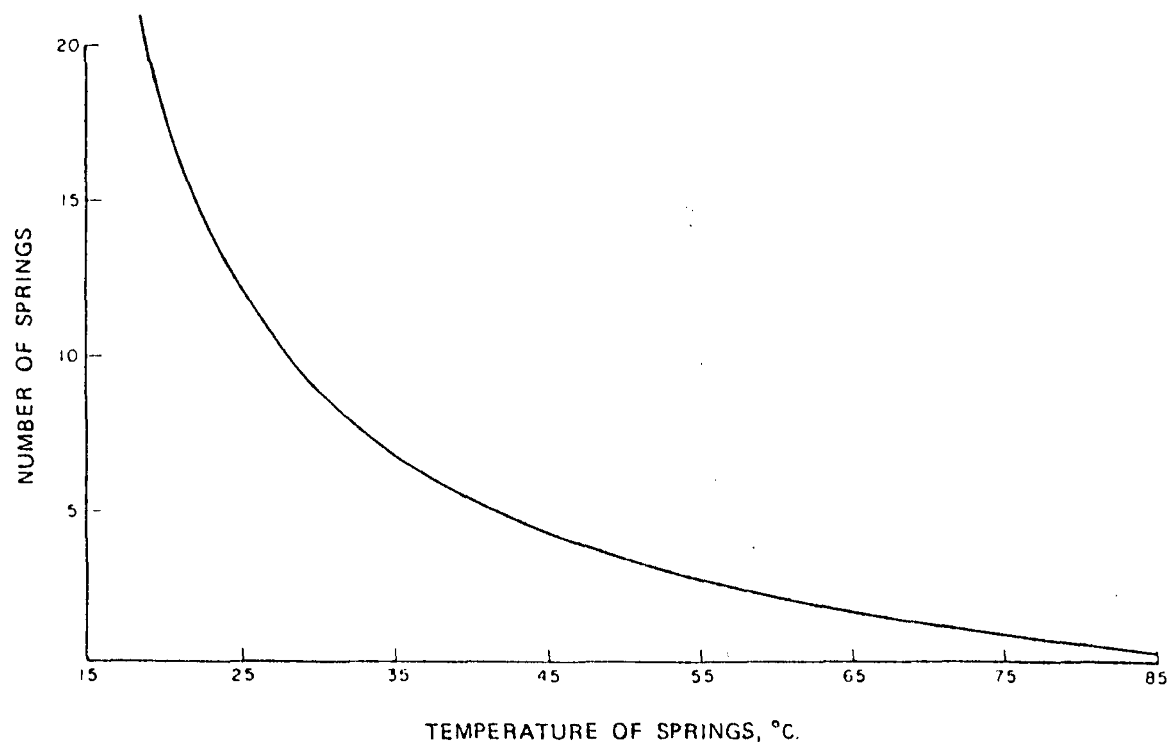

Figure 2. Expected log-normal distribution of spring temperatures.

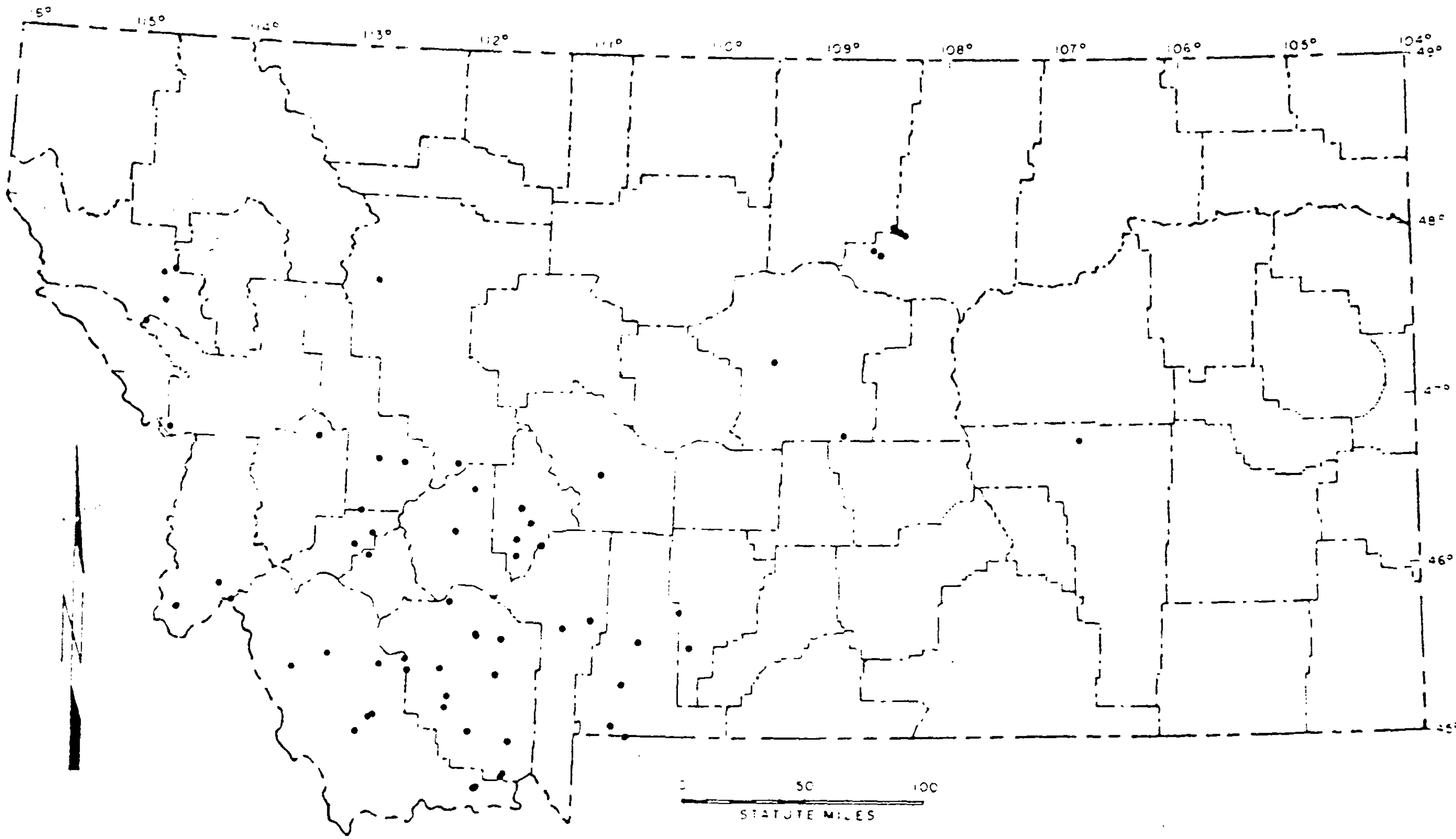

Figure 3. Location of thermal springs in Montana.

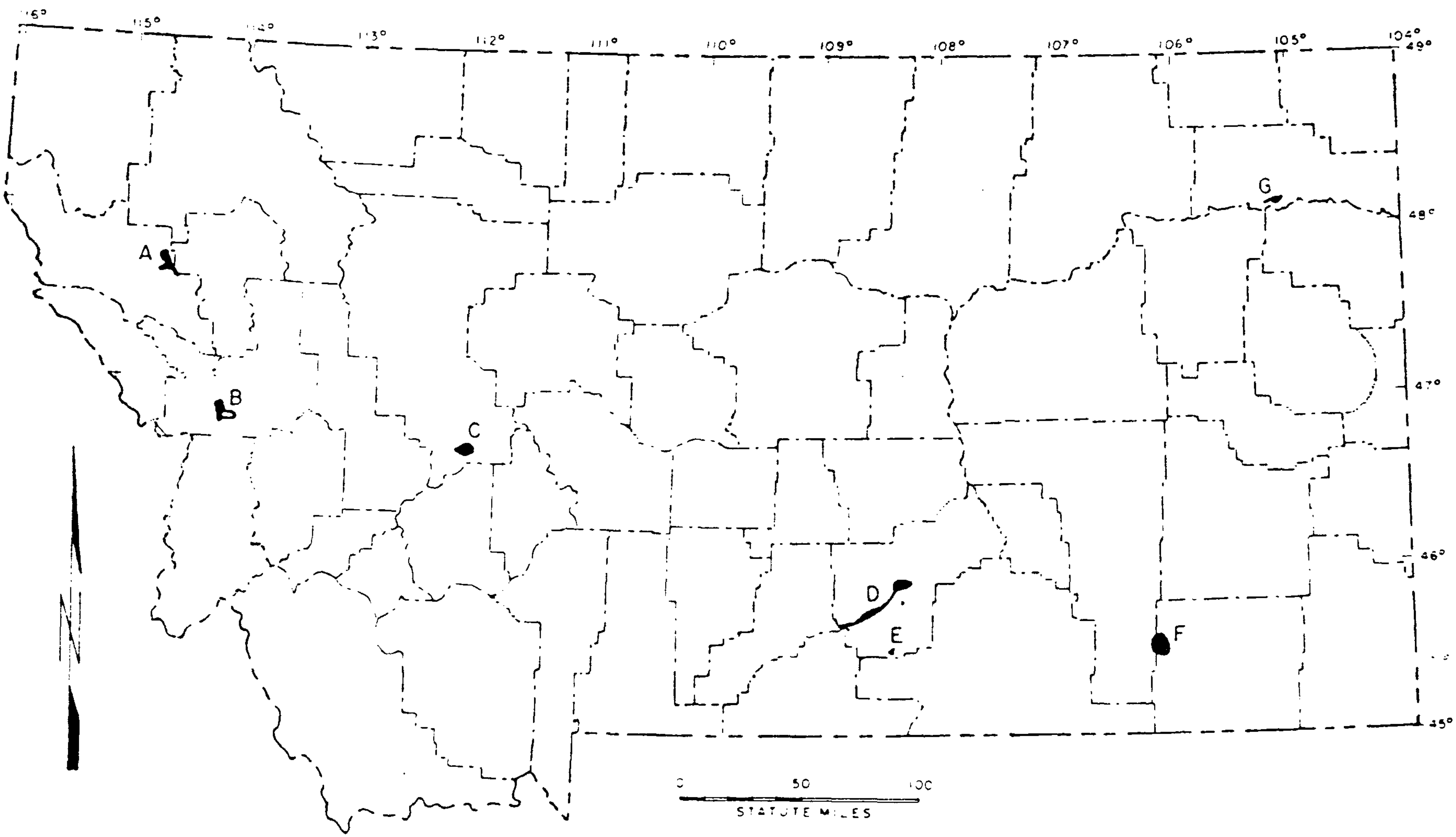

Figure 4. Location of areas favorable for heat pump usage. See text concerning specific areas.

ADDENDUM

This addendum is to explain in greater detail the tasks proposed on November 6, 1979 by Sonderegger and Wideman. The project proposal is entitled "Expanded Geothermal Studies in Montana," the period of performance would be from February 15, 1980 through August 31, 1981, at a cost of $479,659 of which $414,963 is requested from DOE.

The tasks can be divided into "new" and "continuing" categories for purposes of discussion. Continuing tasks are discussed below:

a. Ongoing areal investigations

1. In the West Yellowstone, Montana area, the well and spring inventory is completed. Samples for chemical analysis are currently being run in the laboratory. The gravity studies are complete and a seismic line is planned for late May or early June. Two anomalous areas were depicted by field measurement of silica, flouride, and temperature. The seismic profile will help clarify the relationships between these areas and the gravity map. The western anomaly will be drilled with a heat flow hole after the seismic data are interpreted. The eastern anomaly lies within the proposed two mile buffer zone of Yellowstone Park; consequently, until the status of the buffer zone is decided, no decisions concerning drilling in this area will be made.

2. In the Little Bitterroot Valley, work has progressed to the point where water samples are being collected, and pump and flow tests are scheduled for the end of this month. Additional water samples will be collected during aquifer testing to

evaluate mixing phenomena. Gravity work is essentially complete; resistivity studies are currently ongoing, and a seismic line remains to be run. The area is largely fee land within the Confederated Salish-Kootenai Reservation and cooperative arrangements have been made with the Tribal Council and the Hot Springs School District as part of our Local Assistance Program. Detailed geophysical and hydrologic data will be acquired next spring along a line between the (tribal) Camas Hot Spring and the (fee land) Camp Aqua hot well area to determine if these two systems are hydrologically interconnected. This will involve some test drilling and conversion of test holes to heat flow holes.

3. In the Radersburg basin, pump tests will be conducted next spring. Seismic verification of a gravity model is needed as it appears that a previously unrecognized major thrust system has cut off the carbonate aquifer and created the Plunkett Lake thermal system. The initial suite of water samples are presently being analyzed and additional samples will be collected in the spring during the pump tests.

b. Meeting D.G.E. goals and deadlines for data compilation (item 3 in proposal) is a promissory condition. It is not uncommon for schedules to be shifted or for a new aspect of the national program to require immediate attention. This item covers such changes, committing us to meeting such conditions. Also, by having it listed as a task, it provides the investigators with a measure of leverage to receive high priority ratings for such materials in the editorial and drafting queues.

c. The transfer of ground-water data to the U.S. Geological Survey's W.R.D. data banks provides access to the data for incorporation in the Geotherm file. This program was initiated between the district USGS office and the Bureau prior to the receipt of DOE support. Emphasis for this work is on data from eastern Montana, where wells are more common. However, by agreement with the district, thermal spring and well data from anywhere in the state will be processed as soon as received. At present, data from 30 analyses of warm springs and wells is in process. All additional inventory records and chemical analyses of warm or hot waters will continue to be entered as soon as laboratory results are completed.

d. Completion of the heat sensing imagery study will require more time because Arnold Boetteher was transferred from the USGS district office in Helena to the regional office in Denver. Also, Bob Leonard, who is working with Arnold on this study, was cut back from full-time to half-time on geothermal research; consequently, this work will be extended into the next contract period.

e. The eastern Montana effort consists of two basic approaches: (1) to plot up available oil field information, primarily bottom hole temperatures, from formations believed capable of yielding substantial amounts of water; and (2) to inventory any warm or hot wells that are not plugged. The use of this information is keyed to: (1) assisting Operations Research personnel with data for their purposes; and (2) developing geologic projections in map form showing the depth to a target horizon, the temperature of water expected in the target horizon, and the chemical composition of the water and flow measurements from specific well sites. Work will be restricted to the basal

Cretaceous sandstone units and the Madison Limestone (and the overlying Kibby formation where present) during the time frame of this proposal.

New tasks are keyed around an expanded geophysical program combined with geologic and hydrochemical investigation techniques. The focal point for these investigations will be to evaluate portions of major basins where resource indicators (hot springs and wells) are suggestive of a significant reservoir at depth, within the valley sediments, and where population or industrial energy consumption have lead Operations Research investigators to believe that a transfer from conventional energy usage to direct application of geothermal energy is favorable.

The southern Deer Lodge Valley is a good example of the type of area that we wish to focus upon. The study area will be 13 miles long by 7 miles wide, bounded on the north beyond the Warm Springs State Hospital, on the south by the valley terminous beyond Gregson (Fairmont) Hot Springs, on the west by the old geyser area of the Anaconda Smelter, and on the east near the valley margin. Thermal activity appears to have been restricted to the western side of the valley. Travertine deposits east of Anaconda, which were mined for flux many years ago, indicate to us that the circulation system that feeds the State Hospital could have been connected via faults or fractures back to the valley boundary fault in the vicinity of Anaconda. The Warm Springs-Anaconda-Gregson triangle of thermal indicators (see map at back) in the southwestern corner of the Deer Lodge Valley definitely deserves further study. Site specific gravity data have already been collected at Gregson (Stan Lawrence, 1978), gravity and shallow resistivity data have been collected at the Warm Springs State Hospital (Halvorson, 1980), and the logical next step is an areal study to learn what factors have controlled the occurrence of the springs and how these factors relate to the regional picture. The study will be oriented to test the hypothesis that a fairly extensive stratigraphically controlled geothermal reservoir may exist within the valley fill sediments.

Deep resistivity equipment will be required to trace zones of hot conductive water within the valley fill materials. Geophysical logs of the Warm Springs State Hospital test well show that the producing zone was penetrated at a depth of about 1300 feet. This well was drilled in a downstream direction (and presumably down the potentiometric surface) from the center of resistivity anomaly. We presume that elsewhere in the valley, a permeable zone containing geothermal fluids could be as deep as 3,000 feet (approximately 1,000 meters). Most of the funds requested under capital equipment are to construct a resistivity unit capable of penetrating at least 1,000 meters.

The other two areas for intensive study will be the Helena Valley and a third as yet unselected valley area. The Helena region was selected to conform with state interests, as expressed by the Energy Division of the Montana Department of Natural Resources and Conservation. The study area includes the Broadwater Hot Springs; beyond the study area to the northwest is the Marysville KGRA, and to the southeast is the Alhambra hot spring area. Currently identified hot springs and hot wells occur within intrusive igneous rock units or colluvial materials derived from these rocks, not within the valley proper. The study will be restricted to the northern boundary of the Boulder batholith (and associated small intrusives) and the southern and western edges of the Helena Valley as shown on figure 2. The scheduling of the Helena areal study is set up to coincide with an earthquake hazard reduction study and will utilize low sun angle photography acquired for that project and the neotectonic specialist on that study will help with geologic relationships of the valley fill materials. Microseismic equipment will be utilized to delineate zones of present day fault movement and one or more thermal gradient holes will test these zones.

The third study area will be decided upon once the effectiveness of the methods employed can be evaluated with respect to their geologic setting. Possible areas include the Jefferson Valley, the Bozeman (Gallatin) Valley, the Boulder area (only if results of the Helena area study are very positive), or the Hunters Hot Springs area near Springdale. In part, this decision will also be aided by the statewide compilation of existing geophysical data. In the proposal, items 2 and 7 were separated to ensure that the resource factors, irrespective of immediate application aspects, would control some of major research emphasis. Since the proposal was written, more detailed schedule planning showed a possible conflict between the third study under item 2 and studies under item 7. Consequently, the restraints listed under item 7 will apply to the third study under item 2, and to all additional sites selected for investigation.

Contract No. ____________

Modification No. ____________

Accounting No. ____________

Proposal Submitted to the
U.S. Department of Energy
Division of Geothermal Energy

EXPANDED GEOTHERMAL STUDIES IN MONTANA

John Sonderegger and Charles Wideman
Principal Investigators

Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology
Butte, Montana 59701

IRS No. 81-600-1254
Congressional District No. 1

Period of Performance: September 1, 1981-August 31, 1982

Total Cost: $150,000

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Montana Bureau of Mines and Geology
Montana College of Mineral Science and Technology

Date submitted: 5/13/81

Copies to: Endorsers, John Dunstan and Bureau file.

PROJECT PROPOSAL

Title: Geothermal Resource Evaluation in Montana

Preliminary Statement:

The Montana Bureau of Mines and Geology (MBMG) a department of the Montana College of Mineral Science and Technology, seeks to extend the geothermal research program to include a geological, geophysical, and hydrochemical reconnaissance of the White Sulphur Springs area and a geophysical reconnaissance of the Norris area, and to include a summary report using all available data.

The proposal is for the period September 1, 1981 through August 31, 1982. During this period the principal investigators will concentrate on a unifying report and supervising the areal studies. Our goals for the project period include:

See notes

(1) Publication of areal study reports in technical journals to avoid the delays encountered publishing through the MBMG.

(2) To ~~initiate a~~ study ~~in~~ the White Sulphur Springs area. The study will include geology, geophysics and water chemistry as initial tools; and a proposal to the Renewable Energy Division of the State Department of Natural Resources for test drilling funds at this site to confirm the size of the resource.

(3) To meet D.G.E. goals and deadlines for data compilation and presentation.

(4) To ~~initiate~~ do a ~~geophysical~~ study, using appropriate geophysical, geological, and geochemical techniques, in the Norris area to see if ~~additional~~ shallow resources can be ~~found~~ identified beyond those presently known.

ok → (5) To draw together into a coherent model, the information from geothermal studies in Montana. Areas studied to this point in time have all had some surface manifestation of warm water (with the exception of the Marysville, Montana, N.S.F. study). Part one of this study will be the controls for the several types of systems in Montana; part two will be a speculative discussion of areas without surface manifestation that appear most favorable for a "blind" resource to exist. Publish the results of this task in either MBMG or technical journal format.

→ boilerplate - Monthlys (not 1/4lys as now)
copies to ESL, DOE/DC, DOE/ID

Final report

Discussion of Objectives:

Items (1) and (3) constitute the completion of authorized studies and presentation of the research results. The Bureau's estimated time to publication from receipt of manuscript revised after peer review is currently 18 months, and is expected to increase for the next two years. Consequently, in order to achieve timely publication of research results we are forced to turn to publication in technical journals.

Item (2) is needed as development at White Sulphur Springs has not proceeded from the known resource area immediately around the spring itself. The resource is believed to be controlled by a thrust (Groff, 1965) or range front (Chadwick and Leonard, 1979) fault and it is hoped that a broader resource area can be delineated. The potential resource area shown on the state geothermal resource map is little more than an educated guess at present. Previous work consists of a shallow ground temperature survey over a 1½ block area (Chadwick and others, 1977).

Item (4) is a preliminary study of a precambrian bedrock system with a thin cover of alluvium, in a low blockfaulted range. Previous work in this area is restricted to a shallow (20 and 100 meter) resisistivity survey (Chadwick and others, 1978).

Item (5) is needed to bring together the geophysical, geological and hydrochemical work in a synthesis of results. The synthesis is necessary if predictive models are to be developed.

Facilities

Equipment available for the geophysical studies permit the following types of surveys:

1. Seismic reflection and refraction
2. Microseismic (MEQ 800)
3. Gravity (Lacoste-Romberg and Worden meters)
4. Magnetic (Geometrics 810)
5. Resistivity (10 kV generator, estimated max. depth > 1000 m)

The laboratory has consistently done well on USGS interlaboratory standards for the last eight years. Besides assay furnaces and normal wet chemical equipment, laboratory instrumentation includes:

- 1 Model 34000 Applied Research Laboratories Argon Induction Coupled Plasma Emission Spectrometer (26 channels)
- 1 Model 12 Dionev Ion Chromatograph
- 1 Model AA-4 Varian Techtron Atomic Absorption Spectrophotometer
- 1 Model 403 Perkin-Elmer Atomic Absorption Spectrophotometer with background correction and auto-sample changer
- 1 Model 603 Perkin-Elmer Atomic Absorption Spectrophotometer with background correction and graphite furnace
- 1 Model 51000 Spectrametrics, Inc. Plasma Source Echelle Spectrometer with qualitative comparator attachment
- 1 Model 102 Hitachi Digital Spectrophotometer

Geothermal Project Budget

Montana State-Coupled Program

September 1, 1981-August 31, 1982 (12 months)

		DOE	Montana Tech
I.	Salaries and Wages		
	Sonderegger (2,3)	4,937	7,406
	Wideman (2,2)	6,500	6,500
	Hydrogeologists (6,0)	13,000	---
	Geophysical Students	9,760	---
	Technicians (6,0)	8,000	---
	Total Salaries and Wages	42,197	13,906
	Benefits (18% of S. and W.)	7,595	2,503
	Total (S., W., and B.)	49,792	16,409
II.	Operations		
	Travel and Per Diem	25,000	
	Expendable Equipment	4,500	
	Equipment Rental geophysical vehicle support	9,200	3,000
	Water Analyses	6,000	
	Computer Processing	3,000	
	Equipment Maintenance	1,250	
	Publication Costs	7,744	
	Graduate Student Stipends	19,116	
	Total Operations	75,810	3,000
III.	Indirect Costs		
	49% of Wages, Salaries, and Benefits as established by HEW	24,398	8,040
IV.	Total Costs	150,000 (84.53%)	27,449 (15.47%)

VITA

CHARLES J. WIDEMAN, Professor of Geophysical Engineering

EDUCATION

1974	Ph.D., Geophysical Engineering, Colorado School of Mines
1967	M.Sc., Geophysical Engineering, Colorado School of Mines
1958	B.Sc., Geophysical Engineering, Colorado School of Mines

EXPERIENCE

1/80-Present	On leave of Absence to work on detailed geothermal resource assessment for Southwestern Montana.
7/74-1/80	Associate Professor of Geophysical Engineering, Montana College of Mineral Science and Technology.
1972-7/74	Assistant Professor of Geophysics, Montana College of Mineral Science and Technology. Responsible for courses dealing with gravity, magnetic and seismic prospecting.
1970-1972	Graduate student, Colorado School of Mines. Research dealing with earthquake seismology and emphasizing long term deformations of the earth's crust.
1968-1970	Assistant Professor of Geophsyics, Montana College of Mineral Science and Technology.
1967-1968	Senior Geophysicist; Westinghouse Electric Corp., GeoResearch Lab. Responsible for electrical surveys throughout the United States. Crustal studies and instrument development.

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RESUME

Name: John L. Sonderegger II

Personal:
Born January 14, 1942, Madison, Wisconsin
Married, three children

Education:
B.S.I., Geology, University of Wisconsin (Madison), 1962-1966
M.S., Geology, University of Alabama, 1967-1969
Ph.D., Geochemistry, New Mexico Tech, 1970-1973

Academic Honors:
University of Wisconsin, In-State Tuition Scholarship, 1963-1966
Northwestern University, N.D.E.A. Fellowship, 1969-1970.

Work Experience:
Montana Bureau of Mines and Geology, Research Associate Professor and Hydrogeologist, 1978 to present; Research Assistant Professor and Hydrogeologist, 1974-1978
Georgia Earth and Water Division, Geologist II, 1973-1974; Geologist III, 1974
Geological Survey of Alabama, Geologist I (¾ time), 1967-1969

Organizations:
Geochemical Society
Geothermal Resources Council
American Association of Professional Geologists

M.S. Thesis: A photogeologic and structural study of a limestone terrane with emphasis on fractures affecting ground-water occurrence.

Ph.D. Dissertation: A preliminary investigation of the dissolution kinetics of strontianite and witherite.

Publications:

Sonderegger, J. L., 1968, Geology of the Athens quadrangle, Alabama [abs.]: Journal of the Alabama Academy of Science, v. 39, no. 3, p. 211.

______1969, Calculation of carbon dioxide partial pressure from chemical analyses of limestone ground water: Journal of the Alabama Academy of Science, v. 40, no. 4, p. 227-231.

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______1974, A preliminary investigation of strontianite dissolution kinetics [abs.]: Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 961.

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Work in Progress:

Determination of soluble salt loads in glacial deposits and weathered Cretaceous formations, and interpretation of hydrochemical factors relating to saline seep in Montana.

A reconnaissance study of the geothermal potential of the upper Centennial Valley, Montana.

Research Interests:

Field and laboratory studies of mineral-aqueous interactions which affect ground-water composition.

The use of ground-water chemistry in the evaluation of geothermal and uranium resource potential.