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Proposal To

THE UNITED STATES DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
IDAHO FALLS, IDAHO

For

# PHASE I RESEARCH ON

# HYDROTHERMAL RESOURCES IN WYOMING

By

The Department of Geology
The University of Wyoming

Funding Requested: $101,899.00

Period of Research: October 15, 1978 - October 31, 1979

Submitted by:

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| Edward R. Decker<br>(056-32-1937)<br>Principal Investigator<br>Professor of Geology<br>University of Wyoming | Date |
| Henry P. Heasler<br>(520-62-8409)<br>Co-Investigator<br>Research Associate II<br>University of Wyoming | Date |
| R. S. Houston, Head<br>Department of Geology<br>University of Wyoming | Date |
| Hugh B. McFadden<br>Acting President<br>University of Wyoming | Date |

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## INTRODUCTION

We request funding for studies of hydrothermal resources in Wyoming, exclusive of Yellowstone National Park. The research will be part of the U.S. Department of Energy's Western States Coupled Direct-Heat Geothermal program, an integral element of the Rocky Mountain Basin and Range Commercialization Plan. There are two broad objectives of our program: 1) to extend the inventory of regional geothermal resources; and 2) to confirm and extend data for localities with apparent but unquantified potential for direct-heat or other hydrothermal applications. These objectives will be accomplished with compilations (digital and map form) of hydrothermal and related geoscience data, and a program for regional heat flow studies. Hot springs areas that will be examined are plotted in Figure 1, as are nearby geothermal gradient data and generalized locations for heretofore unanalyzed springs or spring deposits. Figure 1 also shows broad outlines of two areas with commercialization potential: 1) the Bighorn Basin for hydrothermal drying of barley; and 2) the Beaver Rim - Gas Hills area for direct heat or other low temperature applications. Plots of regional heat flow values and contours are shown in Figures 2 and 3, respectively. Figure 4 shows combined heat flow (Q) and radiogenic heat production (A) values for Wyoming and northern Colorado. Specific research topics are briefly itemized below.

1. Although Breckenridge and Hinckley (1978) provide new data for known hot springs, there is a need to define the true lateral extents of many of these systems. Additionally, new "thermal" areas require study and/or documentation. Preliminary evidence for large systems near the Cody, Dubois, and Auburn springs is shown in Figure 1, where the heretofore unanalyzed geothermal deposits and springs could imply "blind" reservoirs or regional systems with large lateral dimensions. There is evidence also that other thermal areas

exist near known springs; for example, hot waters were found in wells south of the Saratoga hot springs (A. Pekarek, pers. com., 1973), and hot artesian waters were encountered in wells (<1 km depths) west (8 mi.) and north (1-1½ mi.) of the springs at Thermopolis (J. Fanshawe, pers. com., 1978; Breckenridge and Hinckley, 1978, see also Fig. 1). Similarly, 45-50°C temperatures were measured in 190-200 m deep holes in the Horse Center anticline about 12 km south of Cody (well cards; J. Fanshawe, pers. com., 1978). We cannot be more specific without additional studies of these and other areas. So regional coverage of existing spring areas will be expanded using available thermal data, new chemical analyses, regional hydrology, and regional geologic structure.

2. Present data are not adequate for quantifying reservoir sizes, locations, etc., of potentially valuable systems. The data for the Thermopolis and Cody - Horse Center anticline systems (?) illustrate this point because their source areas cannot be fixed using presently available spring data and the very sparse regional gradient determinations (see Fig. 1). The origin of waters adequate for direct-heat applications near Casper also is obscure; for example, the temperature of Alcova hot springs was ~54°C, the sediments near Alcova are thin (<1 km), and the gradient in the nearby Pedro Mountains may be low (<19°C/km) (after Breckenridge and Hinckley, 1978; Decker and others, 1978; see also Fig. 1). From conversations with established Wyoming geologists*, the large volume flows in the Thermopolis springs are not explained, and the relations between structure and ground water movement in the Auburn, Alcova and Cody - Horse Center anticline areas are ambiguous. It

*D. L. Blackstone, Jr., Univ. Wyoming.
J. D. Love, U.S.G.S., Laramie, Wyoming.

is our opinion that many of these problems could be resolved with new combined studies of thermal gradients and library research on hydrology, and geologic structure. For some areas, first-order gradient data will be obtained from existing well data. Elsewhere, new measurements will be made in new holes.

3. Recent gradient determinations have located two new areas that may be suitable for direct-heat applications. One area is in the Gas Hills (Fig. 1), where six holes have gradients and temperatures in the ranges of 50-90°C/km and 15-25°C, respectively, and the maximum logged depth is 360 m. The other area is near Douglas (Fig. 1); here, two widely separated (∿40 km) 510 m deep holes have gradients of 40°C/km, and the bottom-hole temperatures are 25°C and 29°C. Further definition of these areas and the location of others should encourage development of direct-heat installations because populations in the Gas Hills, Douglas and other localities could increase due to mineral exploration (uranium, coal, etc.). Consequently, regional gradient and heat flow measurements will be continued. Existing heat flow values and contours for the region are plotted in Figures 2 and 3, respectively. If the inferred high heat flow zones can be confirmed, then direct-heat applications could have significant impact in at least three areas: 1) populated centers (e.g. Casper, Lander, Riverton, and Douglas) near or in the east-west band of elevated flux in the central part of the state; 2) the Black Hills - Great Plains area, a region with active agriculture and mineral exploration; and 3) the western Wyoming Basin - Middle Rocky Mountain region, an area with oil, gas and other exploration, coupled with locally rapid growth (e.g. Rock Springs - Green River area) (see Figs. 2 and 3).

4. Preliminary Q and A values for the North Park, Colorado area plot above the Q-A zone for the Basin and Range heat flow province (see JCK and PM in Fig. 4). To the north, the Q and A data for Keystone, Wyoming imply intermediate deep flux in the Medicine Bow Mountains (see KS in Fig. 4). The unusually high flux, regional fluorspar deposits (Van Alstine, 1976), Oligocene to Miocene(?) intrusive and tectonic activity (Steven, 1975; Tweto, 1977, pers. com., 1978), and Miocene to Pliocene(?) volcanism (Blackstone, 1975) in the North Park, Colorado area all suggest that these areas are a northerly extension of the Rio Grande rift (Decker and others, 1978). The existence of the rift here, in turn, would be important economically because the associated high flux would imply shallow moderate or high temperature hydrothermal reservoirs. So new heat flow and radioactivity research will be conducted in the northern extension of the rift. From combined studies of flux, radioactivity and young volcanic centers, hidden resources might be located.

5. Many oil wells in Wyoming have penetrated or will penetrate potentially valuable hot waters in the Madison Formation; Jackson (1977) infers that artesian thermal waters from a permeable Madison could be used for space heating in Sheridan. Additional study of the Madison and other sediments is warranted; for example, do above-normal gradients (>30°C/km) in shallow holes (∿1 km) near Greybull (E. Sammel, pers. com., 1978) indicate a usable hydrothermal resource? Thus a large body of oil well and other drill hole data will be evaluated. One aspect of this research will focus on the reliability of "oil field" temperature and gradient measurements. Concomitant research will involve studies of depths to water, aquifer production, regional stratigraphy and geologic structure.

In summary, it is proposed to confirm and extend the inventory of hydrothermal resources in Wyoming. These goals will be accomplished with analyses of thermal data for drill holes, studies of related geoscience data, and regional heat flow and radioactivity studies. The program will focus on areas with potential for direct-heat applications. However, moderate or high temperature resources also could be defined because there is evidence for high heat flow zones in the regions that will be studied.

PROCEDURES: ACQUISITION AND AVAILABILITY OF DATA

Down hole temperature data (T) will be compiled and analyzed. We will focus on holes for which T $>20^{\circ}C$ at 600-900 m depths. However, we will also compile gradients, depths, etc., for holes in which T $<20^{\circ}C$ because these data can yield estimates of the depths to potentially usable low temperature reservoirs. Areas with high geothermal gradients will receive special attention. High gradients in the Gas Hills were mentioned above; here, proposed drilling over a lateral distance of 30-50 km (Fig. 5) provides a valuable opportunity for new subsurface temperature studies and thus better definition of the resource. Other topics will be investigated; for example, the thermal waters in the Madison Formation in the Powder River Basin, and the $>30^{\circ}C/km$ gradients near Greybull in the Bighorn Basin. We cannot be more specific without closer examinations of available data. At present we have access to 475 wells for which the calculated gradient exceeds $30^{\circ}C/km$ (file GEOTHERM). Another 3000 well completion cards are available for study (D. Foley, pers. com., 1978). Data for new wells will be examined as records are released and stored in the nearby offices of the Geological Survey of Wyoming.

Water quality data, depths to water, aquifer productivities, regional hydrology and pertinent geology will be compiled for all investigated areas.

Water quality must be studied because the environment can be contaminated if certain elements (e.g. Hg, As, S) in some geothermal fluids are not disposed of properly, and because low-temperature heat exchanger systems must be designed according to local water compositions (Wright, 1978). It is equally important to compile specific or generalized information on regional aquifer production, hydrology, geologic structure, and proximity of potential resources to communities. It is sufficient to state that a resource is not likely to be developed, if the yield of water is too small, or the market is distant, regardless of the temperature at reasonably shallow depths. Geologic and hydrologic data will be obtained from the literature and records of the U.S. Geological Survey in Cheyenne, Wyoming. Water quality data would be abstracted from the literature, and from a limited number ($\sim$12) of new chemical analyses.

Referring to heretofore unstudied areas, we shall be able to determine the geothermal signatures of the geologically-young volcanic activity (1.1 $\pm$ .4 myr (McDowell, 1971)) in the Leucite Hills because this area is being extensively drilled for uranium (see Figs. 1 and 5). New temperature-depth data also should be obtained in the Granite Mountains, an area with historic earthquake activity and late Tertiary faulting or rifting (Love, 1970). Finally, unanalyzed springs and/or spring deposits occur near Cody, Auburn and Dubois (Fig. 1; after Breckenridge and Hinckley, 1978; Pierce, 1965, 1968; Keefer, 1970). These springs will be sampled for chemical geothermometry.

Regional heat flow and radioactivity studies will be continued throughout the region. Figure 5 is a plot of localities where mining company drill holes can be visited to attempt measurements of subsurface temperatures. We also plan to log a limited number of "shut in" oil wells and measure thermal conductivities of regional sediments to determine heat flow in established oil fields. Basic heat flow and radioactivity (U, Th, K) data will be collected using well established techniques (Decker, 1973; Roy and others, 1968;

Sass and others, 1971). To insure acquisition of reliable data in critical areas (e.g. the Gas Hills, the Leucite Hills), selected holes (∿12) will be cased so that they will remain open for temperature measurements.

DELIVERABLES

All data will be used to update file GEOTHERM of the USGS. Maps for the public and geoscientists will be prepared according to the requirements of the Department of Energy, NOAA, the USGS, and the University of Utah Research Institute. We will also cooperate fully with the State Operations Research team, when this group is identified.

Short status reports and preliminary results will be submitted to the Department on a monthly basis. These and other written reports will attempt to quantify reservoirs with direct-heat or other applications. We expect to furnish the following "hard" deliverables by November, 1979:

1. One deliverable will be a compilation of locations, temperatures ($>20^{\circ}C$), depths, gradients, and, if possible, depths to water for at least 600 heretofore unanalyzed drill holes in Wyoming. A regional map of subsurface temperatures and depths will accompany the data, as will a written report. Available water quality and aquifer production will be incorporated into the report, as will relevant stratigraphy and geologic structure. The map will show pertinent control points and relevant geology.

2. Regional gradient maps and interpretations thereof will be prepared and delivered. These deliverables will reflect local geology and the thermal properties of local rock units. This must be done because the conductive gradient varies sympathetically with corresponding conductives of the local rocks; for example, the deep gradient (and hence temperature) can be significantly suppressed, if a poorly conducting marine shale with high gradient

is underlain by high conductivity, indurated sandstone. Reports will summarize available shallow and deep water quality data, aquifer disposition, and aquifer production. It is planned to deliver detailed reports and maps for areas that could be prospectively valuable for near term direct-heat or other applications. One of these areas is expected to be the Powder River Basin, where the Madison Formation is known to locally contain thermal waters.

3. The Saratoga and Cody areas, the Thermopolis system, the moderate temperature system near Auburn (150°C (Renner and others, 1975)), and the Alcova area near Casper will be studied in detail to better define their lateral extents, and to quantify the magnitude of each reservoir. Other systems will be analyzed in a similar manner as data are located. Reports will directly follow available drill hole data, the geologic and hydrologic literature, and the proximity of resources to population centers.

4. Twelve new chemical analyses for heretofore unanalyzed springs or spring systems will be delivered. We also plan to try to collect samples of subsurface waters in areas where gradient data imply low or moderate temperature resources (e.g. the Gas Hills). Water samples and analyses will be accompanied by descriptions of collection sites, local geology and other pertinent geoscience data. From cooperative studies with qualified personnel elsewhere (e.g. the USGS), we expect to deliver preliminary interpretations of the chemical analyses. Following procedures of Breckenridge and Hinckley (1978), chemical analyses will be done in the laboratory of the Wyoming State Chemist.

5. A regional heat flow map will be delivered, as will detailed maps of gradients and heat flow in prospectively valuable areas. All maps will be interpreted. Both heat flow and available radioactivity data will be

used in interpretations. We expect to acquire heat flow data for at least twenty new stations. Approximately twelve holes ($\sim$3650 m total) will be cased for heat flow studies.

PERSONNEL

Dr. Edward R. Decker, Professor of Geology, will be principal investigator of the project. During the academic year, he will devote 40% of his time to research, 50% to teaching, and 10% to other University obligations. The summer of 1979 will be devoted to the proposed research.

Mr. Henry P. Heasler will be co-investigator of the project. He will be in immediate charge of most of the library and field research. He will work intimately with Decker on all aspects of the project. Mr. Heasler has an M.Sc. degree in geophysics (Heat Flow in the Elk Basin Oil Field, Northwestern Wyoming). Because Heasler has been employed by the University of Utah Research Institute, he is familiar with data formats and other requirements of the State Coupled Program.

A qualified graduate student will be employed during the summer of 1979. We expect the student to be Mr. Gerald J. Bucher. Bucher is an excellent field worker, and he has established many contacts with mining companies in Colorado and Wyoming. He is very familiar with all aspects of the University's procedures for field and laboratory studies of heat flow.

Other personnel will include a half-time secretary, and a research assistant for the academic year.

Brief resumes for E. R. Decker, H. P. Heasler and G. J. Bucher are listed below. They illustrate that each researcher has considerable experience and expertise in geothermal studies in Wyoming and bordering regions.

## FACILITIES

Wyoming's heat flow equipment includes portable and truck-mounted temperature cables (1-2 km lengths), two pick-up trucks, three divided-bar systems for thermal conductivity measurements, a conductivity sample saturation facility, a temperature calibration facility ($-30^{\circ}C$ to $235^{\circ}C$, $\pm$ $.001^{\circ}C$ control), and a gamma ray system (Two 5" x 4" NaI (Tl) crystals) for measurements of uranium, thorium and potassium. The temperature calibration facility is traceable to the U.S. National Bureau of Standards. The gamma-ray system and standards are modeled after those used by C. M. Bunker of the U.S. Geological Survey, Denver Federal Center, Denver, Colorado.

The University has a XDS Sigma 7 computer with multiple stream batch and time-sharing capabilities. Calcomp and Versatec plotters are connected to the computer. The Department of Geology has three time sharing terminals that are connected to the Sigma 7. The proposed investigators are experienced computer programmers; so digital data and preliminary maps and figures could be readily prepared at the University. Because the University uses indirect costs as partial support for the computer, etc., we do not request funding for computer time or other services.

The College of Arts and Sciences in the University has well-staffed electronic and machine shops. Both shops have much experienced with construction and maintenance of geothermal equipment. The machine shop also expertly prepares conductivity samples. The Geology Department employs an electronics technician.

The Wyoming Geological Survey occupies offices, etc., in a new building that is connected to the building occupied by the Department of Geology. The U.S. Geological Survey maintains offices in the building of the Wyoming Geological Survey. We enjoy good support and relations with these offices and personnel, and with U.S.G.S. and state personnel in Cheyenne.

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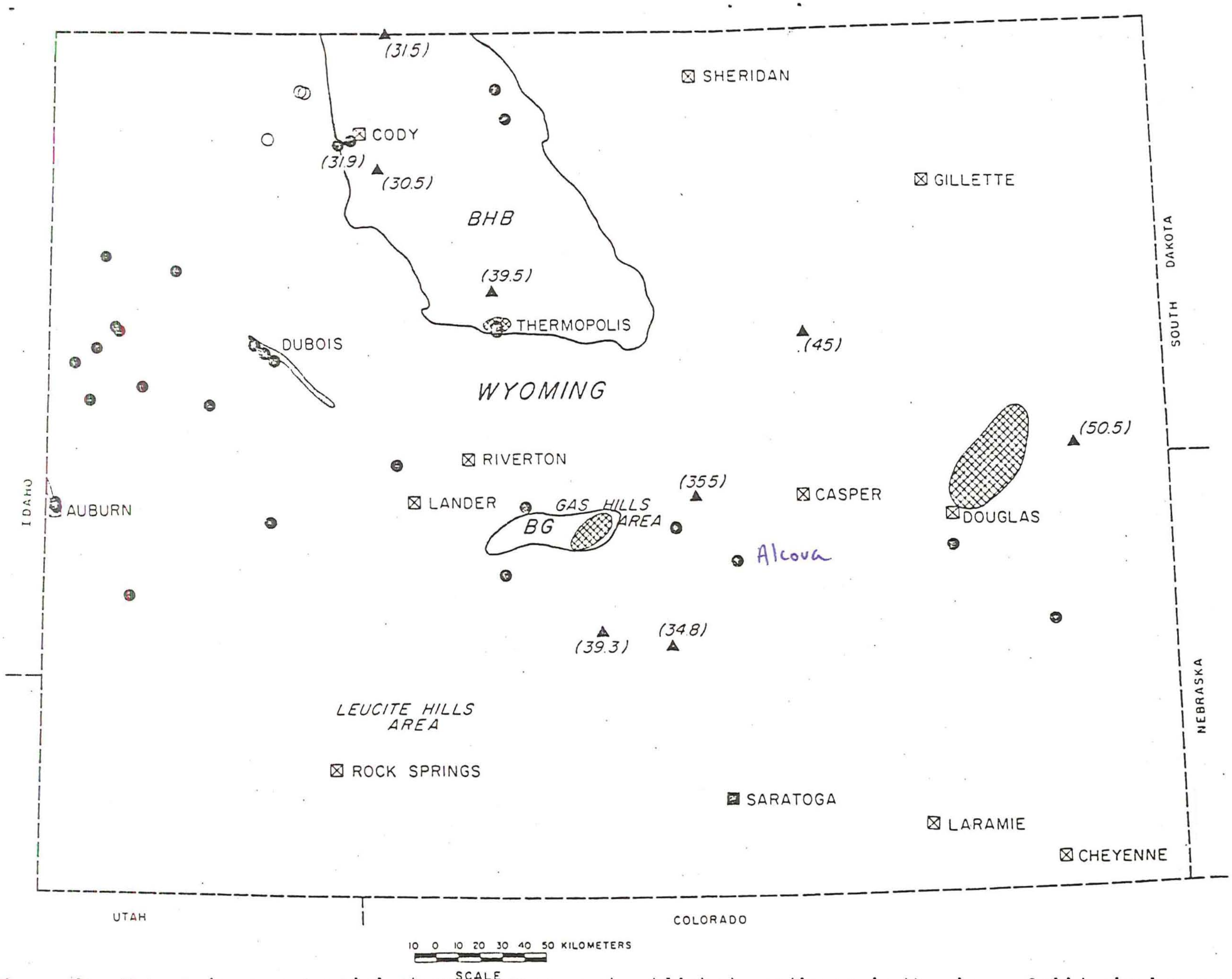


Figure 1. Hot springs, potential thermal areas, and published gradients in Wyoming. Solid circles represent locations of hot spring areas (after Breckenridge and Hinckley, 1978). Open circles represent locations of travertine and/or sinter deposits that require further study. Stipled areas represent areal bounds of unanalyzed geothermal deposits near Dubois and Auburn, Wyoming. Cross-hatched areas represent areal bounds (?) or areas where drill hole data suggest wide-area reservoirs with possible direct-heat applications. Solid triangles represent locations of published gradients (after Blackwell, 1969), the values of which are shown in brackets. The solid lines border the Big Horn Basin (BHB) and the Beaver Rim - Gas Hill Area (BG), two areas with commercialization potential.

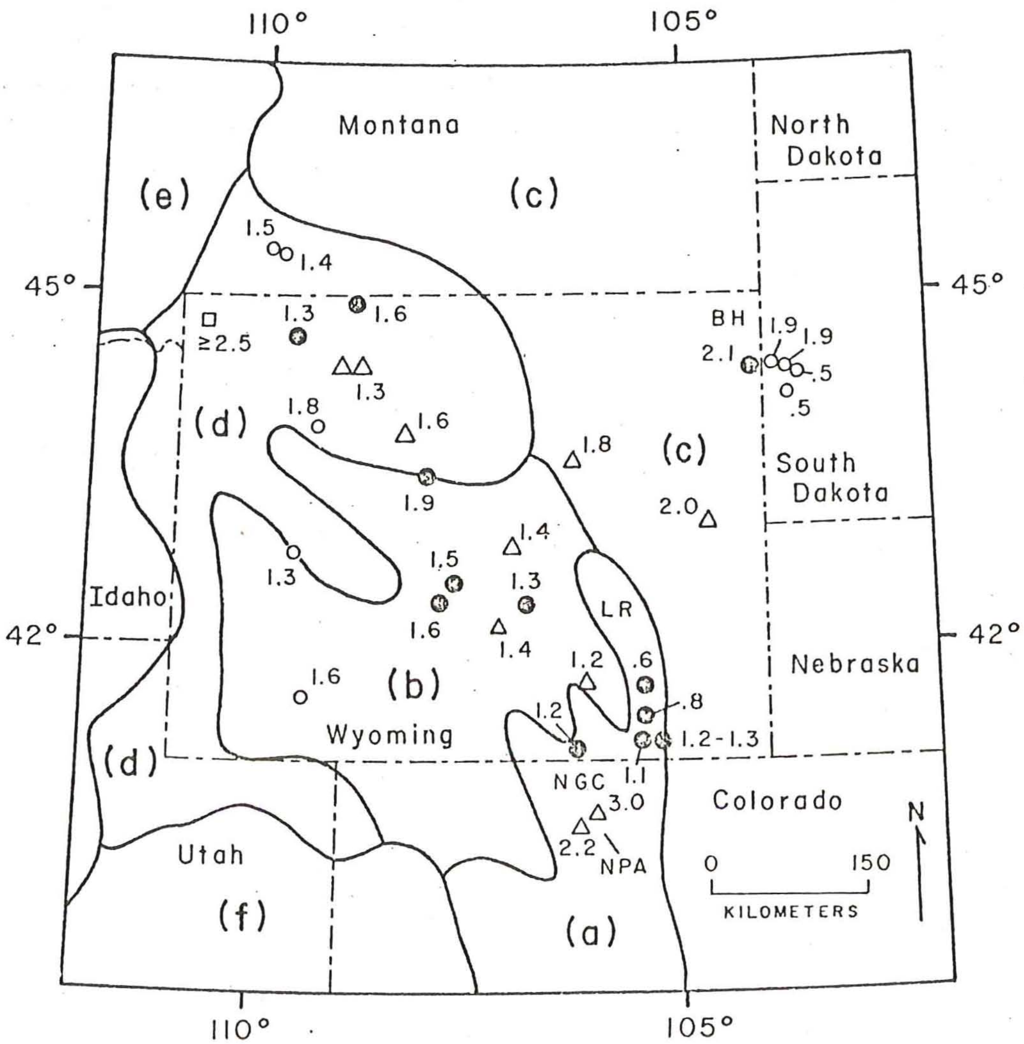


Figure 2. Heat flow in Wyoming and bordering areas. Units are HFU. Large solid circles represent locations of recent values (Decker and others, 1978). Open circles represent locations of previously published calculated values (Blackwell, 1969; Sass and others, 1971). Open triangles represent locations of previously published estimated values (Blackwell, 1969) in Wyoming and two preliminary values in Colorado (Decker, in preparation). Open square represents location of values in the Yellowstone caldera (Morgan and others, 1977). Abbreviations are as follows: LR-Laramie Mountains; BH-Black Hills; NGC-Northgate-Crystal area; and NPA-North Park area. Physiographic provinces after Fenneman (1946): (a) refers to the Southern Rocky Mountains; (b) refers to the Wyoming Basin; (c) refers to the Great Plains; (d) refers to the Middle Rocky Mountains; and (f) refers to the Colorado Plateau.

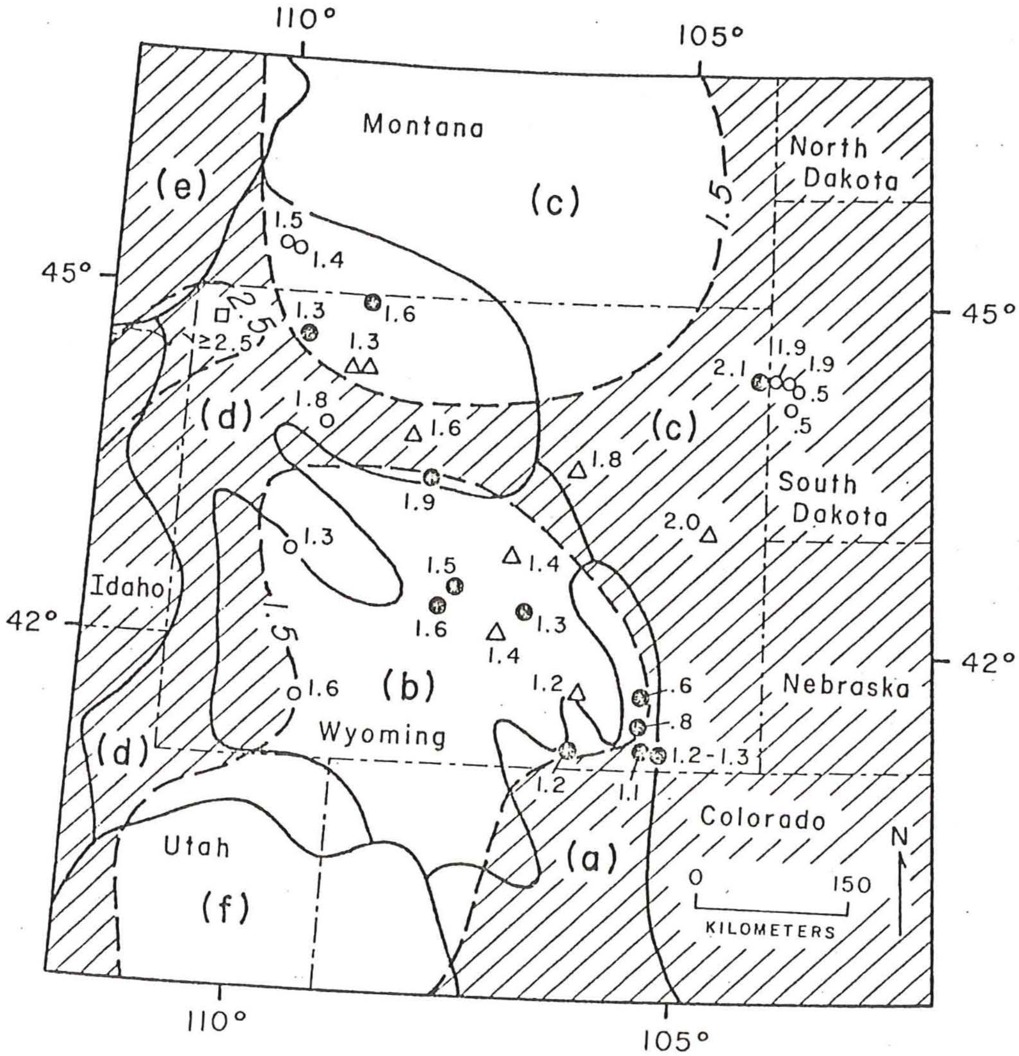


Figure 3. Generalized contours and heat flow values for Wyoming and bordering areas. Units are HFU. Contour map from Lachenbruch and Sass (1977, Fig. 2 and 3). Heat flow values are from Decker and others (1978) and Figure 2 herein. See caption of Figure 2 for explanation of plotting symbols and abbreviations for physiographic provinces.

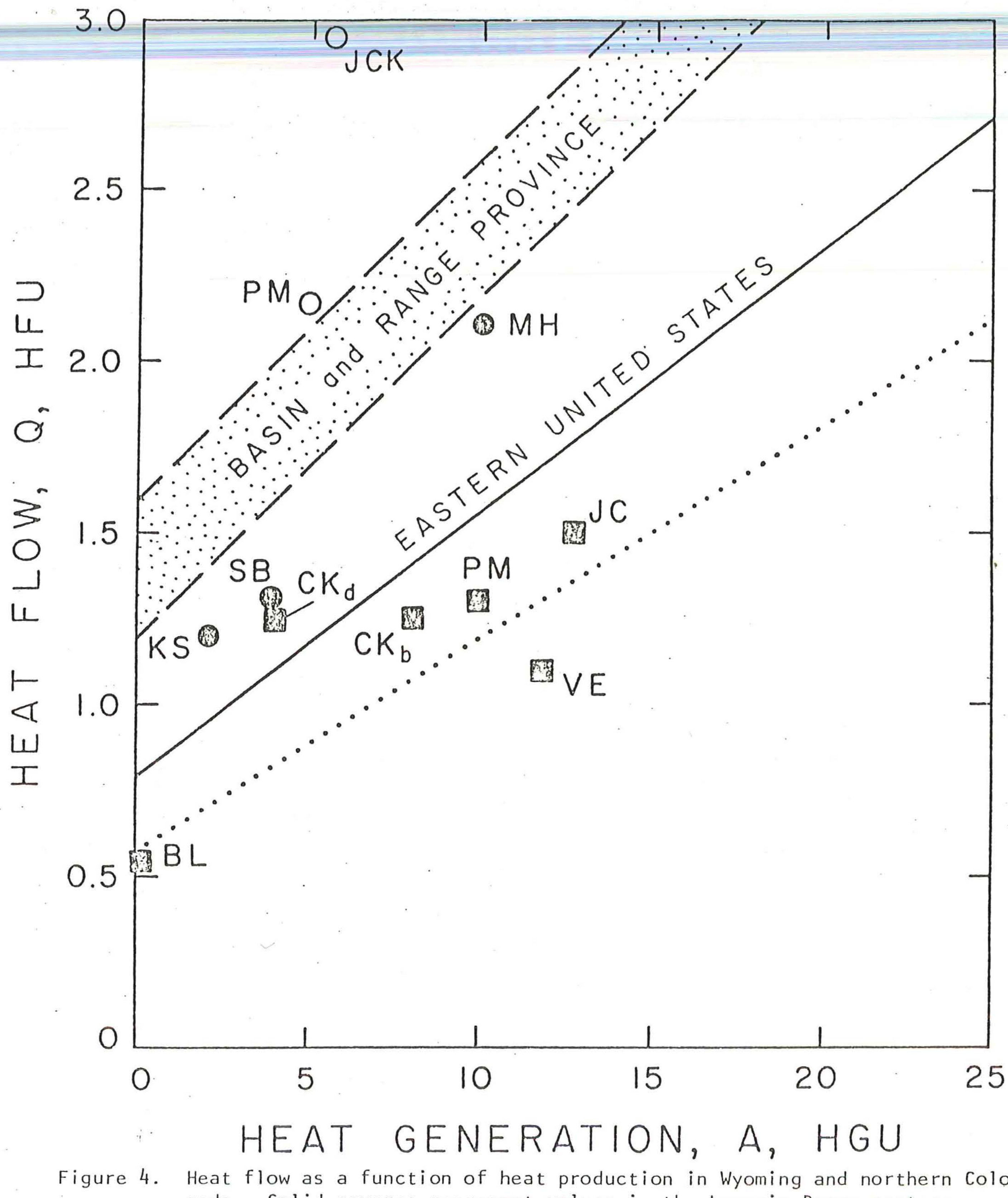


Figure 4. Heat flow as a function of heat production in Wyoming and northern Colorado. Solid squares represent values in the Laramie Range-eastern Wyoming Basin area; solid circles represent values from localities elsewhere in Wyoming. JCK and PM represent preliminary values for two localities in the North Park area, Colorado (Decker, in preparation). The dotted Q-A relation is for the Laramie Range-eastern Wyoming Basin area. The Q-A line for the eastern United States is from Roy and others (1968b). The Q-A zone for the Basin and Range province directly follows data and analyses in Lachenbruch and Sass (1977).

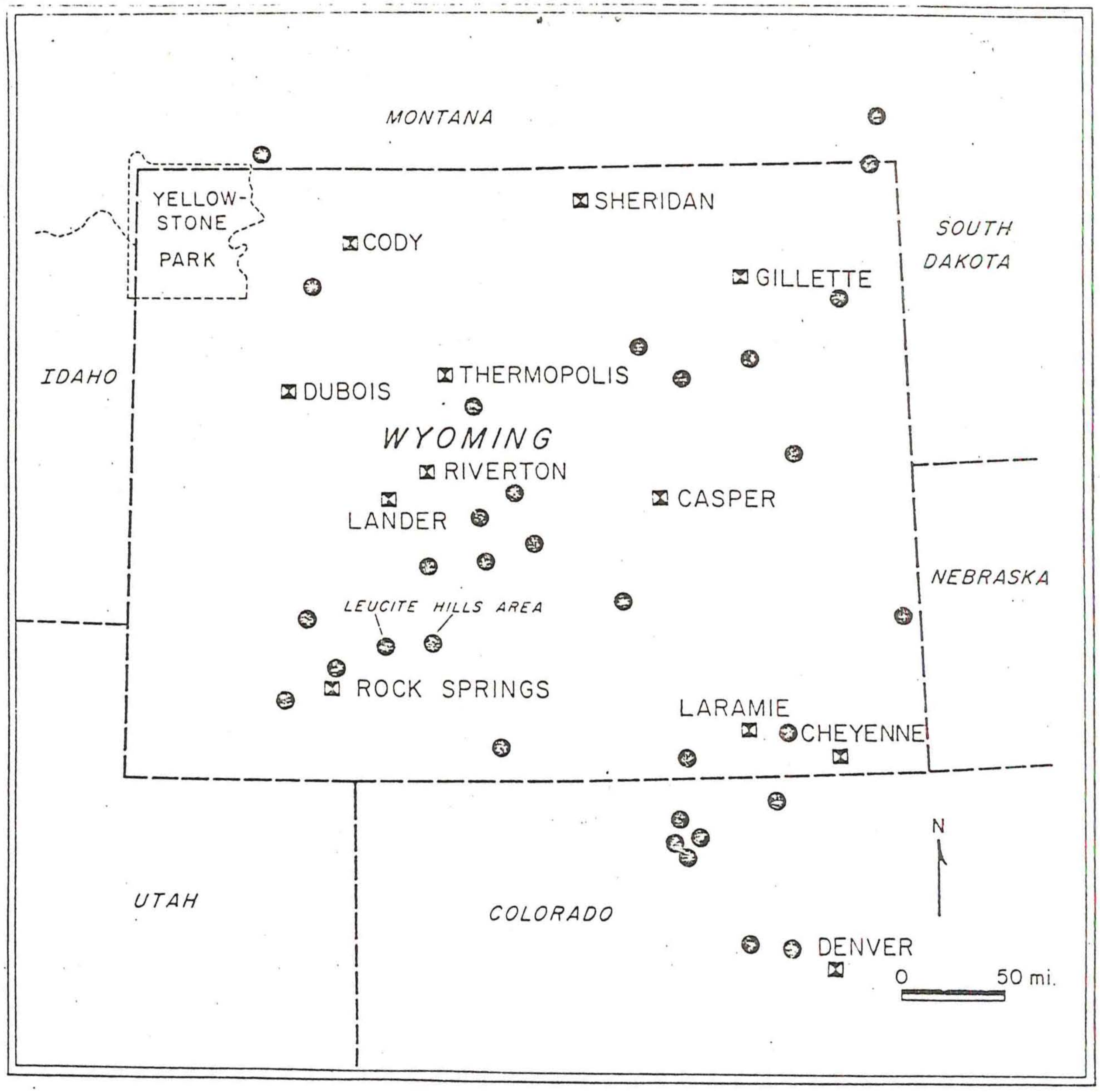


Figure 5. Plot of localities (solid circles) where exploration drill holes may be visited to attempt logging subsurface temperatures and thus determine heat flows.