THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

GEOTHERMAL RESOURCES OF THE WIND RIVER BASIN

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Report of Investigations No. 38
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Cover Photograph: Sweetwater Station Springs at the southern edge of the Wind River Basin. Two warm springs issue from alluvium deposited on Miocene Split Rock Formation. The site is at the intersection of an anticline and a fault. (Photograph by Bern S. Hinckley, from *Thermal Springs of Wyoming*, Geological Survey of Wyoming Bulletin 60, 1978).

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Sheets (back pocket)

Conversion factors

Length	1 meter = 3.281 feet (ft) 1 foot = 0.3048 meter (m) 1 kilometer = 0.6214 mile (mi) 1 mile = 1.6093 kilometers (km)
Mass flow	1 gallon per minute = 3.785 liters per minute (lpm) 1 liter per minute = 0.2642 gallon per minute (gpm)
Pressure	1 pound per square inch = 0.07031 kilogram per square centimeter (kg/cm^2) = 0.06805 atmosphere (atm.) 1 kilogram per square centimeter = 14.22 pounds per square inch (psi) = 0.9678 atm.
Thermal gradient	1 degree Fahrenheit per thousand feet = = 1.823 degrees Celsius per kilometer (°C/km) 1 degree Celsius per kilometer = 0.5486° Fahrenheit per thousand feet (°F/1,000 ft)
Thermal conduc-tivity	1 millicalorie per centimeter per second per degree Celsius (10^{-3} cal/cm sec°C) = = 241.8 British thermal units per foot per hour per degree Fahrenheit (Btu/ft hr°F) = 0.418 watt per meter per degree Kelvin (W/m°K)
Heat flow	1 microcalorie per square centimeter per second ($10^{-6}cal/cm^2sec$)= = 1 heat flow unit (HFU) = 0.013228 British thermal unit per square foot per hour (Btu/ft^2hr) = 41.8 milliwatts per square meter ($10^{-3}W/m^2$ or mW/m^2)
Temperature	1 degree Fahrenheit = 0.56 degree Celsius (°C) 1°Celsius = 1.8°Fahrenheit (°F) °F = 1.8°C + 32 °C = (°F - 32)/1.8

Introduction

This is the fourth in a series of reports describing the geothermal resources of Wyoming basins (**Figure 1**). Each basin report contains a discussion of hydrology as it relates to the movement of heated water, a description and interpretation of the thermal regime, and four maps (**Sheets 1** through **4**, back pocket): a generalized geological map (**Sheet 1**), a thermal gradient contour map (**Sheet 2**), a structure contour map (**Sheet 3**), and a ground-water temperature map (**Sheet 4**). The format of these reports varies, as does the detail of interpretation, because the type of geothermal system, quantity and reliability of thermal data, and amount of available geologic information vary substantially between basins and between areas within basins.

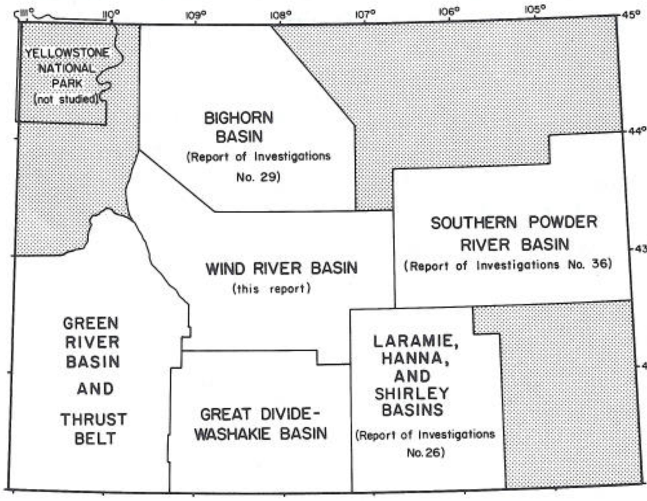

Figure 1. Study areas planned or completed in this series.

This introduction contains (1) a general discussion of how geothermal resources occur, (2) a discussion of the temperatures, distribution, and possible applications of geothermal resources in Wyoming and a general description of the State's thermal setting, and (3) a discussion of the methods used in assessing the geothermal resources. This introduction is followed by a description of the geothermal resources of the Wind River Basin of central Wyoming (**Figure 1**).

Funding for this project was provided by the U. S. Department of Energy to the Wyoming Geothermal Resource Assessment Group under Cooperative Agreement DE-F107-79ID12026 with the University of Wyoming Department of Geology and Geophysics, and by the Wyoming Water Research Center. Compilations of oil-well bottom-hole temperatures can be examined at the office of the Geological Survey of Wyoming in Laramie.

The text uses primarily British units. As outlined in footnotes on the following page, heat flow and thermal conductivity data are generally presented in metric units. A table of conversion factors faces this page.

Geothermal systems and resources

In this report a geothermal resource is heated water close enough to the earth's surface to be useful. Further definitions or classifications of geothermal resources are not attempted here because they are based on changing technological and economic parameters. Rather, we use geothermal data to describe the thermal regime in each basin. Thermal anomalies are identified, but no attempt is made to determine to what degree an anomaly is a resource.

Geothermal systems vary from high-temperature, steam-dominated, naturally pressurized types to warm water, mechanically-pumped systems. The type of system depends on how the heat flowing out of the earth is modified by complex geologic and hydrologic conditions. Commonly, the earth warms up about 14°F for every 1,000 feet of depth (Anderson and Lund, 1979). An attractive geothermal resource may exist where the thermal gradient is significantly higher than 14°F/1,000 feet.

Heat-flow studies in Wyoming basins (Decker and others, 1980; Heasler and others, 1982) have reported heat flows of 33 to 80 milliwatts per square meter (mW/m^2) (**Figure 2**). The most notable exception is in the northwest corner of Wyoming, in Yellowstone National Park, where very high heat flows of over 105 mW/m^2 (Morgan and others, 1977) result in high-temperature water at shallow depth.

By itself, a background heat flow of 33 to 80 mW/m^2 does not suggest a significant geothermal resource. In Wyoming basins, the primary mechanism for translating moderate heat flow into above-normal temperature gradients is ground-water flow through geologic structures. **Figures 3** and **4** illustrate systems based on two different structural regimes. Ground water flowing downward from the recharge area equilibrates with the temperature of the surrounding rock. But locally, folded permeable rocks (**Figure 3**) or faults (**Figure 4**) provide conduits for this heated water to rise rapidly toward the surface. If water proceeds through such a conduit without major heat dissipation, an elevated thermal gradient develops. In **Figures 3** and **4**, the temperatures listed in the axes of synclines represent an undisturbed temperature increase with depth. Bold type values demonstrate rock temperatures increased by groundwater flow. Any natural or man-made zone through which water can rise, such as an extensive fracture system or deep drill hole, serves the same purpose.

Because warm water is less dense than cold water, geothermally heated water tends to rise, a process known as free convection. Free convection is relatively weak, and is significant only under conditions of extreme temperature difference or relatively unrestricted flow. Forced convection occurs where water moves in a confined aquifer from an elevated recharge area at a basin margin to a lower discharge area. Water is forced over folds or up faults, fractures, or wells by the artesian pressure developed within the confined aquifer. Forced convection is more important in Wyoming basins than free convection.

Temperature, distribution, and application of resources

Renner and others (1975), of the U.S. Geological Survey, divide geothermal systems into three groups: (1) high-temperature systems, greater than 302°F (150°C); (2) intermediate-temperature systems, 194-302°F (90-150°C); and (3) low-temperature systems, less than 194°F (90°C). While Yellowstone National Park is a high-temperature system, the sedimentary basins of Wyoming fall mostly into the low-temperature and intermediate-temperature groups.

Due to the great depth of many Wyoming basins, ground water at elevated temperature exists beneath vast areas of the State (Heasler and others, 1983). Where systems like those described in **Figures 3** and **4** create local areas of high gradient, it may be feasible to develop the shallow geothermal resource directly. Outside these scattered areas of high thermal gradients, geothermal development will probably depend upon much deeper drilling, such as that provided by oil and gas exploration.

The geothermal resources in the basins are suited to relatively small-scale, direct-use projects located close by. Energy uses include a wide range of space heating, agricultural, aquacultural, and low-temperature processing applications. (See Anderson and Lund, 1979, for a discussion of direct-use geothermal applications.) Below 100°F,

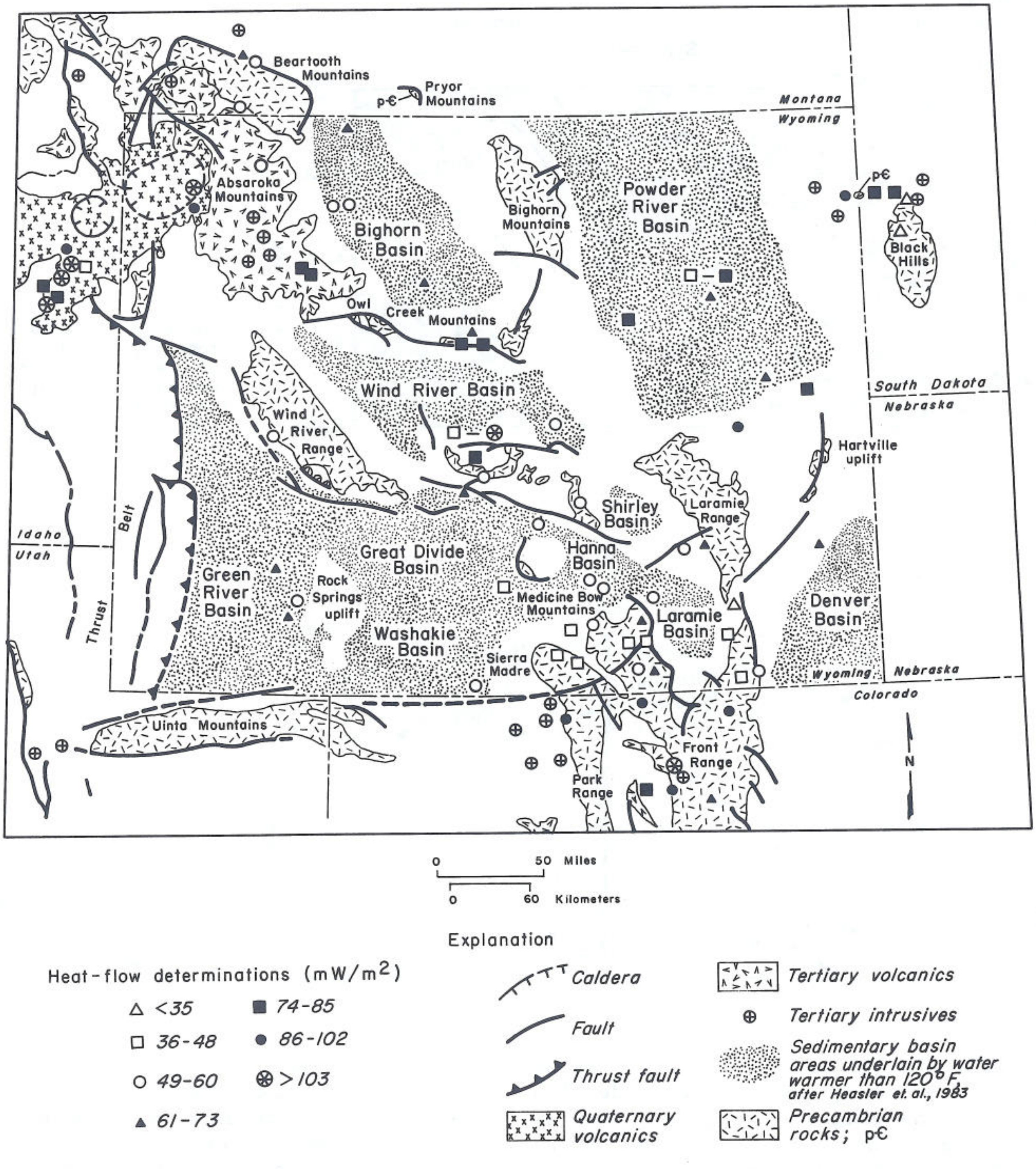

Figure 2. Generalized geology and generalized heat flow in Wyoming and adjacent areas, showing sedimentary basin areas defined in this series of reports to be underlain by water warmer than 120°F (after Heasler and others, 1983). Yellowstone National Park and Jackson Hole were not investigated.

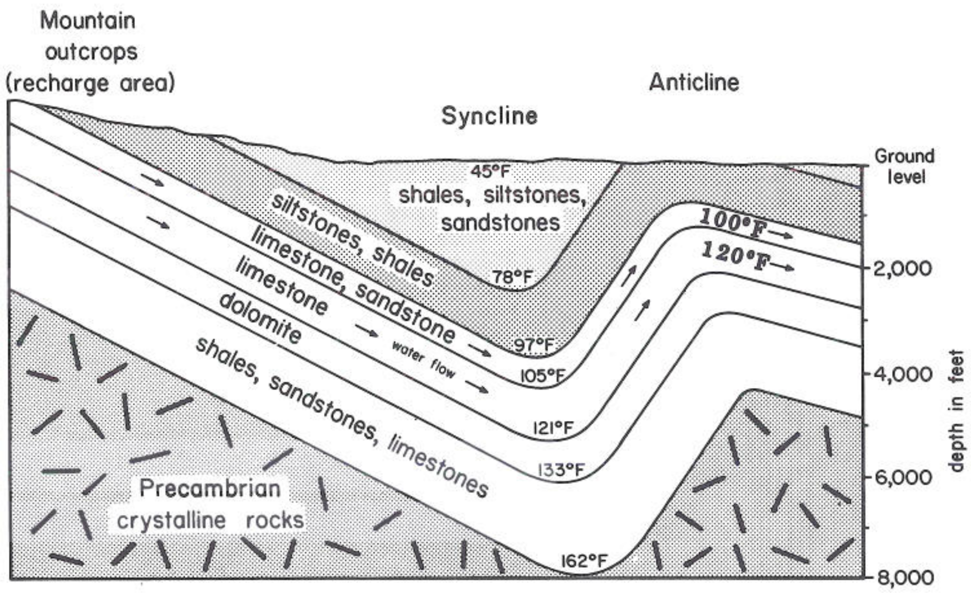

Figure 3. Simplified cross section of a typical Wyoming fold-controlled geothermal system. Arrows indicate flow of ground water.

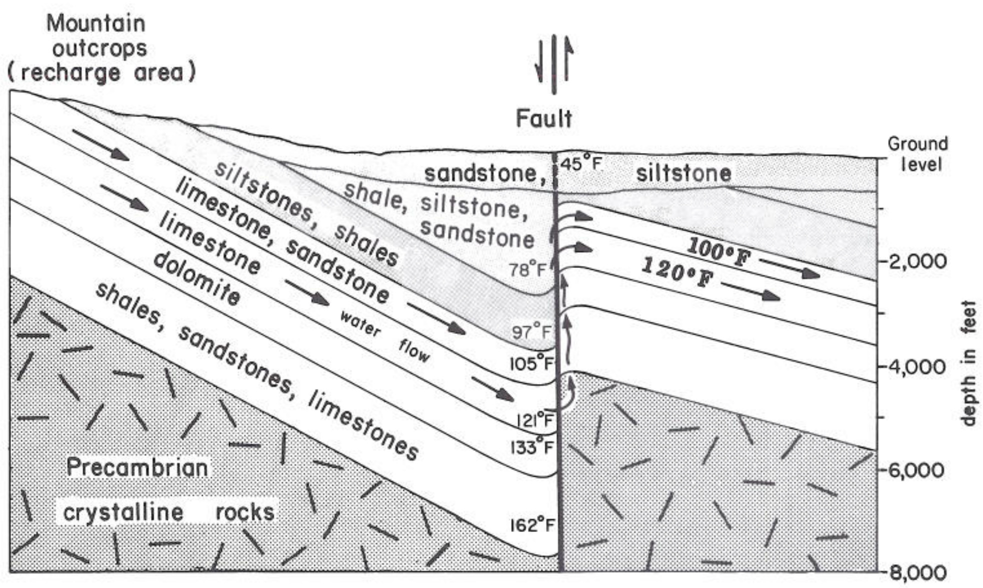

Figure 4. Simplified cross section of a typical Wyoming fault-controlled geothermal system. Arrows indicate flow of ground water.

uses are limited to such applications as soil and swimming pool warming, deicing and fish farming. Through the use of ground-water heat pumps, energy can be extracted from natural waters as cool as 40°F (Gass and Lehr, 1977).

The presently documented thermal springs in the State's basin areas (Breckenridge and Hinckley, 1978; Heasler and others, 1983) release 3.5 trillion British thermal units (Btu's) of heat per year in cooling to ambient temperature. Like the oil springs and seeps that led developers to Wyoming's vast petroleum fields, thermal springs are simply the surface manifestation of the much larger, unseen geothermal resource. For example, Hinckley (1984) calculated that approximately 24 trillion Btu's of heat would be released per year if all the thermal water produced as a by-product in Wyoming oil fields cooled to ambient temperature.

Methods of assessment

The principal purpose of these reports is the documentation and prediction of temperatures in the subsurface. In sections above, we have established a qualitative framework in which higher-than-expected thermal gradients occur where deep-heated water moves to shallow depth. Quantification of temperatures and gradients required a variety of techniques. Sources of subsurface temperature data include: (1) thermal logs of wells; (2) oil and gas well bottom-hole temperatures; and (3) surface temperatures of springs and flowing wells.

Thermal logs of wells

Thermal logs of wells are the most reliable data on subsurface temperatures because they represent direct measurements under thermally stable conditions. Using thermistor probes precise to ±0.005°C (Decker, 1973), the Wyoming Geothermal Resource Assessment Group has obtained temperature measurements in over 380 holes across Wyoming (Heasler and others, 1983). Temperatures were measured at intervals of 32 feet or less in holes up to 6,500 feet deep. Many of the logged holes had had years to equilibrate, so temperatures of sampled intervals approached true rock temperatures. With these temperature-depth data, least-squares statistical analysis was used to determine gradients at depths below the effects of long-term and short-term surface temperature fluctuations. These values are accepted as the most reliable thermal gradients, to which other temperature and gradient information is compared.

Where rock samples from a logged hole were available for testing, laboratory determinations of thermal conductivity were made. Decker (1973) discusses the laboratory techniques used for thermal conductivity determination. This information, coupled with the measured gradients, was used to calculate local heat flow. Where stratigraphic relationships or multiple holes with similar heat flow allowed us to rule out hydrologic disturbance, we could determine a purely conductive heat flow. This heat flow was, in turn, applied to all sequences of strata for which thermal conductivities could be estimated to obtain gradient values in the absence of holes that could be logged. Particularly in the deeper portions of Wyoming sedimentary basins, this technique was used as a semiquantitative check on less reliable data.

Oil and gas well bottom-hole temperatures

Oil and gas well bottom-hole temperatures (BHTs) are the most abundant subsurface temperature data. Because of their abundance, BHTs were used to assess geothermal resources in this study. Over 14,000 oil and gas well bottom-hole temperatures have been collected for the study areas (**Table 1**). Thermal gradients were calculated from BHT information using the formula:

$$\text{Gradient} = \frac{\text{BHT} - \text{Mean annual air temperature}}{\text{Depth}}$$

Mean annual air temperatures for Wyoming basins are between 40° and 48°F (Lowers, 1960). These values, assumed to approximate mean annual ground temperatures, were used in calculating gradients over fairly large areas. This procedure assumes that variations due to elevation and microclimatic effects are negligible compared with BHT inaccuracies. Well log data on file at the Geological Survey of Wyoming were the principal source of BHT data. (A slightly larger data base is available at the Wyoming Oil and Gas Conservation Commission Office in Casper, Wyoming.)

The use of oil field bottom-hole temperatures in geothermal gradient studies is the subject of some controversy among

Table 1. Summary of geothermal data on Wyoming sedimentary basins.

Basin:	Bighorn	Great Divide and Washakie	Green River	Laramie, Hanna and Shirley	Southern Powder River	Wind River
Number of bottom-hole temperatures analyzed.	2,035	1,880	1,530	445	6,100	1,740
Number of wells thermally logged.	70	68	47	57	60	67
Background thermal gradient in °F/1,000 feet (°C/kilometer).	16 (29)	15 (27)	13 (24)	12-15 (22-28)	14 (25)	15 (28)
Highest recorded temperature and corresponding depth.	206°F at 23,000 ft (152°C at 2,035 m)	376°F at 24,000 ft (191°C at 7,300 m)	306°F at 21,200 ft (152°C at 6,453 m)	223°F at 12,000 ft (106°C at 3,600 m)	275° at 16,000 ft (135°C at 4,900 m)	370°F at 21,500 ft (188°C at 6,55 m)
Basin depth in feet (kilometers).	26,000 (8.0)	26,000 (8.5)	30,200 (9.2)	12,000; 39,000; 8,200 (3.7; 12.0; 2.5)	16,400 (5.0)	25,800 (7.6)

geothermal researchers. Problems associated with the thermal effects of drilling and with operator inattention in measuring and reporting BHTs cast doubt on the accuracy of individual temperature reports. It has been suggested, for example, that in some areas BHTs may correlate with the ambient air temperature during drilling and, specifically, that many of the thermometers used in the summer are reading their maximum temperature before they are lowered down the drill hole. Similarly, drilling fluids may transfer heat to the bottom of a drill hole, warming or cooling the rock depending on the drilling fluid temperature and the depth of the hole. The magnitude of a thermal disturbance depends on the temperature difference between the drilling fluid and the rock; the time between the end of fluid circulation and temperature measurement; the type of drilling fluid used; the length of time of fluid circulation; and the degree to which drilling fluids have penetrated the strata.

Theoretical analysis of the deviation of a reported BHT from true formation temperature may be possible on a detailed, well-by-well basis, but is an overwhelming task basinwide. Therefore, for these studies it was assumed that such factors as time of year, operator error, time since circulation, and drilling fluid characteristics are random disturbances that average out over a large number of BHTs. The fact that drilling fluids are circulating, acting to homogenize temperatures within the hole, is, on the other hand, a systematic effect that depresses temperature more with increasing depth. With sufficient data at all depths, anomalous gradients may be identified despite the fact that they are depressed in value.

The following procedure was used to assess geothermal resources in a basin from oil and gas well bottom-hole temperatures: First, all available BHTs were compiled and gradients were calculated. The gradients were then plotted on a map and contoured for the basin. Thermally logged holes define fixed points in the contouring.

As explained above, temperature gradient values may be lower in deeper holes because of drilling effects. This was taken into account in identifying gradient anomalies by grouping all temperature and gradient data for a basin into 500-foot depth intervals and then calculating the mean value and the 50th, 66th, 80th, and 90th percentiles for each interval. These calculations are tabulated in each basin report. The 80th percentile - the value below which 80 percent of the data fall - was chosen arbitrarily as a cutoff for the identification of geothermal anomalies.

A single background thermal gradient was calculated for each basin (**Table 1**), based on thermal logs, thermal conductivities of the basin's sedimentary sequence, and heat flow. Although BHT gradients are assumed to be depressed with depth, we do not feel that we can define as anomalous those gradients that are lower than the background thermal gradient. Therefore, thermal gradient values are identified as anomalous only if they fall above the 80th percentile for their depth range and above the background thermal gradient for the basin in which they occur.

In these basin studies, a lower BHT cutoff of 100°F was used. In our experience, a temperature gradient based on a temperature lower than 100°F is usually not reliable. Also, sub-100°F water is of little economic value unless it occurs at very shallow depth.

The final criterion for identification of an area of anomalous gradient is that a group of anomalous points (determined as outlined above) occur in the same area.

Particularly above and within zones of ground-water movement, gradients defined from bottom-hole temperatures may not completely reflect the character of a geothermal resource. For example, **Figure 5** shows the effect of ground-water movement homogenizing temperatures in the lower portion of a hole at the top of the Thermopolis anticline. A gradient calculated from a single BHT at 800 feet would miss the very high gradients and temperatures in the top part of the hole. Conversely, a gradient calculated from a BHT at 400 feet would give a seriously erroneous temperature at 600 feet. These effects illustrate the importance of thermal logging in areas of suspected hydrologic disturbance. As a general check on the downward projection of thermal gradients, we know from heat flow and rock thermal conductivity considerations that gradients among the Wyoming basins are all similar below levels of hydrologic disturbance.

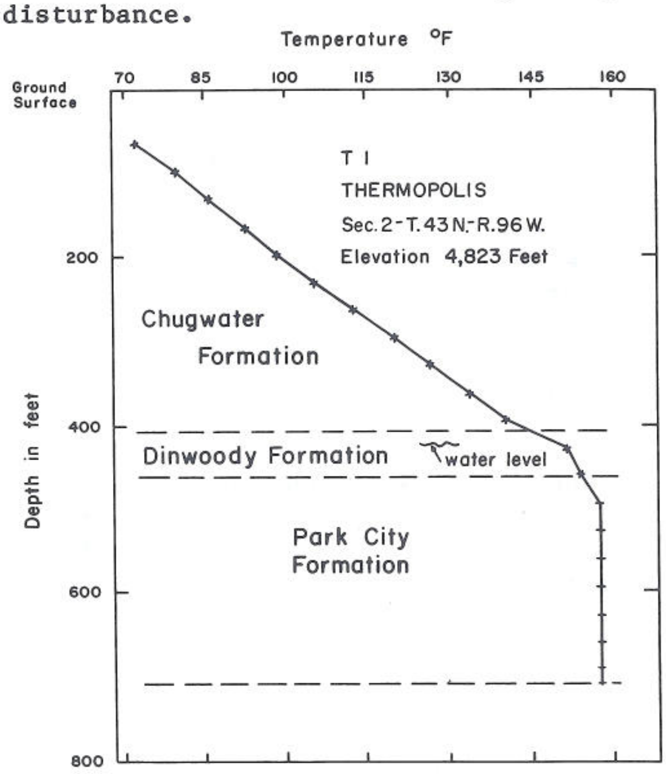

Figure 5. Temperature-depth plot showing hydrologic disturbance, based on a thermal log of a well at Thermopolis (from Hinckley and others, 1982).

An additional constraint on the use of gradient data to evaluate geothermal resources is that ground water must be present to transport the heat. Therefore, we have identified for each basin a productive, basinwide aquifer that is deep enough to contain water at useful temperatures, and for which thermal and hydrologic data are available. A map of temperatures within that aquifer, on which BHTs of that formation are plotted and contoured, is included in each basin report. Verification is provided by the sparse thermal-logging data. No attempt was made to correct BHTs for drilling effects, so a certain degree of underestimation of temperatures may be expected in the deeper zones, as described above. The deviation of BHTs from true formation temperatures is not known; however, a drill hole in an aquifer with active circulation should equilibrate to undisturbed temperatures relatively rapidly.

Surface temperatures of springs and flowing wells

Surface temperatures of springs and flowing wells provide the third source of subsurface temperature data. The amount of cooling before the water reaches the surface is generally unknown; therefore, they provide only a minimum temperature check on BHT data. There is also commonly some uncertainty about the depth and source of flow. One can assume that all flow is from the bottom of a flowing well to obtain a minimum gradient. The most useful subsurface temperature data from springs and wells come from those whose source aquifer can be determined.

The most important aspect of any geothermal resource is the temperature and flow rate that can be delivered to the surface. In this sense, flowing wells and springs give excellent data. Selected locations of surface discharge of thermal water (greater than 70°F) are indicated on the thermal gradient maps.

Summary

The authors investigated the geothermal resources of several Wyoming sedimentary basins. Oil-well bottom-hole temperatures, thermal logs of wells and heat flow data were interpreted within a framework of geologic and hydrologic constraints. Basic thermal data, which includes the background thermal gradient and the highest recorded temperature and corresponding depth for each basin, are provided in **Table 1.**

These investigations of the geothermal resources of Wyoming sedimentary basins have resulted in two main conclusions:

(1) Large areas in Wyoming contain ground water at temperatures greater than 120°F (**Figure 2**). Although much of this water is too deep to be economically tapped solely for geothermal use, oil and gas wells may provide access to this significant geothermal resource.

(2) Isolated areas of high temperature gradients exist within each basin. These areas -- many revealed by hot springs -- represent geothermal systems that might presently be developed economically.

Geothermal resources of the Wind River Basin, Wyoming

Geologic and hydrologic setting

Stratigraphy

The Wind River Basin covers approximately 8,000 square miles in central Wyoming (see **Figure 1** for location). Most of Fremont County and the eastern one-third of Natrona County are in the Wind River Basin.

In the Wind River Basin, the mass transfer of heat by moving water creates areas of high geothermal gradients. Therefore, it is important to identify those strata with favorable water-bearing characteristics. In addition, the confining strata above and below these aquifers must be considered in terms of their effectiveness in restricting ground-water flow patterns.

Sheet 1 presents the surface distribution of the various strata to be discussed. The stratigraphic chart for the Wind River Basin (**Table 2**) lists formation thicknesses, lithologies, general water-bearing characteristics, and water quality. Much of these data were taken from Richter (1981), to whom the reader is referred for a thorough discussion of Wind River Basin hydrogeology. **Table 2** identifies strata as major confining units, confining units, aquifers, or major aquifers. These divisions are very general. Locally, in areas of relatively higher permeability and(or) small water demand, any formation listed may constitute a useful aquifer.

The youngest deposits in the Wind River Basin are the unconfined Quaternary sands, silts, and gravels deposited along stream channels. Because of their easy accessibility, good recharge, and generally high permeabilities, these deposits form one of the most important aquifers in the basin. Ground-water temperature in this aquifer will generally approximate the mean annual air temperature (43°F for most of the Wind River Basin; Lowers, 1960). Such waters have geothermal potential primarily through the use of ground-water heat pumps. These devices can extract heat from any above-freezing waters and are therefore constrained more by general ground-water availability than by the distribution of geothermal anomalies.

Oligocene, Miocene, and Pliocene rocks are present only locally in the basin and in the Granite Mountains region. Like the Quaternary deposits, they are primarily unconfined aquifers. This lack of confinement precludes development of deep, forced-circulation systems like those depicted in **Figures 3** and **4**. These aquifers are therefore unlikely to provide waters of elevated temperature.

The Eocene Wagon Bed, Tepee Trail, and Aycross Formations are poor water producers and occur only in very limited, higher elevation areas in the extreme northwest and southeast parts of the basin. Both the lithology and the location of these formations preclude deep circulation of ground water; thus, there is little geothermal potential.

The Eocene Wind River Formation covers most of the surface of the Wind River Basin. The highly productive sandstones of this aquifer account for approximately 50 percent of all private domestic wells in the basin. An additional 30 percent are developed in Quaternary deposits (Richter, 1981). Although the Wind River Formation is mostly unconfined, interbedded low-

Table 2. Stratigraphic column for the Wind River Basin and Granite Mountains.[1]

Age	Formation	Thickness (in feet)	Lithologies	Water-bearing properties	Water quality[2]
Cenozoic Quaternary	Undivided	0-100	Unconsolidated clay, silt, sand, and gravel	Major aquifer: yields 5-5,000 gpm	TDS: 100-1,000 mg/l
Tertiary Pliocene	Moonstone Formation[3]	0-1,400	Poorly consolidated shale, sandstone, mudstone, tuff, limestone, conglomerate	Major aquifer: yields up to 500 gpm	TDS[4] 100-1,000 mg/l
Miocene	Miocene rocks[5]	0-900	Sandstone with interbedded tuff, limestone, and conglomerate; basal conglomerate	Aquifer: yields $\leq$ 100 gpm Major aquifer: yields generally up to 300 gpm, 100 gpm not uncommon	TDS <600 mg/l; Ca, Na, HCO_3, SO_4
Oligocene	White River Formation	0-1,000	Fine sandstone with interbedded tuff and bentonite	Aquifer: yields 1-300 gpm, maximum 850 gpm	
Eocene	Wagon Bed Formation	0-700	Bentonitic sandstone	Confining unit: yields < 10 gpm	TDS 1,500-2,500 mg/l
Eocene	Tepee Trail Formation	0-2,000	Tuffaceous siltstone, sandstone	Confining unit: yields < 10 gpm	
Eocene	Aycross Formation	0-1,000	Shale, mudstone, conglomerate, volcanics, sandstone	Confining unit	
Eocene	Wind River Formation	250-1,000	Siltstone, shale, mudstone, sandstone	Major aquifer: yields up to 1,500 gpm, 200 gpm flowing wells	TDS 100-5,000 mg/l; HCO_3, SO_4
Eocene	Indian Meadows Formation	0-700	Mudstone, sandstone, limestone	Confining Unit:	
Paleocene	Fort Union Formation	0-8,000	Conglomerate, sandstone, shale, siltstone	Aquifer: yields up to 100 gpm, 10 gpm flowing wells. Basal section is a Confining unit	
Mesozoic Cretaceous	Lance Formation	0-6,000	Sandstone, shale, pebble conglomerate	Aquifer: yields up to 100 gpm	TDS >1,000 mg/l; Na, SO_4, Cl, HCO_3
Cretaceous	Meeteetse Formation	0-1,300	Sandstone, shale, siltstone, mudstone	Confining unit	poor
Cretaceous	Mesaverde Formation	600-2,000	Upper unit sandstone; middle unit shale, siltstone, sandstone; basal sandstone	Aquifer: yields up to 500 gpm, locally artesian	TDS >1,500 mg/l; Na, SO_4, HCO_3
Cretaceous	Cody Shale	3,000-5,500	Shale with interbedded thin sandstones	Major confining unit	poor
Cretaceous	Frontier Formation	500-1,000	Alternating sandstone and shale	Aquifer: yields up to 150 gpm, 10-25 gpm flowing wells	TDS <500-3,000 mg/l; Na, SO_4, HCO_3, Cl
Cretaceous	Mowry Shale	400-600	Interbedded shale and bentonite	Major confining unit	
Cretaceous	Muddy Sandstone	20-150	Fine- to medium-grained sandstone	Aquifer: 10-50 gpm flowing wells	TDS >500 mg/l; Cl, HCO_3
Cretaceous	Thermopolis Shale	120-250	Shale and mudstone, sandstone lenses	Major confining unit	
Cretaceous Jurassic	Cloverly Formation and Morrison Formation	300 to 600	Sandstone, middle shale unit Mudstone and shale, sandstone lenses	Aquifer: yields generally <50 gpm, up to 300 gpm, 1,025 gpm flowing wells Confining unit: yields <5 gpm	TDS <1,500 mg/l; Na, HCO_3, SO_4
Jurassic	Sundance Formation	150-600	Sandstone and siltstone, carbonates at base	Aquifer: 250-500 gpm flowing wells from Sundance-Nugget aquifer	TDS <500-2,000 mg/l; Na, Cl, SO_4
Jurassic	Gypsum Spring Formation	0-230	Alternating siltstone, shale, limestone, gypsum	Confining unit	poor
Jurassic	Nugget Sandstone	0-400	Fine to medium sandstone, siltstone at base	Aquifer: artesian conditions common	generally >1,000 mg/l; Na, Cl, SO_4
Triassic	Chugwater Formation	1,000-1,300	Interbedded siltstone, sandstone, and shale	Major confining unit: sandstone layers locally yield <20 gpm	generally poor, sandstone layers may have TDS <1,000 mg/l
Triassic	Dinwoody Formation	0-250	Interbedded siltstone, sandstone, and limestone	Confining unit	
Paleozoic					
Permian	Phosphoria Formation[6]	150-300	Interbedded limestone, dolomite, siltstone, sandstone; increasing shale content eastward.	Aquifer: yields up to 100 gpm	TDS <100 mg/l; Mg, Ca, Na, HCO_3, SO_4
Pennsylvanian	Tensleep Sandstone	200-600	Massive fine sandstone	Major aquifer: up to 3,000 gpm flowing wells	TDS <500 mg/l near outcrops; TDS >2,000 mg/l in basin interior; Mg, Ca, Na, HCO_3 SO_4
Pennsylvanian	Amsden Formation	0-400	Shale, limestone, dolomite; basal sandstone		
Mississippian	Madison Limestone	200-700	Limestone, dolomite; cavernous near top	Aquifer: yields 1-300 gpm	TDS <500 mg/l
Devonian	Darby Formation	0-300	Dolomite, siltstone, shale	Confining unit: yields springs where fractured	
Ordovician	Bighorn Dolomite	0-300	Dolomite; basal sandstone	Aquifer	
Cambrian	Gallatin Limestone	0-450	Limestone, shale, thin sandstone beds	Confining unit: yields <5 gpm	
Cambrian	Gros Ventre Formation	0-750	Limestone, shale	Confining unit	
Cambrian	Flathead Sandstone	50-500	Sandstone, basal conglomerate	Aquifer: yields 1-25 gpm	TDS <500 mg/l; Ca, Na, SO_4, HCO_3
Precambrian		unknown	granite, gniess, schist	Small yields where fractured	good

[1]Data condensed from Richter (1981) with modifications from Whitcomb and Lowry (1968) and Love and Christiansen (1985).

[2]The quality of water in any water-bearing strata may significantly deteriorate as the water migrates basinward.

[3]Terminology from Love (1961), Pliocene rocks in the Granite Mountains.

[4]TDS = total dissolved solids.

[5]Called Arikaree Formation in Whitcomb and Lowry (1968).

[6]Called Park City Formation in Richter (1981).

permeability shale and mudstone layers create permeability contrasts that produce artesian conditions locally (Richter, 1981). As with the Quaternary deposits, ground-water heat pumping is the most attractive geothermal potential of the Wind River Formation. It is considerably thicker than the Quaternary deposits, however, and in some areas is overlain by several thousand feet of younger sediments. Thus, relatively high temperatures may be available in deep wells.

Beneath the Wind River Formation, strata begin to develop significant geothermal potential. With greater depth of burial, higher temperatures will occur under normal thermal gradients. The Fort Union - Lance aquifer, for example, is over 10,000 feet deep in the central basin and some reported BHTs exceed 200°F. The occurrence of major confining units in this section creates artesian conditions in underlying aquifers and the stage is set for the type of forced convection depicted in **Figures 3** and **4**. Aquifers in the lower Cenozoic and Mesozoic sections are generally dependent on sandstone layers for their productivity. Well yields up to several hundred gallons per minute (gpm) are reported from some of these strata, though most yields fall in the 10 to 50 gpm range. Water quality from these units is quite variable, but is generally poor. Chloride and sulphate are the most common anions; sodium is the dominant cation (Richter, 1981). Since the geothermal potential of the Mesozoic and Paleozoic aquifers is dependent on local structures, generalization beyond overall aquifer productivity and water quality cannot be made.

As the stratigraphic chart indicates (**Table 2**), there are several major aquifers in the Paleozoic section. Most important of these is the Tensleep Sandstone, which is under significant artesian pressure beneath much of the Wind River Basin. Dana (1962) reported a Tensleep-Madison well near Lander flowing 3,000 gpm. Richter (1981) reported that Tensleep wells typically yield up to several thousand gpm. He reported well yields of up to several hundred gpm for the Park City (Phosphoria) and Amsden Formations and the Madison Limestone. Richter proposed that these formations, along with the Darby Formation and the Bighorn Dolomite, be grouped with the Tensleep Sandstone as a single Tensleep aquifer system. This system has generally good-quality water except in the deep, interior basin. Cation dominance varies, but calcium and magnesium are generally greater than sodium. Bicarbonate and sulphate are the dominant anions.

At the base of the sedimentary section is the Flathead Sandstone. This unit has been developed as a highly productive aquifer in parts of the Bighorn Basin. It is known to produce moderate quantities of good-quality water in the Wind River Basin, but has not been significantly developed.

Structure

The basin is bounded by major mountain uplifts on the north (Owl Creek-Bridger Mountains), west (Wind River Range), and south (Granite Mountains). These uplifts are complexly folded and faulted areas from which much of the sedimentary rock core has been eroded, leaving Precambrian metamorphic and igneous rocks exposed. Thus, the uplifts form distinct hydrologic as well as structural and topographic boundaries. On the east, the Wind River Basin is bounded by the Casper arch. The oldest exposed rocks along this broad fold are of Jurassic and early Cretaceous age.

Like other Wyoming basins, the Wind River Basin includes many folds and faults superimposed on the overall downwarp of the basin. These structures, along with background heat flow and ground-water circulation patterns, are the principal controls of subsurface temperature distribution.

At sufficient depth, high temperature water could be developed from any of the aquifers discussed above. This is due to the simple increase in temperature with depth that occurs in the earth. In the structurally lowest part of the Wind River Basin, for example, the Flathead Sandstone should contain water hotter than 450°F. Even so, water temperatures reflecting only normal background gradients are not generally considered valuable enough to justify well drilling costs. A significant geothermal resource will exist only where these deep heated waters are transferred closer to the surface. That transfer can be accomplished artificially with a drill hole or naturally by fold or fault systems such as shown schematically on **Figures 3** and **4**.

Sheet 3 is a structure contour map of the top of the Early Cretaceous Cloverly Formation. In a general, basin-wide sense, all the sedimentary formations older than Late Cretaceous in the Wind River Basin accumulated as a massive, horizontally layered stack. This stack was deformed during the latest Cretaceous and early Tertiary. Thus, the structural relief depicted for the Cloverly Formation (**Sheet 3**) is representative of many higher and lower strata in the basin in all but the absolute elevations.

During and following the period of deformation, sedimentary material was eroded from the uplifts and deposited in the adjacent basin. This created broad, basinward-thickening wedges of the Tertiary sediments. Because these strata, the Fort Union and Wind River Formations, were deposited during and after the deformation of the basin, they are progressively less deformed than underlying strata and less likely to contain thermal gradient anomalies related to fold and fault systems.

Mesozoic and Paleozoic aquifers receive precipitation and runoff recharge where they are exposed at the surface along the basin-bounding uplifts (see **Sheet 1**). Waters then move basinward, escaping upward where faults or erosion have eliminated confinement. A general circulation pattern for the Cloverly Formation has been proposed by Richter (1981) and is indicated by the arrows on **Sheet 3**. Because the geometry and recharge patterns of most Mesozoic and Paleozoic strata are similar, flow patterns are assumed to be similar.

Heat flow

The fundamental component of the geothermal resource is heat flow, the natural flow of thermal energy from the hot interior of the earth to the cool surface. Where heat flow is high, geothermal resources are abundant and less dependent upon other geologic conditions. If heat flow is low, a useful resource is created only where the stratigraphy and structure are favorable.

Heat flow determinations have been made at five sites in the Wind River Basin (**Table 3**). These values were derived through precision thermal logging and conductivity determinations of holes into Precambrian basement rocks. They are believed to be free of hydrologic disturbances and representative of regional patterns. The heat flow values come from two general localities: the Granite Mountains along the southern margin of the basin, and the Owl Creek Mountains along the northern margin. Values from the Granite Mountains vary from 50 to 70 mW/m^2. Values from the eastern Owl Creek Mountains indicate a heat flow in the 70 to 80 mW/m^2 range. The northern values are higher than the moderate heat flows of the southern basin. Higher values correspond to a broad zone of moderate to high heat flows that appears to extend across central Wyoming (Sass and Lachenbruch, 1979; Decker and others, 1980). The origin of this zone of higher heat flow

Table 3. Wind River Basin heat flow values. [1]

Location (Sec-T-R)	Heat flow (mW/m^2)	Thermal conductivity (W/m^oK)
28-28N-89W	54	2.93
27-28N-92W	60	2.93
27-28N-92W	58	2.93
27-28N-92W	68	2.76
27-28N-92W	74	2.76
27-28N-92W	77	2.93
27-28N-92W	71	2.93
27-28N-92W	66	2.93
27-28N-92W	64	2.93
6-29N-90W	63	3.70
6-29N-90W	60	3.67
7-30N-90W	50	2.34
18-30N-90W	59	2.34
22-40N-92W	71	3.30
22-40N-92W	79	3.30

[1] Measurements made by University of Wyoming personnel according to procedures described by Decker (1973). Values primarily from Heasler and others (1982).

is not known, and the boundaries are based on rough contouring of the sparse data available. Given the overall structural fabric of the basin, heat flow values are assumed to be most uniform along east-west or northwest-southeast trends. The distribution of the north to south decrease in heat flow cannot be defined without additional, intermediate data points. Analysis of gradient anomalies within the Wind River Basin (see thermal gradient section below) suggests the higher heat flow of the Owl Creek Mountains may extend an unknown distance into the basin.

Breckenridge and Hinckley (1978) suggested warm springs in the northwestern Wind River Basin may be due to high heat flow associated with the Absaroka volcanic complex. No heat flow determinations have been made for this part of the basin. However, Hinckley and others (1982) calculated that the Absaroka igneous activity is too old to create significant modification of present regional heat flow patterns. The effect on the study area of Late Cenozoic volcanism in the Yellowstone-Teton National Parks area immediately northwest of the Wind River Basin is not clearly understood. This activity is recent enough to create local, present-day heat flow anomalies, but the main centers of activity are distant from the Wind River Basin.

Heat flow determinations in the Wind River Basin indicate geothermal conditions similar to the other Wyoming Basins. In drill holes greater than 4,000 ft deep, purely conductive thermal gradients will generally fall in the 12° to 15°F/1,000 feet range. Gradients may be slightly higher in the northern basin due to somewhat higher heat flow. Such gradients are not usually considered sufficient to provide a useful geothermal resource by themselves, but will lead to the development of high temperatures at depth. Thus, where ground water warmed at depth is brought close to the surface by circulation over folds or up fault systems, highly elevated gradients and attractive energy resources may exist.

Areas of anomalous thermal gradients

Information on thermal gradients in the Wind River Basin comes from two sources: oil and gas well bottom-hole temperatures (BHTs), and precision thermal logging. **Tables 4** and **5** present summaries of the 1,733 bottom-hole temperatures and calculated gradients collected for the Wind River Basin. Temperatures range from 65° to 370°F; gradients range from 2.6° to 144.4°F/1,000 feet. Shallower than approximately 2,500 feet, all reported temperatures are less than 100°F and, along with their calculated gradients, are subject to considerable error as discussed earlier (p. 7). Nonetheless, the table lists many gradients greater than 20°F/1,000 feet that are confidently based on deep holes with high temperatures. **Appendix A** lists data from precision thermal logging of wells in the Wind River Basin. These data are plotted on **Sheet 2**.

Table 4. Summary of bottom-hole temperature data and statistics including the 50th, 66th, 80th, and 90th percentiles, from the Wind River Basin. A temperature under a percentile heading is the temperature below which that percent of the BHTs fall. Depth intervals with few BHT measurements do not give meaningful percentile temperatures.

Depth interval (feet)	Number of measurments	Temperature (°F) high	low	mean	50%	66%	80%	90%
0 - 500	10	84	65	72.4	72	75	82	84
500 - 1,000	18	100	60	79.2	80	86	94	95
1,000 - 1,500	76	152	50	83.2	81	90	93	98
1,500 - 2,000	103	117	62	88.8	89	95	99	103
2,000 - 2,500	57	123	62	90.7	90	95	97	113
2,500 - 3,000	82	146	69	96.6	96	102	107	113
3,000 - 3,500	164	172	72	107.9	109	117	121	126
3,500 - 4,000	142	164	79	107.8	105	115	121	126
4,000 - 4,500	83	156	78	107.1	108	111	117	122
4,500 - 5,000	105	171	78	110.2	109	113	120	129
5,000 - 5,500	92	234	61	117.2	116	121	128	131
5,500 - 6,000	63	160	89	122.1	120	126	138	143
6,000 - 6,500	75	163	97	126.9	126	134	143	149
6,500 - 7,000	79	185	95	131.3	129	135	146	152
7,000 - 7,500	75	198	109	142.2	138	152	160	180
7,500 - 8,000	64	212	64	148.9	150	159	164	174
8,000 - 8,500	39	182	122	152.4	156	162	168	175
8,500 - 9,000	46	190	112	150.7	151	160	166	181
9,000 - 9,500	27	195	120	153.2	151	165	171	184
9,500 - 10,000	34	230	68	158.3	160	169	180	205
10,000 - 10,500	34	250	125	175.0	181	189	204	215
10,500 - 11,000	31	214	124	163.8	163	173	184	198
11,000 - 11,500	45	240	134	187.4	192	199	205	211
11,500 - 12,000	43	250	142	196.9	195	202	208	214
12,000 - 12,500	22	260	135	197.0	208	214	217	225
12,500 - 13,000	14	306	170	217.9	212	226	242	265
13,000 - 13,500	12	245	159	207.2	216	238	238	240
13,500 - 14,000	17	267	172	221.2	230	240	255	264
14,000 - 14,500	9	268	218	245.7	256	262	262	268
14,500 - 15,000	6	290	174	246.8	268	281	281	290
15,000 - 15,500	7	284	200	241.4	250	252	265	284
15,500 - 16,000	7	292	216	248.3	252	254	270	292
16,000 - 16,500	11	316	245	294.0	305	309	314	316
16,500 - 17,000	2	278	258	268.0	278	278	278	278
17,000 - 17,500	4	340	317	331.3	338	338	340	340
17,500 - 18,000	8	345	268	315.3	338	340	345	345
18,000 - 18,500	9	345	308	331.2	337	338	344	345
18,500 - 19,000	2	351	338	344.5	351	351	351	351
19,000 - 19,500	5	356	318	331.4	325	340	356	356
19,500 - 20,000	4	343	318	327.3	343	343	343	343
20,000 - 20,500	1	310	310	310.0	310	310	310	310
20,500 - 21,000	3	348	323	338.0	343	348	348	348
21,000 - 21,500	-	-	-	-	-	-	-	-
21,500 - 22,000	2	370	309	339.5	370	370	370	370
22,000 - 22,500	-	-	-	-	-	-	-	-
22,500 - 23,000	1	370	370	370.0	370	370	370	370

Total: 1,733 bottom-hole temperature measurements.

Table 5. Summary of thermal gradient data and statistics, including the 50th, 66th, 80th, and 90th percentiles, derived from the bottom-hole temperatures from the Wind River Basin. A gradient under a percentile heading is the gradient below which that percent of the gradients fall. Depth intervals with few BHT measurements do not give meaningful percentile temperatures.

Depth interval (feet)	Number of measurements	Gradient (°F/1,000ft) high	low	mean	50%	66%	80%	90%
0 - 500	10	144	48	79.0	67	72	104	144
500 - 1,000	18	81	20	45.9	45	50	55	65
1,000 - 1,500	76	77	5	30.9	30	34	39	43
1,500 - 2,000	103	43	11	26.4	25	28	31	34
2,000 - 2,500	57	37	9	21.4	21	23	24	29
2,500 - 3,000	82	39	8	19.5	19	21	22	24
3,000 - 3,500	164	38	8	19.6	19	21	23	24
3,500 - 4,000	142	30	9	17.5	16	19	21	22
4,000 - 4,500	83	26	8	15.2	14	15	17	18
4,500 - 5,000	105	26	7	14.1	13	14	16	18
5,000 - 5,500	92	35	3	14.1	13	14	15	17
5,500 - 6,000	63	20	7	13.8	13	14	16	17
6,000 - 6,500	75	18	8	13.4	13	14	15	16
6,500 - 7,000	79	20	7	13.0	12	13	15	16
7,000 - 7,500	75	21	9	13.7	12	15	16	18
7,500 - 8,000	64	21	2	13.6	13	14	15	17
8,000 - 8,500	39	17	9	13.3	13	14	15	15
8,500 - 9,000	46	16	7	12.3	12	13	13	15
9,000 - 9,500	27	16	8	11.9	11	13	13	15
9,500 - 10,000	34	19	2	11.8	11	12	13	16
10,000 - 10,500	35	20	7	12.9	12	14	15	16
10,500 - 11,000	31	16	7	11.3	11	12	12	14
11,000 - 11,500	46	17	8	12.8	13	13	14	14
11,500 - 12,000	43	17	8	13.1	12	13	14	14
12,000 - 12,500	24	17	7	12.7	13	13	14	14
12,500 - 13,000	13	17	9	13.2	13	13	14	15
13,000 - 13,500	12	15	8	12.3	12	13	14	14
13,500 - 14,000	19	16	9	12.8	12	14	14	15
14,000 - 14,500	9	15	12	14.3	15	15	15	15
14,500 - 15,000	6	16	8	13.8	15	16	16	16
15,000 - 15,500	6	15	10	13	13	14	14	15
15,500 - 16,000	7	15	10	13.1	13	13	14	15
16,000 - 16,500	12	16	10	15.0	16	16	16	16
16,500 - 17,000	2	14	12	13.5	14	14	14	14
17,000 - 17,500	4	17	15	16.7	17	17	17	17
17,500 - 18,000	9	17	12	15.3	16	16	16	17
18,000 - 18,500	9	16	14	15.8	15	16	16	16
18,500 - 19,000	2	16	15	16.2	16	16	16	16
19,000 - 19,500	5	16	14	15.0	14	15	16	16
19,500 - 20,000	4	15	13	14.3	14	14	15	15
20,000 - 20,500	1	13	13	13.1	13	13	13	13
20,500 - 21,000	3	14	13	14.3	14	14	14	14
21,000 - 21,500	-	-	-	-	-	-	-	-
21,500 - 22,000	2	15	12	13.7	15	15	15	15
22,000 - 22,500	-	-	-	-	-	-	-	-
22,500 - 23,000	1	14	14	14.5	14	14	14	14

$$\text{Gradient} = \frac{\text{Bottom-hole temperature} - \text{Mean annual surface temperature}}{\text{Depth}} \times 1{,}000$$

An alternative view of the BHT data is presented in **Figure 6**, which shows the effect of drilling mud in creating unrealistically high gradients at shallow depths. The divergence of the 100°F mud curve from a significant portion of the data (for example the 80th percentile curve) indicates that only below 2,000 to 3,000 feet will thermal gradients be consistently free of drilling-fluid induced increases. Points to the right of the 80th percentile line on this plot are those considered to represent possibly significant geothermal anomalies.

Figure 7 plots bottom-hole temperatures by depth. Reference lines for gradients of 12° and 14°F/1,000 feet are included. Note the general agreement of these data with the 12° to 15°F/1,000 feet average gradient proposed earlier on the basis of heat flow and thermal conductivity considerations.

The areal distribution of gradients is presented on **Sheet 2.** All available bottom-hole temperature, thermal logging, thermal spring, thermal well, and heat flow data are plotted on this map and approximate gradient contours are proposed. Where gradients identified as anomalous (based on **Table 5** and **Figure 6**) occur in the same vicinity, an area of anomalous gradient is mapped. Due to the uncertainty of individual gradient points, contours and anomalous areas are generally based on consideration of a group of values for a given area.

Table 6 provides summary information on each of the areas of anomalous gradient identified on **Sheet 2.** The thermal gradients in **Table 6** are calculated from depths and temperatures for the listed principal formations. While there is no implication that the anomaly is confined to these brackets, extrapolation to much shallower or much deeper zones must be done cautiously.

Even in these anomalous areas, gradients are not extreme. Nowhere, for example, are there confirmed gradients as high as those for the Thermopolis and Cody areas of the Bighorn Basin (Heasler and Hinckley, 1985). Since the estimated heat flow into the Wind River Basin is generally insufficient to create conductive gradients higher than 12° to 15°F/1,000 feet, geothermal anomalies are primarily a function of convective redistribution of heat. The complex interaction of ground water and geologic structure is the principle geothermal agent. The following pages discuss what is known or can be deduced about that interaction in the Wind River Basin. General principles are developed, along with individual system specifics, through analysis of each of the mapped anomalous areas. Considerations of temperatures, depths, and general character of the potential geothermal resource, and possible, unverified extensions of the anomalous areas are included. The density of data points on **Sheet 2** demonstrates the variation in certainty with which anomalous areas are identified. In many cases, additional thermal logging, geochemical studies, and (or) structural analysis would be useful in verifying the indicated anomaly.

Area 1

Area 1 essentially coincides with the Dubois oil field. The structure is complicated and not well understood in this area. The thick mantle of volcanic rocks in the area further confuses outcrop/recharge relationships. The anomaly is well defined by numerous data points of sufficient depth and temperature to be free of the most obvious sources of error. Hydrologic control is assumed to be some combination of folding and faulting of undetermined extent.

Areas 2 and 3

The high gradients of area 2 are among the best established of any in the Wind River Basin. In addition to abundant oil and gas well bottom-hole

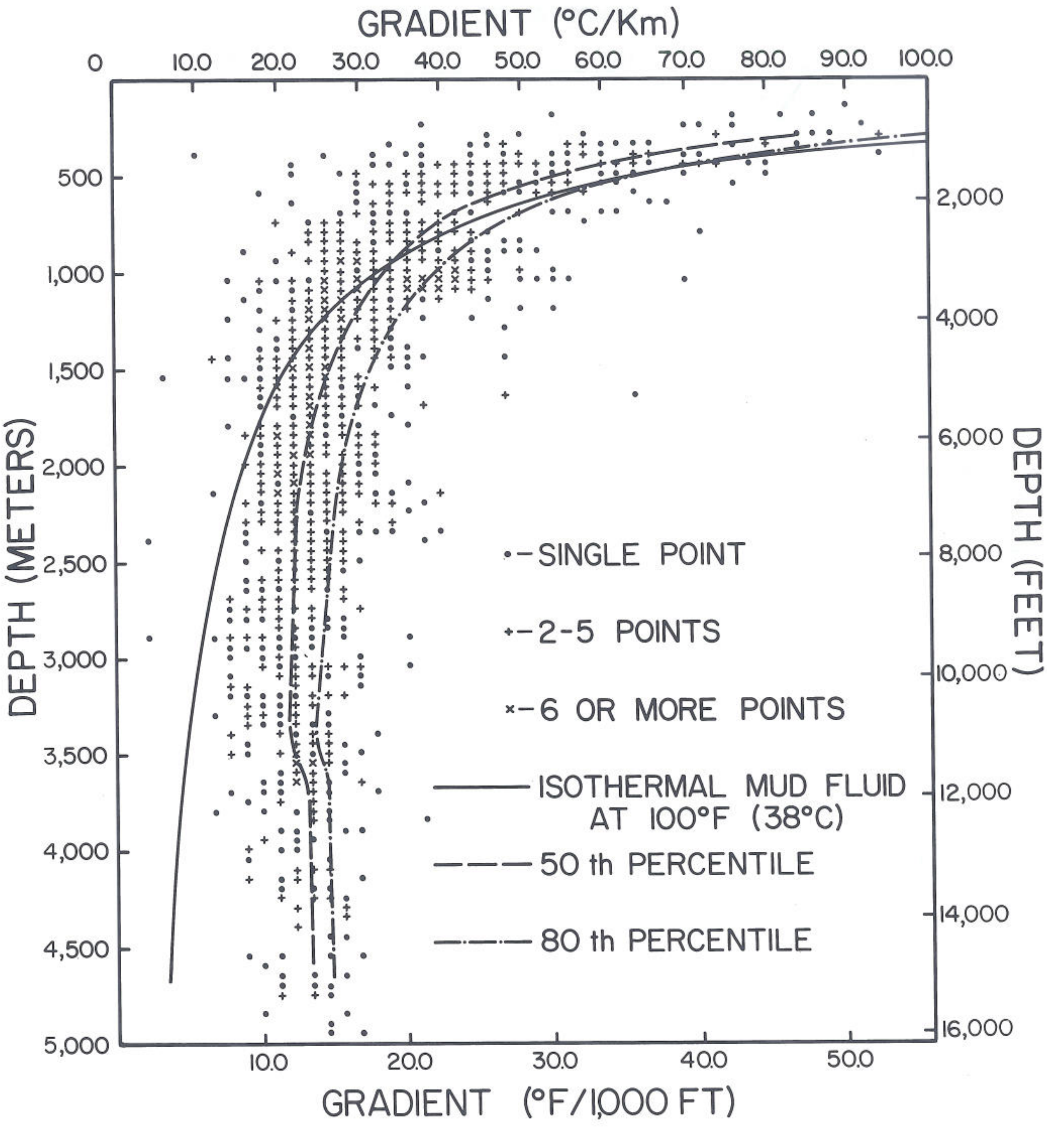

Figure 6. Gradient-depth plot for Wind River Basin, based on 1,733 bottom-hole temperatures.

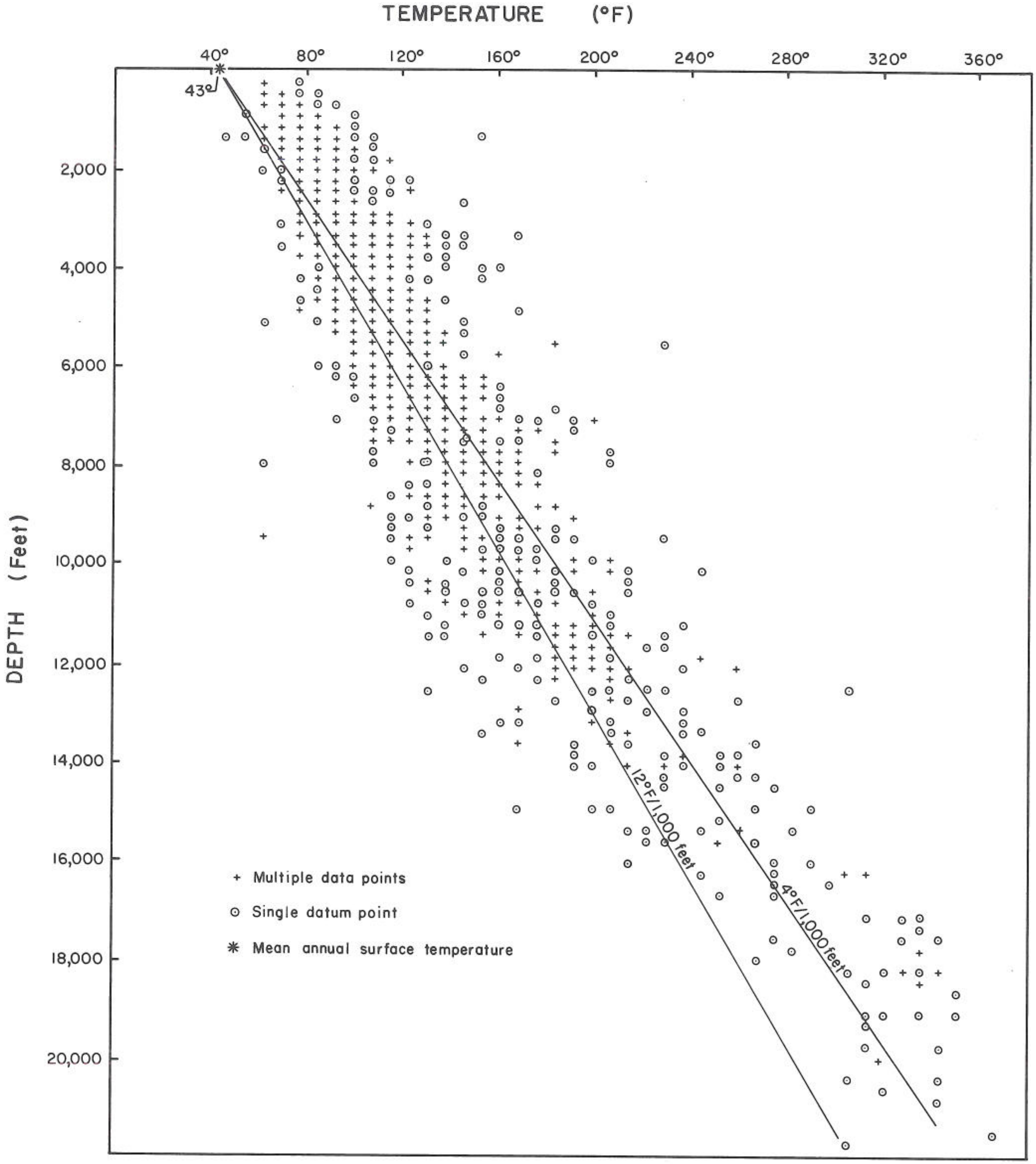

Figure 7. Bottom-hole-temperature depth plot for Wind River Basin, based on 1,733 bottom-hole temperatures.

Table 6. Geothermal gradient anomalies in the Wind River Basin, Wyoming.

Area	Location		Thermal gradients (°F/1000 ft.)	Approximate depths (feet)	Approximate temperatures (°F)	Principal formation(s)	Structural control
	Township	Range					
1	42,43N	107W	15-30	3,000-4,000	110-160	Tensleep, Phosphoria	?
2	1,2N	1W	20-40	2,000-3,500	100-130	Phosphoria, Tensleep, Madison	fault/fold
3	2S 33N	2E 99W	20-30	≤2,000	90-110	Phosphoria	fault/fold
4	1S	5E	24-25	3,000	110-120	Fort Union	fold
5	1S	6E	16-20	2,500-9,000	170-230	Morrison, Tensleep	fold(?)
6	33,34N	94,95W	15-18	5,000-8,000	130-170	Shell Creek, Madison, Tensleep, Sundance	fault
7	33N	93,94W	20-25	4,000-5,000	130-140	Tensleep	fault/fold
8	32N	94,95W	15-19	6,000-8,000	120-180	Tensleep	fault/fold
9	38,39N	89-91W	15-17	7,000-19,000	140-330	Wind River, Fort Union, Lance, Cody, Frontier	fold/fault
10	37N	90,91W	15-20	9,000-15,000	190-250	Fort Union, Lance, Meeteetse	?
11	37,38N	89W	15-17	5,000-15,000	190-270	Fort Union, Lance	fold(?)
12	33N	90W	18-28	3,000-6,000	100-154	Tensleep	fault
13	37N-	85,86W	20-35	2,000-4,000	100-140	Cody, Frontier, Mowry	fault
14	37,38N	83W	19-22	3,500-5,000	110-170	Tensleep (?)	fold

temperature data, there are a confirming thermally logged hole and a major hot spring (see **Sheet 2**). **Sheet 3** shows the intersection of the area with a major fault system paralleling nearly the entire length of the Wind River Range. In addition, at area 2 there is a significant fold immediately northeast of the fault system. The indicated ground-water flow direction is northeastward and eastward off the flank of the mountains, descending into the Wind River Basin. Subtracting the structure contour elevations (0-1,000 feet) from the approximate surface elevation (6,000 feet) shows the top of the Cloverly to be around 6,000 feet deep adjacent to the fault. Addition of the intervening strata (see **Table 2**) places the Phosphoria Formation at 8,500 feet with the Madison Limestone at 9,500 feet. A gradient of only 12°F/1,000 feet would thus lead to ground-water temperatures of about 150°F in the Madison Limestone. Displacements across the fault system range from 3,000 to 6,000 feet. In the vicinity of area 2, strata are uplifted approximately 4,000 feet on the northeast side of the fault. Folding has raised the strata an additional 3,000 feet (see **Sheet 2**). Waters in the Paleozoic aquifers remain confined beneath relatively impermeable strata, moving up and over the fault/fold system and delivering deep-heated waters to the near surface.

The presence of the Paleozoic aquifers at relatively shallow depths is particularly advantageous in this area due to their productivity and their relatively high water quality. The depth/gradient calculations for this system indicate around 140°F as the maximum temperature likely to be encountered. This is in reasonable agreement with the 100° to 130°F bottom-hole temperatures reported when allowances are made for moving ground water cooling the deep portion of the system and for some cooling as waters ascend to shallower zones.

Area 3 is basically a less anomalous version of area 2. The synclinal portion of the system is shallower; the anticlinal portion is deeper; and the gradient anomaly is correspondingly weaker than in area 2. The flow system appears to be quite similar.

The major complication in the flow systems of areas 2 and 3 is faulting. Where strata are simply deformed into folds, stratigraphic continuity and ground-water flow patterns are generally maintained (although the fracturing attending folding of competent rock layers may greatly enhance permeabilities). The effect of faulting, however, is quite variable. Faulting may create ground-water pathways through normally confining beds, allowing deep-heated waters to rise to the near surface and creating thermal gradient anomalies in the absence of folding. On the other hand, faulting may produce tight, impermeable zones that seriously restrict ground-water movement. Also, the juxtaposition of permeable and impermeable strata across a fault may reduce or eliminate hydraulic continuity. Because the configuration of a fault may be spatially quite variable, the effect of the fault on hydrologic systems can be locally unpredictable. In addition, large deep faults presented on **Sheet 3** are somewhat conjectural, based on interpretation of subsurface data, in some cases with little or no surface expression.

The effect of large-scale faulting on geothermal systems can best be analyzed empirically. The existence of geothermal anomalies strongly suggests that water is moving up and across the fault system in the vicinity of areas 2 and 3. Elsewhere along the fault the effect is different. North of area 2, for example, there are many bottom-hole temperature data points, yet no gradient anomaly is indicated. The deep syncline just west of the fault and the 5,000-foot fault displacement could provide the setting for a major thermal gradient anomaly. But apparently the fault in this area does not permit the free passage of ground water. Such restriction is also indicated by ground-water flow parallel to the fault system in this area as proposed by Richter (1981) (see **Sheet 2**).

There are few data points to confirm or deny a gradient anomaly between areas 2 and 3. If the general ground-water flow directions of Richter (1981) are correct, the anomaly may extend all along the length of the fault (although adjacent folding is most developed in and around areas 2 and 3). The thermal well southeast of Lander is also on this fault system. It flows 99°F water from a depth of 1,884 feet for a gradient of 30°F/1,000 feet. Bottom-hole temperature values between here and area 3 do not indicate high gradients, but data are sparse. Thus, it is not known whether the Lander well marks an isolated area of anomalous gradient or a continuation of the area 3 anomaly along the fault.

Area 4

Area 4 is established by only 2 data points, both from depths of approximately 3,000 feet. The area occupies the crest of a major fold where it could receive a component of ground-water flow from deep areas to the southwest.

Area 5

Area 5 is established by three data points. These points range over 6,500 feet of depth. The fairly high temperatures from this area are unlikely to have been increased by surface conditions. The area is located near the top of a fold, the southeast limb of which is faulted as it dips steeply into the adjacent syncline. Confined ground water arriving at area 5 from the east and southeast rises around 7,000 feet in four miles. For the Cloverly Formation, this is sufficient to produce a gradient of 25°F/1,000 feet and temperatures of over 200°F (based on a background gradient of 12°F/1,000 feet). For the Tensleep Sandstone, approximately 2,500 feet deeper, around 30°F can be added.

Ground-water flow from the southwest could produce only normal gradients at area 5 and is therefore not indicated. Also, it appears that the fault just west of area 5 does not seriously restrict ground-water movement.

Area 6

Area 6 is in essentially the same configuration as area 5, except that area 6 occupies both sides of the fault. This is additional evidence that the fault is not a ground-water barrier and that it may actually create a fractured zone of locally increased permeability. Gradients are somewhat lower in area 6 than in area 5, reflecting the shallower nature of the adjacent syncline. This anomaly may extend all along the fault/fold system between areas 6 and 5. However, numerous data northwest of area 5 indicate a generally normal gradient in that area.

Area 7

Area 7 coincides with the faulted portion of the Conant Creek anticline. Thermal springs issue from the Phosphoria Formation in this area, where erosion has cut through the confining beds of the Chugwater Formation near the anticlinal crest. Although the springs flow only 61°F, within a third of a mile is a well (with more direct subsurface access) flowing 70°F (Breckenridge and Hinckley, 1978). The Phosphoria and Tensleep aquifers plunge northward from the spring site, and bottom-hole temperatures are as high as 140°F from 4,000 to 5,000 feet deep. Breckenridge and Hinckley (1978) discussed this geothermal system in reference to the springs and presented the model of northeastward ground-water flow heated in the depths of the syncline between area 7 and area 8. Any flow from the west or southwest would be adequate to produce the observed temperatures in the Paleozoic formations at area 7. Richter's (1981) proposal of flow from the southeast would almost certainly be inadequate, and is therefore not indicated.

Area 8

Area 8 is defined by numerous and consistent bottom-hole temperatures from deep zones with high temperatures. Although there are no surface flows from this system, thermal logging confirms the bottom-hole temperature derived gradients. Most of the temperature values are from 150° to 180°F and come from the Tensleep Sandstone. The highest temperature reported for this area is 234°F from the Phosphoria Formation at a depth of 5,443 feet. Like most of the anomalous areas discussed so far, area 8 occupies the top of a fold, adjacent to a fault with large displacement (2,000 to 3,000 feet) and a deep syncline. The Tensleep Sandstone is approximately 12,000 feet deep just west of area 8, and is around 10,000 feet deep even in the shallower part of the syncline south of the anomaly. This is sufficient to produce temperatures of 180°F even at a 12°F/1,000 feet gradient. Ground-water flow from the structural depression just northwest of area 8 would be 230°F at this gradient. Thus, the gradient anomaly is consistent with ground-water flow northward and eastward off the flanks of the Wind River Range, through the intervening syncline, and up the fold/fault system to area 8.

As in previous cases, this interpretation of the anomaly requires that the fault not seriously impede ground-water movement in the vicinity. Bottom-hole temperatures north and south of area 8 along the same structural trend are not generally anomalous. Changes in the hydrologic effect of the fault or hydraulic conductivity of the aquifer are possible explanations for this gradient distribution.

Areas 9, 10, and 11

Areas 9, 10, and 11 are weak anomalies. Gradients of 15° to 20°F/1,000 feet are well established by deep wells into a variety of upper Mesozoic and lower Cenozoic strata. The highest reported temperature in these areas is 348°F, from a depth of 20,853 feet in area 9. These areas occupy one of the structurally lowest portions of the Wind River Basin, just south of a major and complex fault zone. The Precambrian-cored Owl Creek-Bridger Mountains are on the uplifted north side of this fault system. Displacements of more than 20,000 feet are common; stratigraphic and hydrologic disruption is total. Due to the great depths involved and the very thick Tertiary section in this area, pre-Cenozoic structure is not well known. As discussed earlier, **Sheet 3** is compiled for the Cloverly Formation but corresponds in general geometry to all strata deposited prior to the folding and faulting of the Cloverly Formation. The rocks of areas 9, 10, and 11 were deposited during and following these deformational events, which further complicates understanding of the structural environment of any geothermal systems.

Area 9 roughly conforms to the crest of a broad anticline, as defined by the Cloverly Formation contouring of **Sheet 3**. Structural mapping by Barlow and Haun (1978) indicated this fold involves strata as young as the Waltman Shale Member of the Fort Union Formation. Ground-water flow is not known for the area, so maximum temperatures and the extent of the the anomaly cannot be predicted. Because of the great thickness of the overlying Wind River Formation, and the moderate gradients involved, this anomaly probably only represents a useful resource where existing drilling provides subsurface access.

The origin of areas 10 and 11 is even less clear, for no folds or faults are indicated. There may be unrecognized structures controlling the flow of heated ground water in these deep systems. Given the total thickness of sedimentary rocks in these areas, temperatures in excess of 400°F may be generated in the Paleozoic aquifers under normal gradients. If the ground water in these units flows into higher strata, significant gradient anomalies could exist.

An alternative explanation for the apparent anomalies in areas 9 through 11 is higher heat flow. Measured heat flows to the north, in the Owl Creek Mountains, are sufficient to create purely conductive gradients in the range of those observed (depending on formation thermal conductivities). If these higher heat flows extend into the basin beneath areas 9 through 11, the moderately high gradients observed could be explained without convective heat transport.

Area 12

Area 12 is on the margin of the Wind River Basin, in a structural setting similar to that of areas 6 through 8. The area occupies the crest of a north-trending anticline; there are also major faults through the area. The elevation difference between the anticline crest and adjacent synclinal areas is insufficient to create the observed anomaly. Thus, vertical migration of ground water along the faults is a more likely gradient-increasing mechanism. The thermal gradients of the three data points identifying area 12 are not high, however, and more data are needed to verify these gradients.

Area 13

Area 13 is in a complexly faulted region that is an extension of the basin-bounding fault system of area 9. In this structural environment it is highly unlikely that continuous confined aquifers exist. It is much more difficult to assess the geothermal effects of fault-created zones of vertical permeability than to analyze simple fold systems. At the present, we can only infer that waters heated in deeper strata are rising along fault zones to create the gradient anomalies observed in overlying units. If so the anomaly will decrease with depth.

Area 14

Area 14 appears to be fold controlled. Waters confined to the Tensleep aquifer and moving into the area from the south and southeast pass through depths sufficient to produce the observed temperatures (120° to 170°F) under normal thermal gradients. Waters in deeper aquifers may be 20° to 30°F warmer, so the maximum temperature likely to be developed for this area is less than 200°F.

Thermal springs

Breckenridge and Hinckley (1978) identified seven thermal spring localities in the Wind River Basin. They provided detailed discussions of water temperatures, flows, chemistry, and flora. Fort Washakie Hot Springs and Conant Creek Springs were discussed above in connection with anomalous gradient areas 2 and 7, respectively. Although the remaining five localities are definitely geothermally anomalous, they were not included in the previous discussion, which was based primarily on subsurface thermal information. All seven thermal spring localities are shown on **Sheet 2.**

Horse Creek Springs are in the southeast corner of the basin (sec. 35, T.32N., R.86W.). According to Breckenridge and Hinckley (1978) the springs flow at 75°F from alluvium along the east-west-trending north Granite Mountains fault system. Eocene igneous rocks in the area and deep circulation along the fault system are offered as possible heating mechanisms. As discussed earlier, igneous activity of this age is probably too old to continue to contribute significant heat. The fault system is the most plausible mechanism for the thermal springs, raising the possibility that a thermal anomaly may extend for some distance east and west from the springs.

Sweetwater Station Springs (sec. 15, T.29N., R.95W.), west of Jeffrey City, are also fault controlled (Breckenridge and Hinckley, 1978). Nearby bottom-hole temperatures reflect normal gradients, indicating that the spring system is localized.

The most enigmatic geothermal phenomena in the basin are the thermal springs near Dubois. From north to south these three spring localities are: Warm Spring Creek Springs (sec. 32, T.42N., R.107W.), Little Warm Spring (sec. 14, T.41N., R.107W.), and Jakeys Fork Spring (sec. 29, T.41N., R.106W.). Together, they flow a total of 700 gpm at an average temperature of 78°F (Breckenridge and Hinckley, 1978). These springs define a line parallel to the northeast flank of the Wind River Range (**Sheet 2**). All three localities are along the contact of the Phosphoria Formation and the overlying Chugwater Formation. Extensive travertine deposits, developed southeast from the springs over 30 miles, reflect this same strong stratigraphic control (Breckenridge and Hinckley, 1978). Gilliland (1959) reported a total sub-Chugwater sedimentary thickness of 3,000 feet. Mapping by both Gilliland (1959) and Keefer (1970) indicated no significant disruption of the gentle basinward dip of the strata in this area, and nearby bottom-hole temperatures indicate gradients no higher than 15°F/1,000 feet. Thus, circulation of ground water to the lowest strata in the sedimentary section is necessary to produce the observed temperatures at the indicated gradient, yet there is no sign that such a circulation system exists.

Tensleep aquifer temperatures

The usefulness of geothermal energy in a particular area is governed by two main parameters: (1) the geothermal gradient (which indicates how deep one must drill to encounter the desired temperature) and (2) the availability of a mechanism for extracting the heat from the earth. The chemistry of geothermal waters can also be important, depending on the intended application. At the relatively low temperature of Wind River Basin geothermal resources, naturally occurring circulation of ground water is necessary both to create gradient anomalies (as discussed above) and to provide a mechanism for heat extraction. Only where a productive aquifer occurs can a useful geothermal resource exist.

The Tensleep Sandstone was chosen to present the temperatures occurring in the aquifers of the Wind River Basin (**Sheet 4**). This sandstone is a major aquifer basinwide and is also one of the deeper aquifers. It is approximately 2,000 feet from the Tensleep Sandstone to the base of the sedimentary section (the maximum depth of any possible aquifer system). Thus, maximum ground-water temperatures in even the Flathead aquifer will not be more than 20° to 30°F warmer than those of the Tensleep Sandstone. Where an anomaly exists due to vertical, interformational flow along a fault or fracture zone, temperatures may be homogeneous through the strata involved and interformational thermal gradients may drop to near zero.

Sheet 4 was compiled using only temperatures that could be identified as being from the Tensleep Sandstone. In areas of sparse data, the structure contour map (**Sheet 3**) was used to guide contouring. In the north-central areas of the Wind River Basin, the depth of the Tensleep Sandstone is greater than 20,000 feet. Data from such great depths are sparse. Our estimation of temperatures greater than 400°F is based on the extrapolation of high temperatures measured in the much shallower Fort Union Formation.

Summary and conclusions

Background heat flow in the Wind River Basin is generally insufficient to produce high conductive gradients. High temperatures will occur at shallow depths only where hydrologic systems redistribute heat through water movement. Aquifers that may have the confinement and structural characteristics necessary to create such geothermal systems are the Lance-Fort Union, Mesaverde, Frontier, Muddy, Cloverly, Sundance, Nugget, Phosphoria, Tensleep, Amsden, Madison, Bighorn, and Flathead formations. Of these, the Tensleep Sandstone and Madison Limestone are the most attractive in terms of both productivity and water quality.

Folds and faults provide structural control on hydrology (and hence geothermal systems). Oil and gas exploration holes are common in folded regions, and generally provide sufficient temperature data to evaluate geothermal gradients. Where faulting alone provides the flow patterns necessary to generate a geothermal anomaly, high gradients may be localized, drilling may be less common, and the data used in this report may be insufficient to delineate such an anomaly. Fault systems tentatively identified as anomalous by bottom-hole temperatures and(or) the occurrence of thermal springs warrant further study.

Most of the identified geothermal anomalies in the Wind River Basin occur along complex structures in the southwest and south. Large, weakly anomalous areas in the north-central basin area are unexplained and may simply reflect the overall increase in heat flow believed to occur from south to north across the basin.

The most attractive geothermal prospects identified are anomalous areas 2 and 3 north of Lander, Sweetwater Station Springs west of Jeffrey City, and the thermal springs southwest of Dubois. Even in these areas, it is unlikely that aquifer temperatures are higher than 130° to 150°F. Geothermal resources elsewhere in the study area are probably best pursued in conjunction with oil and gas production or water-development projects. Particularly in the Paleozoic aquifers, the coincidence of structurally controlled oil and gas deposits and useful thermal waters is very likely. This may allow exploitation of more valuable petroleum resources to pay drilling and development costs, with thermal waters being produced as a valuable by-product.

There is also potential in the Wind River Basin for normal-temperature geothermal applications such as ground-water heat pumps and surface deicing operations. The extensive surface occurrence of the highly productive Wind River Formation is very favorable in this respect, for small supplies of 40° to 50°F ground water should be readily available over a large portion of the basin.

Areas in which further studies of geothermal potential could be most useful are the fault systems previously mentioned and the thermal springs system in the vicinity of Dubois. Not only would such studies help to define potentially significant energy resources, but they may also provide useful data on overall basin hydrogeology.

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Appendix A

Appendix A. Thermally measured wells in the Wind River Basin[1].

Location		Depth		Bottom-hole Temperature		Gradient[2]		Interval[3]	
Longitude	Latitude	Meters	Feet	(°C)	(°F)	°C/km	°F/1,000 ft	Meters	Feet
				Fremont County					
109° 42.1'	43° 38.5'	67.9	223	6.6	43.8	10.0	5.5	131- 220	400- 670
109° 38.5'	43° 37.2'	630.0	2,066	25.7	78.3	31.1	17.1	295- 688	900- 2,100
109° 2.3'	43° 31.4'	274.0	899	16.0	60.8	29.3	16.1	66- 899	200- 2,740
109° 2.2'	43° 31.3'	284.5	933	18.1	64.5	25.8	14.1	558- 787	1,700- 2,400
109° 2.4'	43° 31.1'	208.5	684	13.8	56.8	25.4	13.9	328- 682	1,000- 2,080
107° 54.5'	43° 24.7'	193.5	635	13.6	56.4	23.5	12.9	66- 633	200- 1,930
107° 54.8'	43° 24.6'	193.0	633	13.4	56.1	21.3	11.7	328- 633	1,000- 1,930
107° 54.5'	43° 24.5'	197.5	648	13.4	56.1	23.0	12.6	361- 623	1,100- 1,900
107° 52.6'	43° 24.5'	172.2	565	12.5	54.5				
107° 55.0'	43° 24.4'	140.7	461	11.9	53.4	20.2	11.1	328- 459	1,000- 1,400
107° 55.0'	43° 24.4'	141.0	462	11.9	53.4	20.2	11.1	328- 459	1,000- 1,400
107° 54.8'	43° 24.4'	190.7	625	13.7	56.6	19.7	10.8	262- 623	800- 1,900
107° 53.5'	43° 24.4'	133.2	437	10.7	51.2	4.2	2.3	30- 436	90- 1,330
107° 52.9'	43° 24.4'	152.0	499	13.3	55.9	34.4	18.9	66- 492	200- 1,500
107° 51.7'	43° 24.4'	99.5	326	11.0	51.8	24.3	13.3	164- 325	500- 990
107° 52.5'	43° 24.3'	164.3	539	12.6	54.6	5.3	2.9	95- 538	290- 1,640
107° 53.4'	43° 24.2'	118.7	389	11.6	52.8	6.8	3.7	98- 387	300- 1,180
107° 53.7'	43° 24.1'	84.3	309	12.2	54.0	6.3	3.5	30- 276	90- 840
107° 51.2'	43° 20.7'	40.0	131	13.1	55.6				
107° 51.4'	43° 20.6'	75.0	246	12.6	54.6				
107° 51.4'	43° 20.6'	89.0	292	11.4	52.5	20.0	11.0	197- 292	600- 890
107° 52.0'	43° 20.3'	173.0	567	15.3	59.5				
108° 54.2'	43° 16.3'	1,610.0	5,281	53.5	128.3	30.2	16.6	656-5,281	2,000-16,100
108° 53.6'	43° 7.0'	165.0	541	17.0	62.6	60.1	33.0	262- 535	800- 1630
108° 53.4'	43° 7.0'	1,080.0	3,542	53.3	127.9	36.3	20.0	1,115-3,542	3,400-16,100
107° 35.5'	42° 54.7'	38.0	125	9.5	49.1				
107° 32.9'	42° 54.6'	38.0	125	7.2	44.9				
107° 32.7'	42° 54.6'	66.0	216	9.5	49.1				
107° 32.3'	42° 54.6'	58.0	190	9.4	49.0				
107° 31.1'	42° 54.6'	63.0	207	9.9	49.8				
107° 33.2'	42° 54.4'	52.0	171	9.4	49.8				
108° 7.0'	42° 52.7'	89.0	292	11.4	52.5	20.0	11.0	197- 292	600- 890
108° 19.4'	42° 52.2'	215.0	705	14.6	58.2	19.2	10.5	66- 705	200- 2,150
108° 17.3'	42° 52.2'	120.0	394	12.9	55.2	17.8	9.8	98- 394	300- 1,200
108° 17.6'	42° 50.5'	180.6	592	14.1	57.3	19.6	10.8	164- 590	500- 1,800
108° 17.3'	42° 50.5'	290.0	951	15.9	60.6	18.1	9.9	131- 394	400- 1,200
108° 51.5'	42° 50.2'	60.0	197	9.5	49.1	30.6	16.8	33- 164	100- 500
108° 52.8'	42° 50.1'	291.0	954	9.8	49.6				
108° 9.5'	42° 46.2'	220.0	722	14.3	57.7	25.9	14.2	262- 722	800- 2,200
107° 10.4'	42° 45.4'	1,410.0	4,625	62.1	143.7	39.0	21.4	328-4,625	1,000-14,100
107° 40.7'	42° 45.4'	41.0	134	8.7	47.6	11.8	6.5	66- 134	200- 410
107° 40.7'	42° 45.4'	29.0	95	8.3	46.9				
108° 40.7'	42° 45.4'	38.0	125	8.8	47.8				
107° 10.7'	42° 44.6'	1,900.0	6,232	71.9	161.4	33.4	18.3	33-6,232	100-19,000
107° 35.4'	42° 44.6'	339.0	1,112	14.6	58.2	27.8	15.3	492- 689	1,500- 2,100
107° 35.3'	42° 44.5'	340.0	1,115	14.6	58.2	21.5	11.8	492-1,115	1,500- 3,400
107° 35.2'	42° 44.0'	232.0	761	14.9	58.8	38.7	21.2	66- 492	200- 1,500
107° 48.4'	42° 41.9'	127.0	417	10.1	50.1	20.2	11.1	164- 417	500- 1,270
107° 48.5'	42° 41.8'	60.0	197	9.0	48.2	20.8	11.4	66- 197	200- 600
107° 48.3'	42° 41.8'	96.0	315	10.0	50.0	15.1	8.3	131- 295	400- 900

Appendix A continued.

Location		Depth		Bottom-hole Temperature		Gradient[2]		Interval[3]	
Longitude	Latitude	Meters	Feet	(°C)	(°F)	°C/km	°F/1,000 ft	Meters	Feet
107° 46.1'	42° 40.7'	87.0	285	10.9	51.6				
107° 48.0'	42° 40.4'	65.0	213	10.8	51.4	45.2	24.8	66- 213	200- 650
107° 44.3'	42° 40.4'	137.0	449	11.7	53.1	35.1	19.3	197- 426	600- 1,300
107° 42.9'	42° 40.4'	126.0	413	10.3	50.5	25.6	14.1	164- 394	500- 1,200
107° 42.0'	42° 40.4'	177.0	581	12.0	53.6	31.6	17.3	98- 558	300- 1,700
107° 40.5'	42° 40.4'	127.0	417	10.0	50.0	22.4	12.3	164- 417	500- 1,270
107° 42.9'	42° 39.4'	203.0	666	12.0	53.6	26.1	14.3	131- 666	400- 2,030
107° 41.9'	42° 39.4'	180.0	590	14.4	57.9	54.2	29.8	131- 426	400- 1,300
107° 40.6'	42° 39.4'	185.0	607	13.0	55.4	20.4	11.2	164- 525	500- 1,600
107° 40.6'	42° 38.5'	216.0	708	13.6	56.4	40.3	22.1	295- 623	900- 1,900
107° 40.6'	42° 35.1'	255.0	836	12.5	54.5	26.4	14.5	230- 623	700- 1,900
107° 40.0'	42° 35.0'	195.0	640	12.2	53.9	17.5	9.6	295- 525	900- 1,600
107° 40.0'	42° 35.0'	180.0	590	12.2	53.9	20.9	11.5	262- 590	800- 1,800
107° 40.0'	42° 35.0'	57.0	187	9.8	49.6	13.5	7.4	66- 187	200- 570
107° 39.5'	42° 34.3'	310.0	1,017	13.3	55.9	18.4	10.1	295- 820	900- 2,500
107° 56.2'	42° 25.3'	1,310.0	4,297	59.6	139.2	38.7	21.2	131-4,297	400-13,100
107° 56.4'	42° 23.4'	1,530.0	5,018	52.7	126.9	28.0	15.4	328-3,608	1,000-11,000
Natrona County									
106° 46.4'	42° 51.4'	670.0	2,198	33.4	92.1	26.6	14.6	652-2,427	2,000- 7,400
106° 46.4'	42° 51.4'	380.0	1,246	24.3	75.7	33.3	18.3	66- 918	660- 2,800

[1] Measured by University of Wyoming personnel following the method of Decker (1973); data from Heasler and others (1983).

[2] Gradient represents a linear least squares fit of the temperature-depth data over the most thermally stable portion of the hole.

[3] Interval refers to the depth range over which the least squares gradient was calculated.

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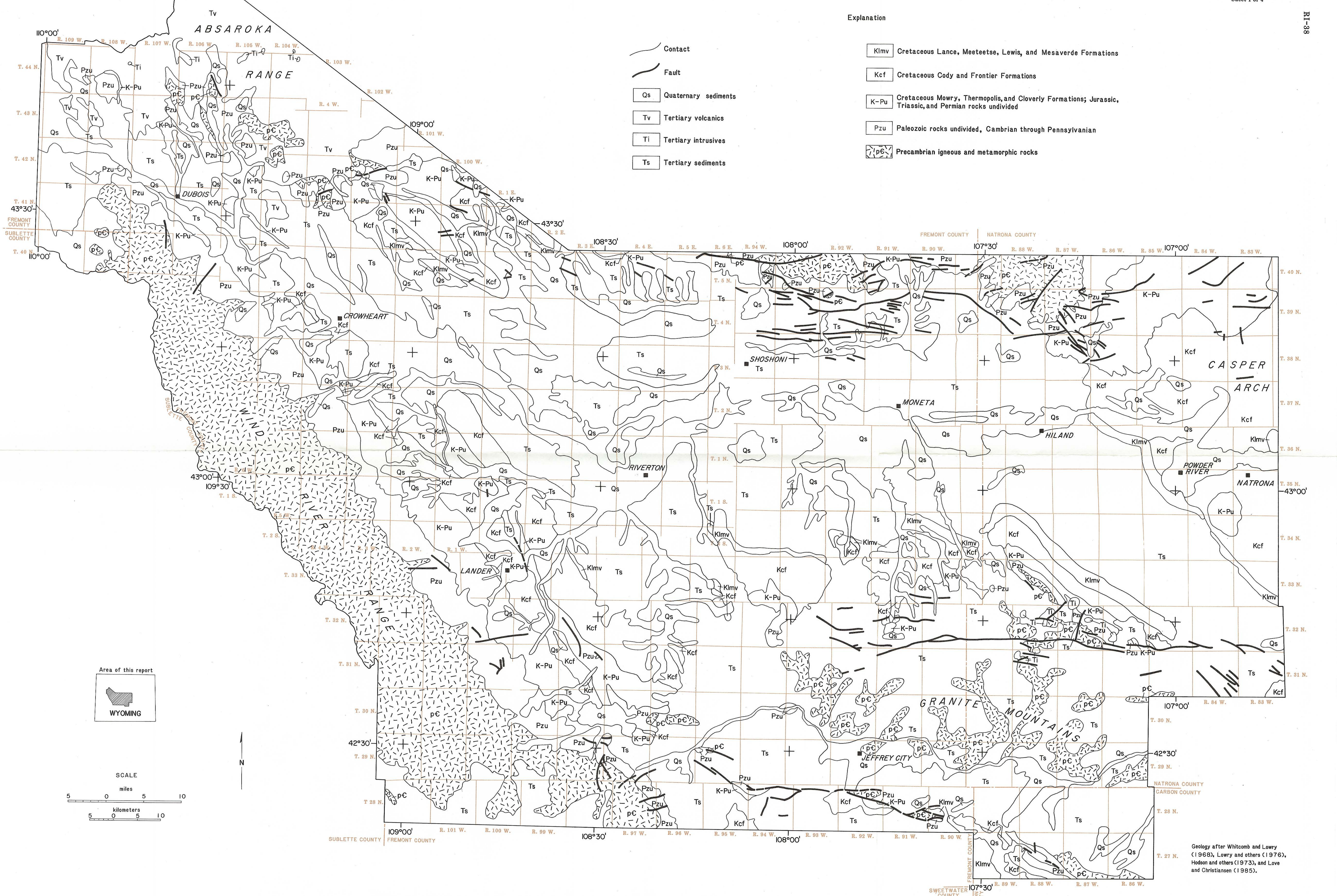

GENERALIZED GEOLOGIC MAP OF THE WIND RIVER BASIN, WYOMING

Compiled by
B.S. Hinckley and H.P. Heasler
1987

THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

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Sheet 2 of 4

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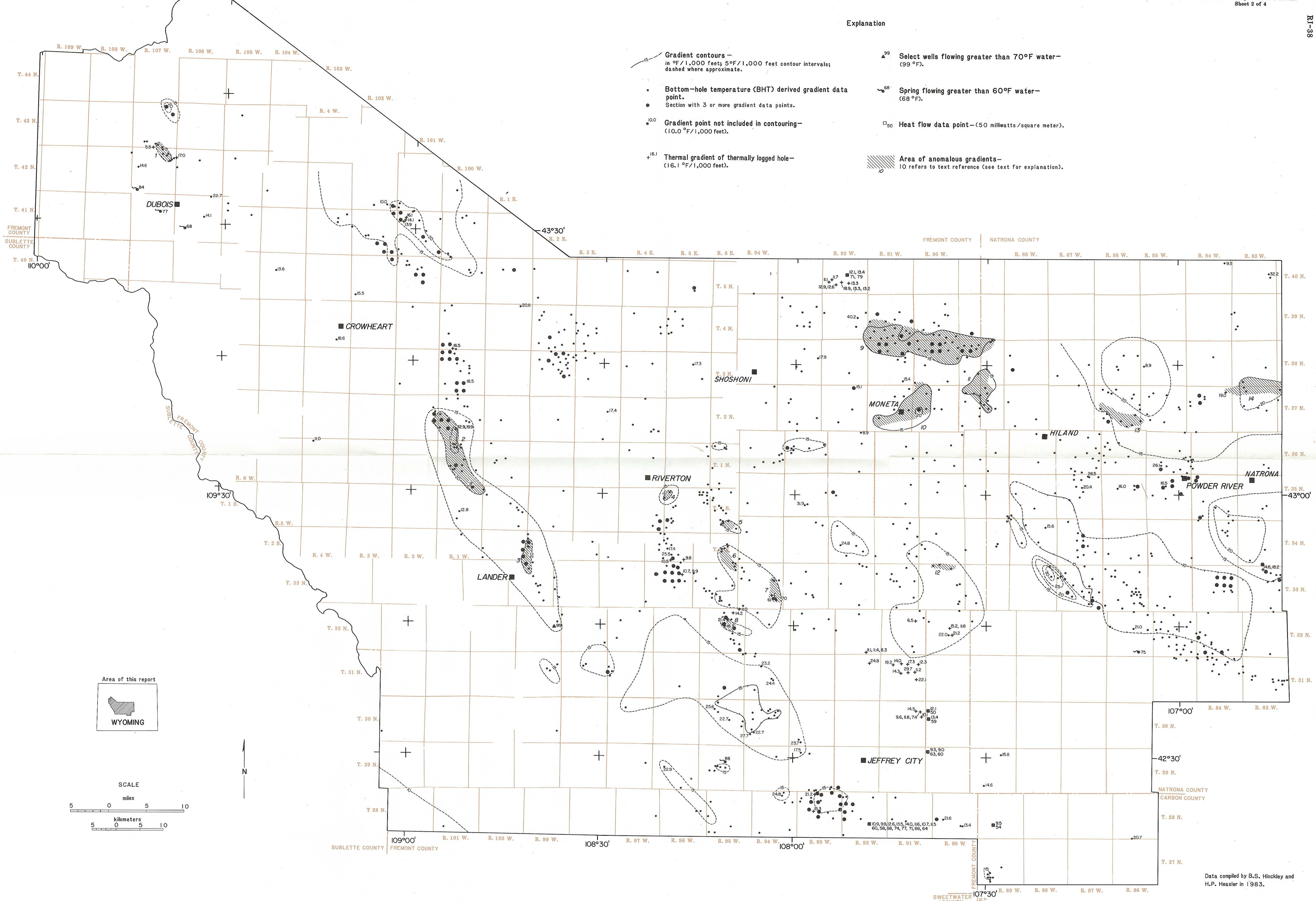

THERMAL GRADIENT CONTOUR MAP OF THE WIND RIVER BASIN, WYOMING

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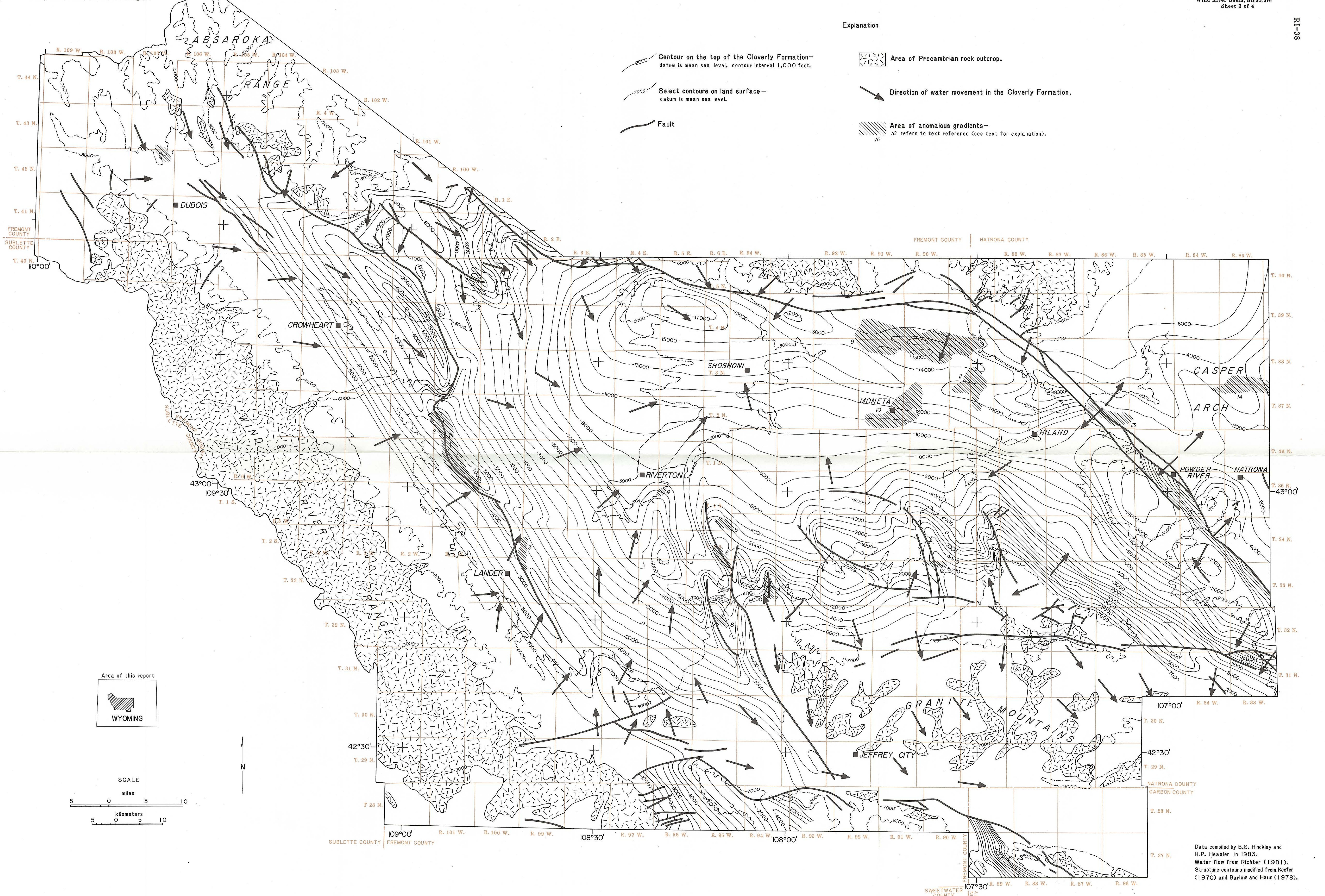
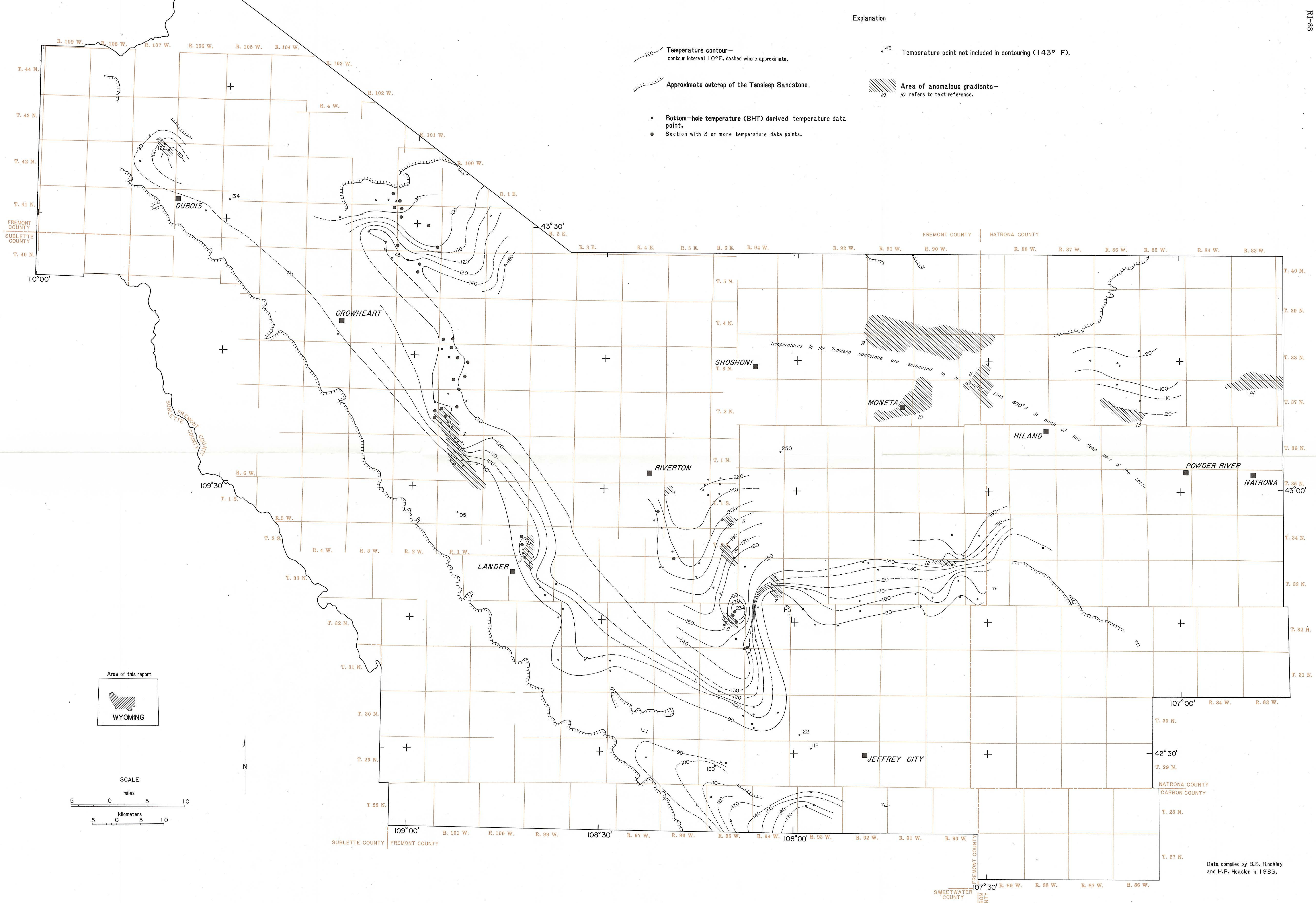


GENERALIZED STRUCTURE CONTOUR MAP ON THE TOP OF THE CLOVERLY FORMATION, WIND RIVER BASIN, WYOMING

Compiled by
B.S. Hinckley and H.P. Heasler
1987

THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist



TEMPERATURE CONTOUR MAP OF THE TENSLEEP SANDSTONE, WIND RIVER BASIN, WYOMING

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