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DISCLAIMER

Heat Flow Studies in Wyoming: 1979 to 1981

by

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INTRODUCTION

This report presents heat flow values and updated maps of flux in Wyoming and adjacent areas. Most of the report directly follows previous technical reports by Decker et al. (1981) and Decker and Buelow (1981). Funding for all research was furnished by Cooperative Agreement DE-FC07-79ID1206 between the University of Wyoming and the U.S. Department of Energy.

Throughout this report, depths are in meters (m) and kilometers (km), temperatures are in degrees Celcius (°C), and thermal gradients are in degrees Celcius per kilometer (°C/km = m°K/m). The thermal conductivity unit is abbreviated to CDU (1CDU = 1 x 10^{-3} cal/cm s °C = 0.4184 W/m °K), the heat flow unit to HFU (1HFU = 1 x 10^{-6} cal/cm^2 s = 41.84 mW/m^2), and the radiogenic heat generation unit to HGU (1HGU = 1 x 10^{-13} cal/cm^3 s = 0.4184 W/m^3). Values of gravity are plotted in milligals and the density unit is gm/cm^3. Standard errors are shown to indicate measures of the internal consistencies of the geothermal data.

DATA

Table 1 is a list of locations and basic geothermal data for recently completed heat flow stations in Wyoming, northern Colorado, and southern Montana. The least-squares gradients (Grad.) were calculated using temperature-depth data for "reliable" portions of the holes. The average thermal conductivities (Cond.) were calculated using measurements on rotary drill chips, or by using measurements on core samples. Established divided-bar techniques (Sass et al., 1971a, b; Roy et al., 1968b; Decker, 1973) were used for all conductivity measurements. The heat flow values were calculated as the products of average conductivity multiplied by the indicated least-squares gradients for each hole. The observed heat flow values (UNC) refer to the values obtained using uncorrected gradients and measured conductivities. The corrected values of flux (CORR) are the values that were obtained after the observed temperatures and/or gradients were corrected for the effects of three-dimensional terrain. Birch's (1950) methods was used to correct for topography out to a lateral distance equal to twenty times the deepest temperature measurement in each hole.

Decker (1973) shows that gradient determinations are a very accurate part of the geothermal studies research program at the University of Wyoming. The reliability of our "chip" conductivity measurements is difficult to assess because the porosity of the penetrated rocks was not always accurately known. A reasonable average porosity was assumed for most of the samples. Thus some of the individual heat flow values may be inaccurate or uncertain by a significant amount, and so some of the tabulated changes of flux in a studied area may be "artificial". The tabulated average flux for an area may be significant, however, and may provide a reasonable estimate of the actual ragional flux. For example, the 1.36 HFU (56.9 mW/m^2) average flux for the ten sites in the Boot Heel Quadrangle, Wyoming area suggests that heat flow in this region is normal, if it is assumed that conductivity errors are randomly distributed.

HEAT FLOW MAPS

Figure 1 is a map of physiographic provinces, geography and heat flow in Wyoming and bordering areas. Generalized geology and generalized flux in these areas are plotted in Figure 2. The heat flow data in both figures are after Table 1 herein, Blackwell (1969), Sass et al. (1971b), Morgan et al. (1977), Decker and Bucher (1979), Heasler (1978), Reiter et al. (1979), Decker et al. (1980), Buelow (1980), Decker et al. (1981), and unpublished values being reduced by various personnel at the University of Wyoming. The physiographic provinces are after Fenneman (1946), and the generalized geology is after the compilation for the United States by King and Beikman (1974). Both maps are considered reliable representations of the regional heat flow patterns in the depicted areas.

DISCUSSION OF DATA

WYOMING

The widely spaced heat flow stations in Wyoming can not be used for reliable quantitative assessments of the geothermal resource potential of the State. A few generalizations are permitted by the current data base, however, and some of these are briefly discussed below.

It is seen in both maps that most of the heat flow values in the Wyoming Basin - Southern Rocky Mountains region in southern Wyoming are low or normal. Thus, these data are not consistent with shallow, moderate or high temperature hydrothermal reservoirs in these areas. This generalization may appear to be inconsistent with hot springs (54°C) in the Saratoga Valley (Fig. 1) (Breckenridge and Hinckley, 1978). However, our 1.2 HFU (50.2 mW/m^2) flux on the Walck Ranch about 5 km west of the town of Saratoga implies that the springs are not surface manifestations of a shallow subsurface hydrothermal reservoir with large lateral dimensions. Because there is geologic evidence for young faults in Saratoga (Montagne, 1955), one interpretation is that the springs emerge from near-surface fractures (faults) that tap an underlying, low-temperature hydrothermal reservoir.

The recently calculated heat flow values in the Gas Hills area on the Sweetwater Arch are in the range 1.1-3.2 (48-134 mW/m^2) (Figs. 1 and 2). The meaning of these data is obscure, but the large heat flow variation could be explained by a complex distribution of circulating ground waters in this extensively faulted terrane. A similar mechanism could explain the low temperature (32°C) of the hot springs at Sweetwater Station in a nearby portion of the Hills (Breckenridge and Hinckley, 1978). Future investigations of the hydrothermal resource base in this region should focus on detailed studies of the correlation between faulting and ground water hydrology.

Decker et al. (1980) reported heat flows of 1.7 HFU (71.1 mW/m^2) and 1.9 HFU (79.5 mW/m^2) for two stations near Lysite, Wyoming. These data and the more recently obtained 1.6 to 1.9 HFU (66-80 mW/m^2) values in this area suggest that the regional flux in this part of the Owl Creek Mountains is above normal (see Figs. 1 and 2). Additionally, our values of flux for a 298 m deep hole that terminated in Precambrian basement near the northern end of the Laramie Mountains is 1.7 HFU (69.0 mW/m^2) and above-normal flux (1.7 and 2.1 HFU (71.1 and 87.9 mW/m^2)) has been obtained at two sites near Douglas, Wyoming about 70-100 km to the northeast (see Table 1, Fig. 1). There is also evidence for above-normal flux in parts of the Powder River Basin that are north, east and south of Douglas, although the range of calculated values is large (1.1-2.1 HFU (41.8-87.9 mW/m^2)) (see Figs. 1 and 2). Thus the Lysite-northern Laramie Mountains - Douglas area may be an east-west trending heat flow high that extends into part of the Powder River Basin (also see Lachenbruch and Sass (1977)). One implication of this inferred high heat flow zone is that high yield aquifers (e.g. the Madison Limestone) at depth could be valuable reservoirs for moderate temperature hydrothermal fluids in large parts of the Powder River Basin. Another speculation is that potentially valuable hydrothermal reservoirs could exist in the postulated above-normal heat flow band between Douglas and Lysite, an area that contains one of the larger populations centers (Casper) in Wyoming.

From combined heat flow and radioactivity data (1.8 HFU (75.3 mW/m^2), 4.2 HGU (1.79 mW/m^3)), Buelow (1980) infers that the Meadow Creek Basin area in the Absaroka Mountains in northwestern Wyoming is in a zone of high flux. This view agrees with Blackwell's (1969) above-normal value of 1.8 HFU 975.3 mW/m^2) for the Kirwin Mine area about 10 km southeast of Meadow Creek Basin (Figs. 1 and 2).

A 0.9 HFU (37.7 mW/m^2) heat flow is tabulated for the Picket Creek area in the southern part of the Absaroka Mountains (Table 1). In the northern part of these mountains, two recently obtained uncorrected values in the Sunlight Basin area are 1.5 and 1.8 HFU (62.8 and 75.3 mW/m^2) (Table 1). Corrections for steady-state terrain near the Sunlight Basin sites would lead to lower heat flows at these stations, and the tabulated value for the Picket Creek area may be uncertain by about 40% because we suspect that the porosity of the penetrated volcanics and sediments is high. We can not be more specific about the "true" regional heat flows at these localities without detailed reductions for terrain and actual porosities.

We may speculate, however, that two significant transitions of flux exist in the Absaroka Mountains. One transition occurs along an east- west profile that crosses the eastern part of Yellowstone National Park (YNP); as discussed by Morgan et. al. (1977) and Decker et. al. (1980) the change to unusually high flux in YNP (>2.5 HFU (104.6 mW/m^2)) must be due to shallow (magmatic?) heat sources in the crust below the Park area. Additionally, a significant north-south change of flux may occur in the Absaroka Mountains that are east and south of the Park. We suggest that the northern boundary of this transition is between the high surface and reduced heat-flows of 1.8 and 1.4 HFU (75.3 and 58.6 mW/m^2) in Meadow Creek Basin (Buelow, 1980) and the normal unreduced and reduced values of 1.3 and 1.0 HFU (54.4 and 41.8 mW/m^2) in Sunlight Basin (Decker et. al., 1980) (see Figs. 1 and 2). Continued heat flow and radioactivity studies are needed to define and model this inferred transition.

Finally, currently available heat flow values in the vicinity the Bighorn Basin (Figs. 1 and 2) are normal (1.3-1.6 HFU (45.4 = 77.9 mW/m^2)). These values suggest that the Basin is not characterized by large, shallow hydrothermal reservoirs.

SOUTHERN MONTANA

The uncorrected heat flows for three recently obtained holes in the Beartooth Mountains are in the range 1.3 - 1.8 HFU (54.4 - 75.3 mW/m^2), values that roughly agree with previously published determinations for these mountains (Blackwell, 1969; Sass et. al., 1971b). The different heat flow values for the recently analysed stations may be due to effects of local topography, or they may result from uses of mean conductivities that are uncertain because the porosities of individual samples are not accurately known.

NORTHERN COLORADO

Heat flow values and generalized geology in the neighborhood of the Colorado-Wyoming border are shown in Figures 1 and 2. Data are after Table 1 herein, Baker (1976), Blackwell (1969), Hallin (1973), Roy et al. (1968b), Decker (1966, 1969) and Decker et al. (1980) and Buelow (1980). Combined flux and radioactive heat production data long a north-south profile at 106° 15' west longitude are plotted in Fig. 3; data are from Buelow (1980) and Decker et al. (1980) (also see Decker et al., 1981).

Figure 3 shows that the surface and reduced heat flow in the southern Rockies in Wyoming is low to normal, whereas that in the mountains in extreme northern Colorado is high. There is significant scatter in the values in the Park areas in the Colorado Rockies, but the averages of the most reliable surface and reduced heat flows in this region are unusually high (Fig. 3). As depicted in the figure, the transition of flux between the Wyoming Rockes and the Northgate (NGT), Colorado area is less than 50 km wide, as is the transition of flux between the Northgate area and the Park region (JC, PM2, PVM) in Colorado immediately to the south.

Steady-state interpretations of the regional geothermal data imply subsolidus temperatures in the lower crust and upper mantle beneath the southern Rockies in Wyoming, and near-melting conditions near the crust-mantle boundary in the northern Front Range in Colorado (Fig. 4). In striking contrast, calculated equilibrium temperatures in the Park areas in Colorado imply massive amounts of melting of the lower crust and upper mantle (Fig. 4). There are at least two interpretations of the geothermal studies of the Park areas. First, the unrealistically high calculated temperatures (Fig. 4) suggest that the very high flux may be explained by transient conductive or nonconductive heat sources in the subsurface. Secondly, the heat sources that produce the excess flux must be in the crust because the depicted northern border of the anomaly is narrow (≤50 km). Decker et al. (1980) also suggested that this transistion was narrow (<75 km) and implied that the high flux could be due to nonsteady conductive or convective heat sources in the crust or uppermost mantle.

Buelow (1980) synthesized regional gravity measurements and showed that the Bouguer gravity anamolies increase in a region of transition between Middle Park in Colorado and the Medicine Bow Mountains in Wyoming. There is evidence also for a seismic low velocity zone in the upper crust in northern Colorado (Prodehl and Pakiser, 1980), and the Park areas and other parts of the northern Colorado Rockies experienced tectonism, igneous activity, uplift, and erosion in the late Cenozoic (Buelow, 1980, pp. 60-68). Thus, one reasonable speculation is that the regional gravity and heat flow anomalies are related to the same geologically-young masses in the crust. A "preferred" interpretation of regional Bouguer gravity anomalies along 106° 15' west longitude is shown in Fig. 5. As implied by the thermal parameters shown in Fig. 3, transient cooling of the low density bodies between 5 and 10 km in the upper crust also would explain the heat flow high in the Park areas, if large tabular masses were implaced about 2 MY ago at intrusion temperatures 600-700°C higher than those of the bordering units (also see Buelow, 1980, p. 76, Table III).

The geology in northern Colorado is complex, and the associated thermal regime is not well determined because the number of heat flow and radioactivity stations is small. Additionally, the young (≤ 2 MY) igneous rocks in the Basalt Mountain-Flat Top-State Bridge area, the late Micocene volcanics in the Elkhead Field, and the high reduced flux at Hahn's Park suggest that the unusually high regional heat flow may not be confined to a simple north-south trending zone (Larson et al., 1975; Buelow, 1980). Thus, the actual heat flow field could be complex and a likely interpretation is that the area is underlain by a three-dimensional distribution of young intrusions, bedrock radioactivity, and/or nonconductive heat sources. Although such models are appealing, it is desirable to better establish the regional heat flow regime in northern Colorado before pushing the interpretation much beyond the generalized two-dimensional conductive cooling model discussed above.

Table 1. Summary of basic Geothermal data for drill holes.
No. refers to number of conductivity samples. Standard erros (±) shown below man and/or least-squares values.

Locality[1]	North Latitude	West Latitude	Depth (Meters)	No.	K CDU	Grad °C/km UNC	Grad °C/km CORR	Heat Flow HFU UNC	Heat Flow HFU CORR
NORTHERN COLORADO									
Hahn's Peak (HP)+ DDH-7A	40° 50.3'	106° 55.4	280	66*	6.24	21.8	39.2	1.36	2.45
					±.06	±.2	±.4	±.02	±.05
DDH-101			330	18	6.09	37.1	42.4	2.29	2.56
					±.05	±.2	±.3	±.03	±.04
			850	45	6.33	35.4	40.1	2.24	2.54
					±.03	±.1	±.2	±.03	±.03
Poison Ridge (PR)+ DDH-105	40° 19.2'	106° 14.9'	980	67*	5.91*	30.3	30.1	1.78	1.78
					±.09	±.3	±.04	±.04	±.04
DDH-105	40° 29.1'	106° 15.1'	920	67	5.91	27.3	26.4	1.61	1.56
					±.09	±.2	±.1	±.04	±.04
Parkview Mountain (PM2)+ PV-105	40° 19.9'	106° 08.0'	680	26	6.28	30.3	36.8	1.90	2.32
					±.25	±.16	±.6	±.09	±.13
Northgate (NGT)+ FS-105	40° 55.9'	106° 16.6'	840	64	8.29	27.0	26.4	2.32	2.27
					±.07	±.2	±.2	±.03	±.03
WYOMING									
Sierra Madre+ SM-8 (SM2)	41° 10.7'	106° 53.8'	200	12	8.64	8.3	9.2	.75	.80
					±.64	±.2	±.2	±.07	±.6
SM-11(SM1)	41° 13.3'	107° 08.2'	256	20	6.32	15.2	15.0	.96	.95
					±.25	±.3	±.3	±.06	±.05
Medicine Bow Mountains+ MB-13 (MB2)	41° 27.4'	106° 21.0'	170	51*	13.56	7.6	7.2	1.03	.98
					±.22	±.1	±.1	±.06	±.05
MB-5 (MB1)	41° 28.7'	106° 13.8'	330	51	13.26	7.2	8.1	.95	1.07
					±.22	±.1	±.1	±.06	±.05

Locality	North Latitude	West Latitude	Depth (Meters)	No.	K CDU	Grad °C/km UNC	Grad °C/km CORR	Heat Flow HFU UNC	Heat Flow HFU CORR
Baggs	41° 3.8'	107° 45.9'	219	24	6.0	20.0		1.20	
					±.9	±.4		±.18	
Finley Reservoir	41° 27.5'	106° 40.0'	82	8	5.9	34.7		2.05	
						±.7		±.32	
Walck Ranch	41° 26.2'	106° 53.8'	168	18	6.0	20.0		1.20	
					±.9	±.2		±.18	
Boot Heel Quad.	42° 9.3'	105° 45.8'	91	10	6.7	14.1		.94	
					±2.0	±.6		±.38	
	42° 9.1'	105° 46.1'	155	18	5.8	21.0		1.22	
					±.8	±.6		±.17	
	42° 9.1'	105° 46.1'	146	15	5.8	23.2		1.35	
					±1.3	±.7		±.30	
	42° 8.4'	105° 47.8'	101	11	5.7	30.0		1.71	
					±1.6	±1.0		±.48	
	42° 10.5'	105° 49.4'	91	10	5.8	23.5		1.36	
					±.9	±1.0		±.22	
	42° 10.5'	105° 59.7'	91	10	6.5	25.8		1.68	
					±1.5	±.9		±.39	
	42° 9.9'	105° 58.0'	91	10	5.7	22.3		1.27	
					±1.3	±.5		±.29	
Bringolf Ranch	42° 17.1'	108° 52.1'	274	11	6.0	17.8		1.07	
					±.9	±.2		±.16	
	42° 17.3'	108° 50.6'	274	27	6.0	18.1		1.09	
					±.9	±.2		±.16	
	42° 18.4'	108° 52.2'	201	20	6.0	19.2		1.15	
					±.9	±.2		±.17	
	42° 18.6'	108° 51.4'	165	14	6.0	19.6		1.18	
					±.9	±.3		±.18	

Locality	North Latitude	West Latitude	Depth (Meters)	No.	K CDU	Grad °C/km UNC	Grad °C/km CORR	Heat Flow HFU UNC	Heat Flow HFU CORR
Squaw Springs	42° 27.4'	106° 3.9	299	47	5.7 ± .8	29.0 ± 1.5		1.65 ± .25	
Bulb Springs	42° 6.4'	107° 35.9'	229	24	5.3 ± .7	14.4 ± .3		.76 ± .10	
	42° 5.4'	107° 36.1'	152	15	5.0	18.5 ± .4		.93 ± .11	
Hadsell Springs	42° 11.2	107° 38.3	457	49	5.8 ± .6	11.0 ± .4		.64 ± .07	
Osborne Well	42° 10.4'	107° 45.8'	503	54	5.8 ± .6	17.3 ± .2		1.00 ± .10	
Highland Flats	43° 2.9'	105° 42.1	140	15	5.9 ± .6	15.6 ± 1.9		.84 ± .12	
North Butte	43° 48.2'	105° 59.0'	165	17	5.5 ± 1.1	25.0 ± .4		1.38 ± .28	
	43° 48.2'	105° 59.2'	82	9	5.0 ± .5	65.0 ± 2.3		3.3 ± .3	
	43° 48.4'	105° 59.6'	183	20	5.1 ± .9	17.9 ± .5		.91 ± .16	
	43° 48.8'	105° 59.7'	174	19	5.5 ± .9	21.3 ± .4		1.17 ± .19	
Fort Reno SE	43° 48.2'	106° 0.0'	152	18	5.0 ± .9	21.7 ± .4		1.09 ± .20	
	43° 48.9'	106° 0.1'	82	9	4.4 ± 1.0	26.7 ± 1.3		1.17 ± .27	
	43° 50.1'	106° 1.8'	812	9	5.5 ± 1.1	3.5 ± 1.4		1.29 ± .27	
	43° 50.1'	106° 1.8'	73	8	5.1 ± .7	18.6 ± 1.7		.95 ± .16	
	43° 48.9'	106° 2.6'	119	13	4.8 ± 1.2	6.9 ± .8		.33 ± .09	

Locality	North Latitude	West Latitude	Depth (Meters)	No.	K CDU	Grad °C/km UNC	Grad °C/km CORR	Heat Flow HFU UNC	Heat Flow HFU CORR
Fort Reno	43° 49.2'	106° 3.2	119	17	5.1 ±.9	16.4 ±.4		.84 ±.15	
Pickett Creek	44° 19.6'	109° 18.3'	186	10	3.9 ±.6	23.3 ±.5		.90 ±.14	
Sunlight Basin									
SBE-3	44° 44.9	109° 25.3'	254	42	6.18 2.07	24.5 ±.6		1.51 +.5	
SBE-2	44° 45.0	109° 24.3'	220	33	4.98 ±.80	36.2 ±.5		1.80 ±.29	
SOUTHERN MONTANA									
Beartooth Mountains									
BE-5	45° 04.9'	109° 14.1'	288	19	4.55 ±1.71	29.9 ±1.18		1.36 ±.51	
BE-4	44° 04.9'	109° 14.1'	230	19	4.55 ±1.71	29.0 ±1.88		1.32 +.50	
BE-2	45° 05.3'	109° 14.2'	123	18	4.28 ±1.21	41.0 ±5.0		1.75 ±.50	

1 - Locality abbreviations referred to in text are in parentheses.

* - Thermal conductivity values used were taken from nearby holes (See Buelow, 1980).

+ - From Buelow (1980, Table 1).

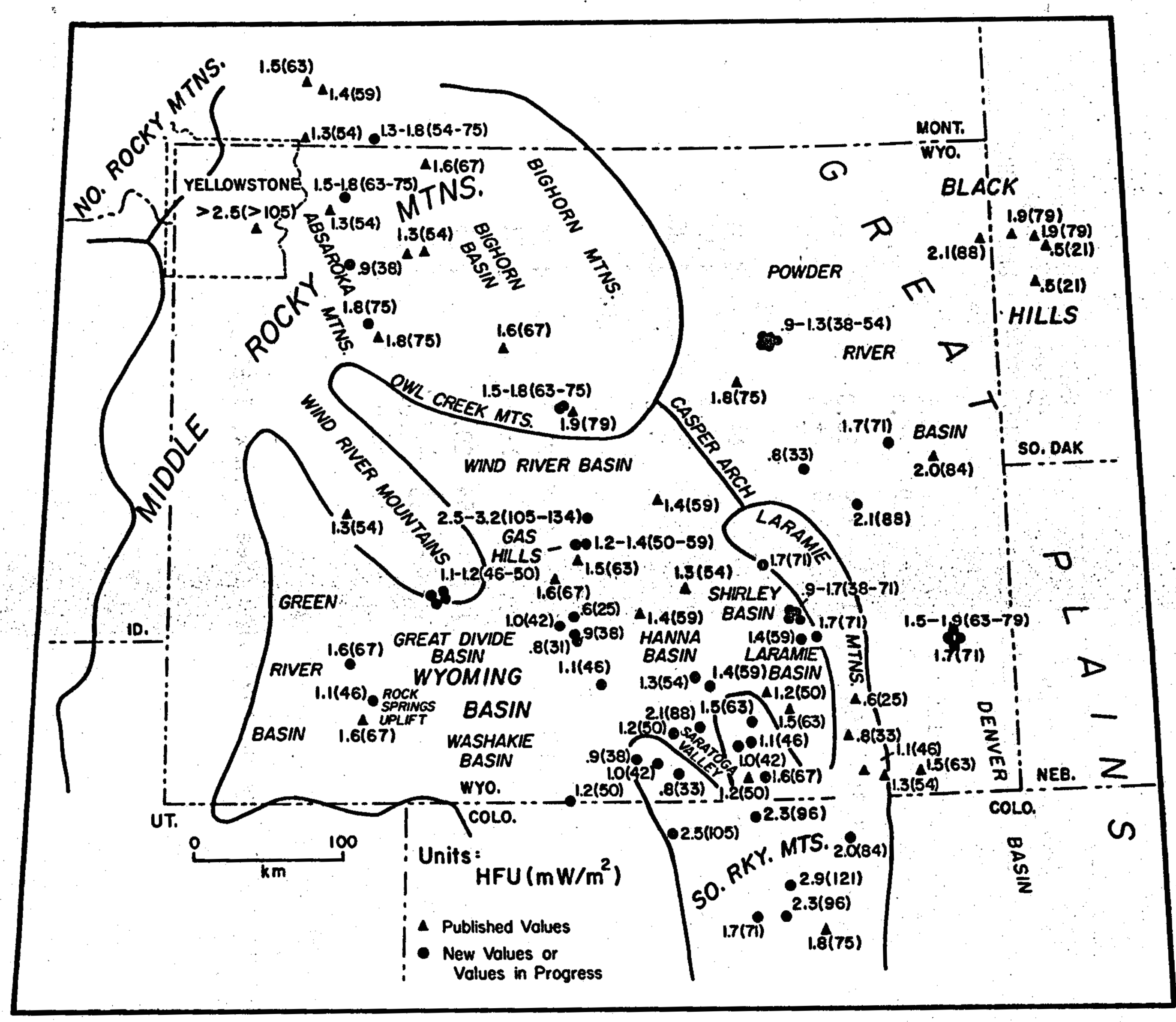

Figure 1. Map showing geography, physiographic provinces and heat flow in Wyoming and bordering areas. See text for published values references.

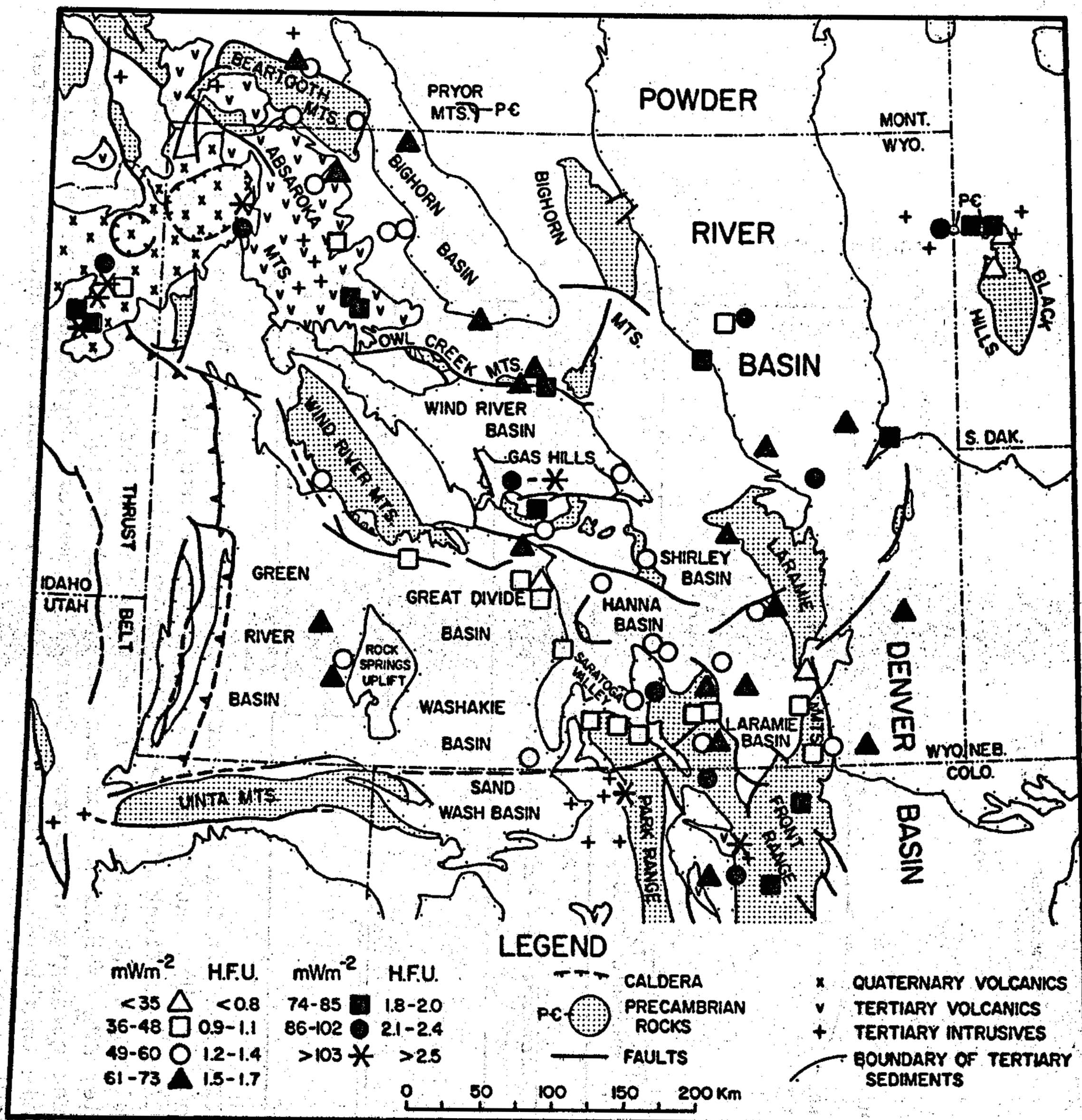

Figure 2. Map showing generalized geology and generalized heat flow in Wyoming and bordering areas.

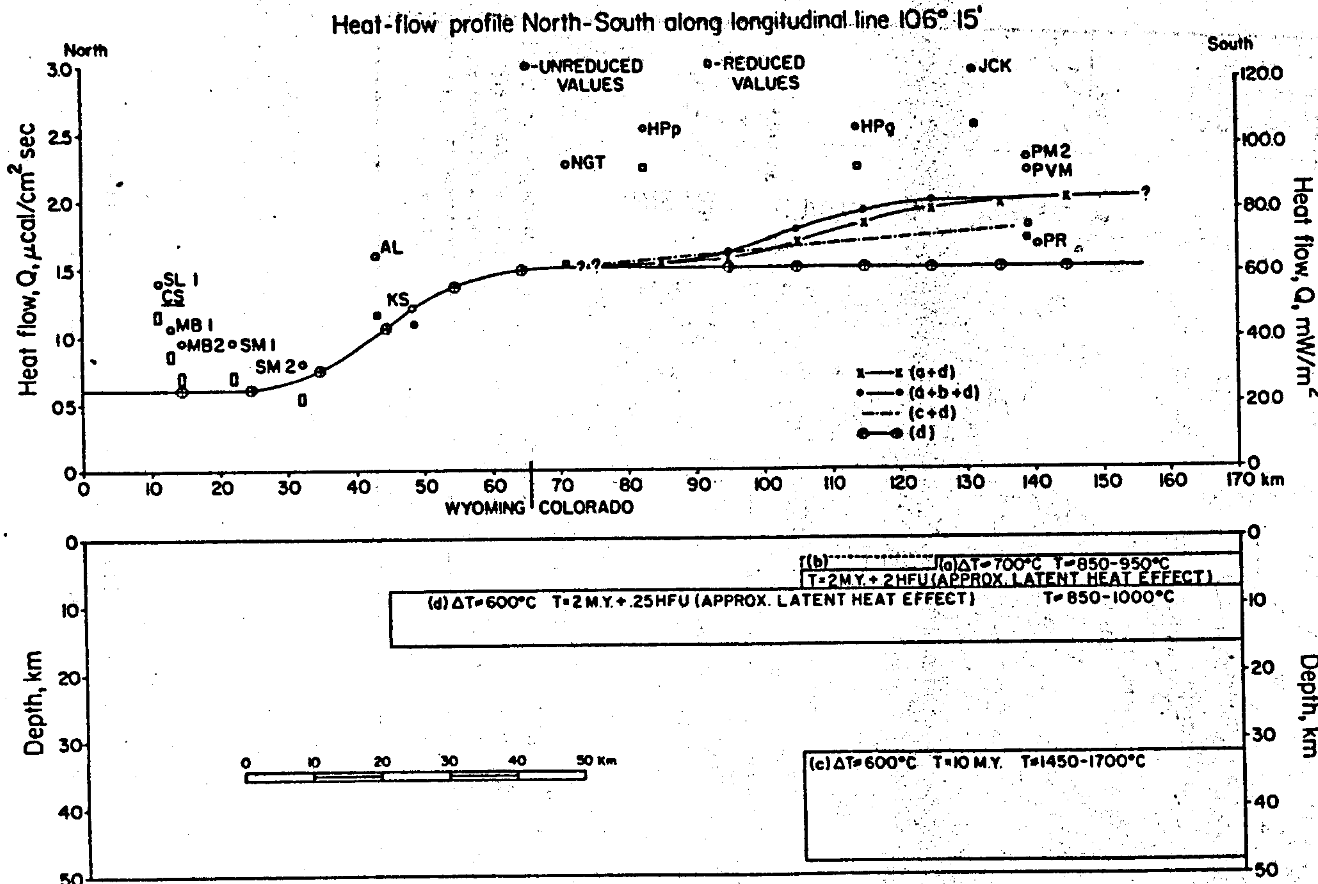

Fig. 3. Heat flow data along line A-A' in Fig. 11. Data from Tables I and II, Decker et al. (1980), and Decker (unpubished). Abbreviations: SL = Sand Lake, WY.; AL = Albany, WY.; KS = Keystone, WY.; JCK = Jack Creek, CO.; and NGT = Northgate, CO. (after Decker et al. (1980)). Other abbreviations shown in Table I. HP_p is Hahn's Peak data projected perpendicularly to profile; HP_g is Hahn's Peak data projected to profile according to geology; and CS means complicated geologic structure. Thermal parameters depicted in prisms are for transient cooling models that Buelow (1980) used to explain the heat flow anomalies. After Fig. 16 in Buelow (1980).

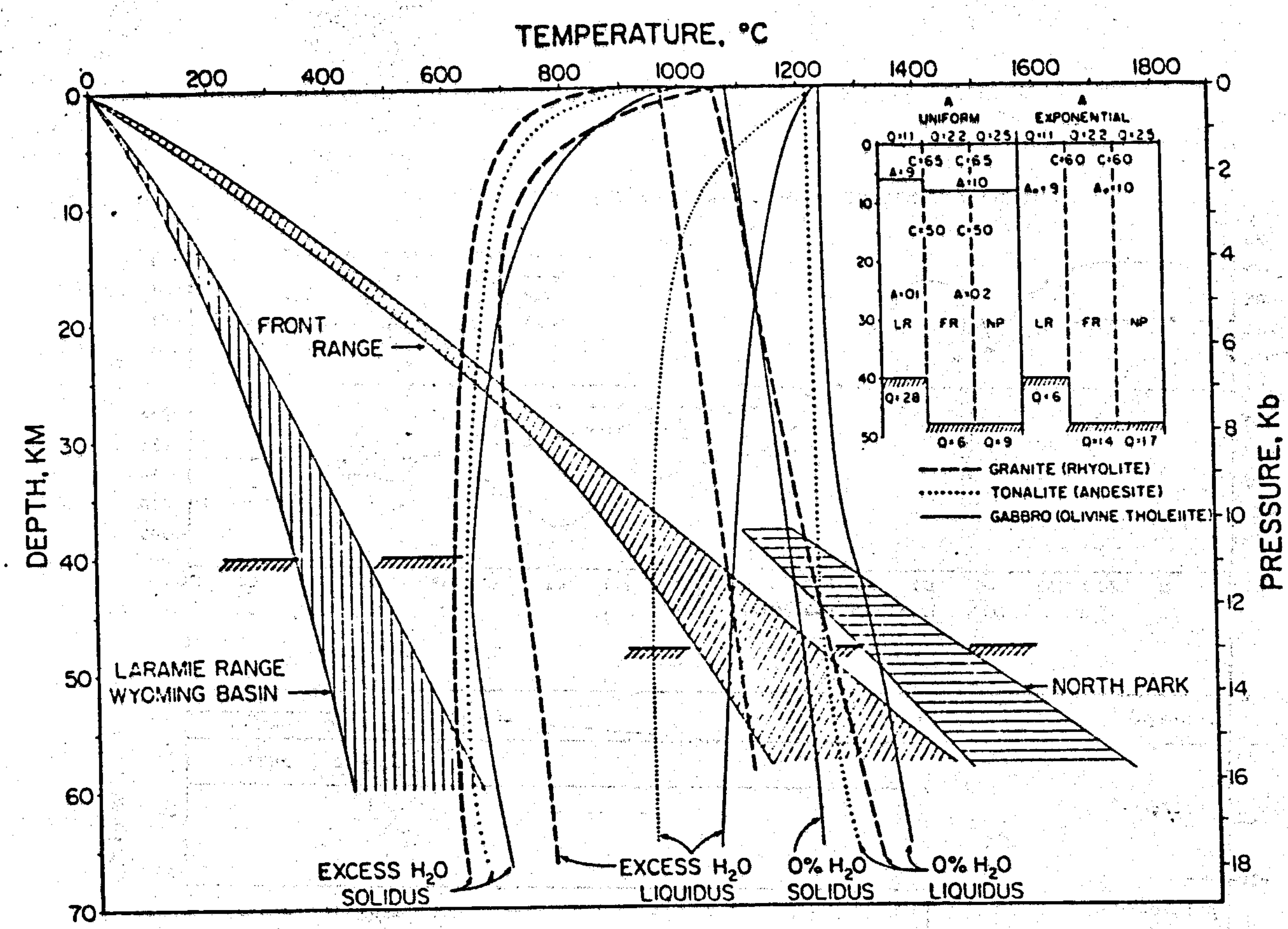

Fig. 4. Possible steady-state temperature-depth models for the Laramie Range-eastern Wyoming Basin area, the eastern Front Range, and the North Park region. Temperatures calculated for models depicted in the upper right hand corner of figure. Lined areas represent the range of temperatures using uniform (lower bound) and exponentially decreasing (upper bound) crustal radioactivity for the various models. Values of parameters directly follow surface values or commonly used values (see Roy et al., 1968a, 1972; Lachenbruch, 1968, 1970; Decker et al., 1980). Crustal thicknesses are indicated by hatching; thicknesses are from Prodehl and Pakiser (1980). Solidus and liquidus curves are for granite (rhyolite), tonalite (andesite), and gabbro (olivine tholeite) from Lambert and Wyllie (1972, 1974), Stern and Wyllie (1973), and Stearn et al. (1975). After Fig. 14 in Buelow (1980).

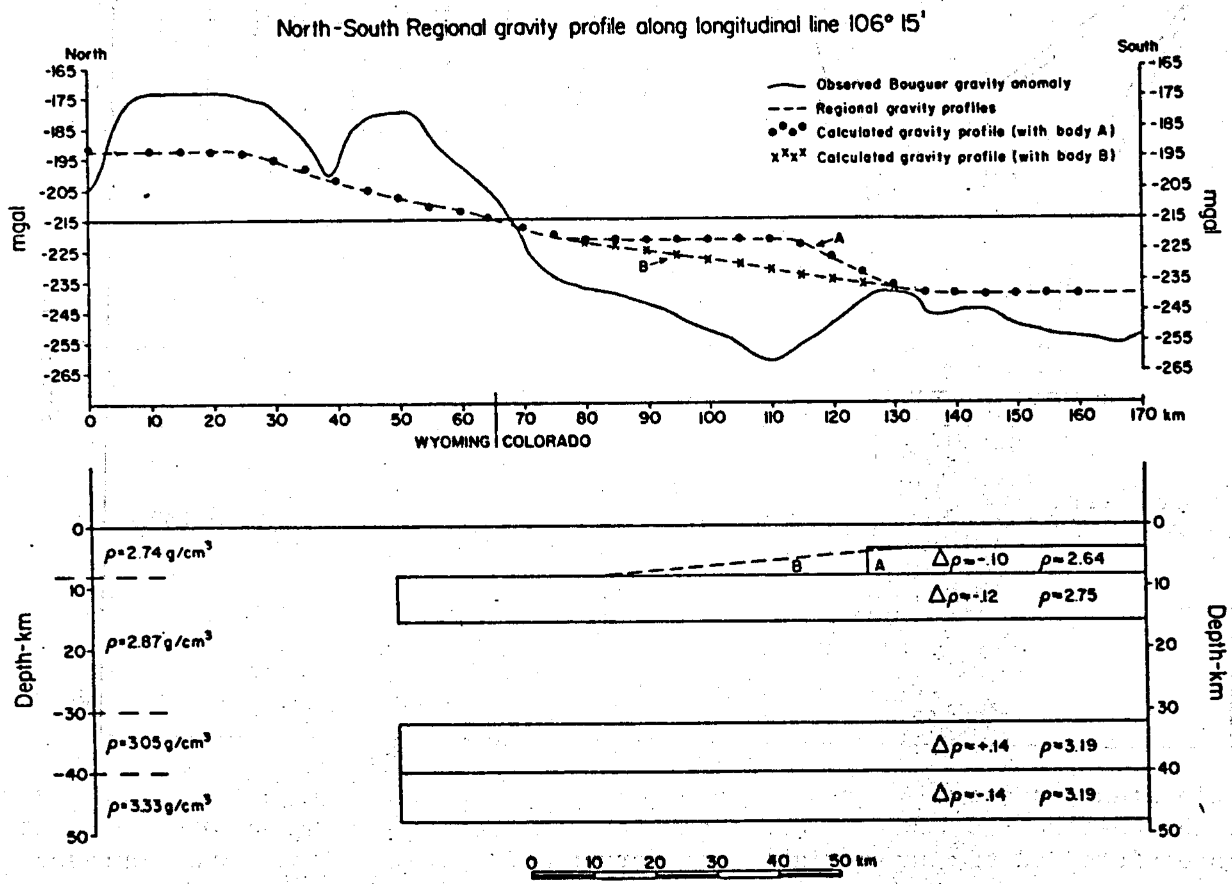

Fig. 5. Interpretations of regional gravity profile (dashed lines) along line A-A in Fig. 11. The effect of generalized near-surface geology and structure was stripped from the Bouguer gravity anomaly (solid curve) to obtain the regional gravity. Figure and procedures after Buelow (1980, Fig. 19, p. 84-94).

REFERENCES CITED

Baker, K. H., 1976, Heat Flow Studies in Colorado and Wyoming (M.S. Thesis): Laramie, University of Wyoming, p. 142.

Birch, F., 1950, Flow of Heat in the Front Range, Colorado: Geological Society of America Bulletin v. 61, p. 567-630.

Berry, G. W., Grim, P. J. and Ikelman, J. A., 1980, Thermal Springs List for the United States: National Oceanic and Atmospheric Administration, Boulder Colorado, Key to Geophysical Records Documentation No. 12, 59 pp. 3 maps.

Blackwell, D. D., 1969 Heat flow determinations in the northwestern United States, J. Geophys. Res., 74, p. 992-1007.

Breckenridge, R. M., and Hinckley, B. S., 1978 Thermal springs of Wyoming, Geol. Surv. Wyoming, Bull. 60, 104p.

Buelow, K. L., 1980, Geothermal Studies in Wyoming and Northern Colorado, with a Geophysical Model of the Southern Rocky Mountains near the Colorado-Wyoming Border. (M.S. Thesis): Laramie, University of Wyoming, 150 pp.

Decker, E. R., 1973, Geothermal Measurements by the University of Wyoming: Contributions to Geology, v. 12, p. 21-24.

Decker, E. R., 1969, Heat Flow in Colorado and New Mexico: Journal of Geophysical Research, v. 74, p. 550-559.

Decker, E. R., 1966, Terrestrial Heat Flow in Colorado and New Mexico (Ph.D. Thesis): Cambridge, Mass., Harvard University, p. 76.

Decker, E. R., and Buelow, K. L., 1981, Heat Flow, Radioactivity, Gravity, and Geothermal Resources in Northern Colorado and Southern Wyoming: Technical Report to the U.S. Department of Energy, Contract No. DE-F107-79ID12026, 43 p.

Decker, E. R., Heasler, H. P., and Buelow, K. L., 1981, Heat Flow studies in Wyoming 1979 to 1981: Technial Report to the U.S. Department of Energy, Contract No. DE-F107-79ID12026, 26 p.

Decker, E. R., Baker, K. H., Bucher, G. J., and Heasler, H. P., 1980, Preliminary Heat FLow and Radioactivity studies in Wyoming: Journal of Gephysical Research, v. 85, p. 311-321.

Decker, E. R., and Bucher, G. J., 1979 Thermal Gradients and Heat Flow Data in Colorado and Wyoming: a preliminary report, Los Alamos National Laboratory, Informal Report LA-7993-MS,

Fenneman, N. M., 1946, Physical Divisions of the United States, scale 1:7,000,000, U. S. Dept. of the Interior, Washington, D. C.

Hallin, J. S., 1973, Heat FLow and Radioactivity Studies in Colorado and Utah (M.S. Thesis): Laramie, University of Wyoming, 108 pp.

Hail, W. J., Jr., 1965, Geology of Northwestern North Park, Colorado: U.S. Geol. Surv. Bull. 118, 133 pp.

Heasler, H. P., 1978 Heat flow in the Elk Basin Oil Field, Northwestern Wyoming M.S. thesis, 168 pp., Univ. of Wyoming, Laramie, Wyoming

Karlstrom, K. E., Houston, R. S., Flurkey, A., Kratocchvil, A., and Collidge, C., 1980, Geolog and Uranium Potential fo Precambrian Conglomerates in Medicine Bow Mountains and Sierra Madre of Southeastern Wyoming: Bendix Field Engineering Corporation Open-File Report.

King, P. B., and Beikman, H. M., Compilers, 1974, Geologic map of the United States (exclusive of Alaska and Hawaii), U. S. Geological Survey, Reston, Va.

Lachenbruch, A. H., 1970, Crustal Temperature and Heat Production: Implications of the Linear Heat flow Relations: Journal of Geophysical Research, v. 75, p. 3291-3300.

Lachenbruch, A. H., 1968, Preliminary Geothermal Model of the Sierra Nevada: Journal of Gephysical Research, v. 73 p. 6977-6989.

Lachenbruch, A. H., and J. H. Sass, Heat flow in the United States, 1978 in The Earth's Crust, Geopys. Monogr. Sear., vol 20, edited by J. G. Heacock, pp. 626-675, AGU, Washington, D. C.

Lambert, I. B., and Wyllie, P. J., 1972, Melting of gabbro with exess water to 35 Kilobars, with Geological Applicatons: Journal of Geology, v. 80, p. 693-708.

Lambert. I. B., and Wyllie, P. J., 1974, Melting of Tonalite and crystallizaton of andesite liquid with excess water to 30kbars: Journal of Geology, v. 82, p. 88-97.

Larson, E. E., Ozima, M., and Bradley, W. C., 1975, Late Cenozoic Basic Volcanism in Northwest Colorado and its implications concerning Tectonism and the Origin of the Colorado River System: in Curtis, Bruce, ed., Cenozoic History of the Southern Rocky Mountains, Geological Society of America Memoir 144. p. 155-178.

de la Montagne, John, The Cenozoic history of the Saratoga area, Wyoming and Colorado, 1955, University of Wyoming Ph.D. Thesis, 140p.

Morgan, P., D. C. Blackwell, R. E., Spafford, and R. B. Smith, 1977, Heat flow measurements in Yellowstone Lake and the thermal structure of the Yellowsonte caldera, J. Geophys. Res. 82, 3719-3732,

Prodehl, C. and Pakiser, L. C., 1980, Crustal Structure of the Southern Rocky Mountains from Seismic Measurements: Geological Society of America Bulleitn, Part I. v. 91, p. 147-155.

Reiter, M., Mansure, A. J., and Shearer, C., 1979 Geothermal characteristics of the Rio Grande rift within the Southern Rocky Mountains compelex, in Rio Grande Rift: Tectonics and Magmatism, R. E., Reicker, editor, Amer. Geophys. Union, Washington, D. C., p. 253-268.

Roy, R. F., Blackwell, D. D., and Decker, E. R., 1972, Continental Heat Fow in The Nauture of the Solid Earth, edited by E. C. Robertson, McGraw-Hill, New York, p. 506-543.

Roy, R. F., Blackwell, D. D., and Birch, F., 1968a, Heat Generation of Plutonic Rocks and Continental Heat FLow Provinces: Earth and Planetary Sciences Letters, v. 5, p. 1-12.

Roy, R. F., Decker, E. R., Blackwell, D. D., and Birch, F., 1968b, Heat Flow in the United States: Journal of Geophyscial Research, v. 73, p. 5207-5221.

Sass, J. H., Lachenbruch, A. H., and Munroe, P. J., 1971a, Thermal conductivity of rocks from measurements on fragments and its application to heat flow determinatiosn, J. Geophs. Res., 76, p. 3391-3401.

Sass, J. H., A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr. 1971b, Heat flow in the western United States, J. Geophys. Res., 76, 6376-6412.

Stern, C. R., Huang, W., and Wyllie, P. J., 1976, Basalt-Andesite-Rhyolite H_2P-undersaturated Liquidus Surfaces to 35 Kilobars, with Implications for Magma Genesis: Earth and Planetary Science Letters, v. 28, p. 189-196.

Stern, C. R., and Wyllie, P. J. 1973, Water-saturated and Undersaturated Melting Relations of Granite to 35 Kilobars: Earth and Planetary Science Letters, v. 18, p. 163-167.