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U.S. GEOTHERMAL DATABASE AND OREGON
CASCADE THERMAL STUDIES

May, 1988

by

David D. Blackwell, John L. Steele,
and Larry Carter

Prepared under U.S. Department of Energy
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INTRODUCTION

This report describes two tasks of different nature. The first of these tasks was the preparation of a data base for heat flow and associated ancillary information for the United States. This data base is being used as the basis for preparation of the United States portion of a geothermal map of North America. This "Geothermal Map of North America" will be published as part of the Decade of North American Geology (DNAG) series of the Geological Society of America. The second of these tasks was to make a geothermal evaluation of holes drilled in the Cascade Range as part of a Department of Energy (DOE)/Industry co-sponsored deep drilling project. This second task involved field work, making temperature logs in the holes, and laboratory work, measuring thermal conductivity measurements on an extensive set of samples from these holes. The culmination of this task was an interpretation of heat flow values in terms of the regional thermal conditions; implications for geothermal systems in the Cascade Range; evaluation of the effect of groundwater flow on the depths that need to be drilled for successful measurements in the Cascade Range; and investigation of the nature of the surface groundwater effects on the temperature-depth curves. Each of these two tasks will be treated in a separate section of the report. The work reported here was funded by the Department of Energy under contract No. DE-FG07-86ID1263.

HEAT FLOW DATA BASE FOR THE UNITED STATES

The object of this task was to compile a comprehensive data base of heat flow and ancillary measurements for the United States. Many of these measurements have been associated with DOE geothermal programs during the past ten

years and thus these results include a summary of thermal studies carried out as part of the DOE programs. In addition, a complete bibliography of heat flow studies for the United States was also compiled. This data base and resulting map represent a significant new data source available for studies by the geologic and resource analysis community.

The heat flow data base consisting of entries for over 2,000 sites has been compiled for the United States. Assisting in the compilation were Douglas Smith, University of Florida; Edward R. Decker, University of Maine at Orono; Paul Morgan, Northern Arizona University; William R. Gosnold, University of North Dakota; Marshall Reiter, New Mexico Tech; and James Witcher, New Mexico State University. The heat flow data base will be made available through the NOAA World Data Center, Boulder, Colorado. Specific information on the availability of the thermal data base, and data for the DNAG gravity and magnetic maps of North America can be obtained by writing Herbert Meyers, Solid Earth Geophysics, NOAA, 325 Broadway, Boulder, CO 80303. The objective of the compilation was to compile as much relevant information for each site as possible to allow other investigators and researchers to study relationships between the heat flow data and geology, elevation, physiographic province, location, geothermal gradient, etc. Because of the size of the data base and the fact that the data base will be made available on machine readable media (floppy disk and magnetic tape), it is not repeated in this report. However, in Appendix A, a detailed description of the type of information included in data base and the format of the data are given.

Where possible original authors were contacted to supply additional information not originally available in published reports. Thus the data base contains significant additions of information beyond those available in the

open literature and so should be of unique value to researchers studying the thermal character of the United States.

In addition to the detailed compilation of heat flow and ancillary information, a detailed reference list was compiled for drill-hole thermal data for the United States. This bibliography was compiled using a commercial reference program (REF-11) which allows output in a variety of different types of formats as well as downloading into word processors. In addition key word and content information are also contained in the reference data base. This reference data base will be made available through the NOAA release as well. The bibliography includes a reference list of unpublished open-file reports as well as more conventionally published material from the literature. Thus it should be of significant use to those researchers interested in thermal data for a particular area that may not appear in most bibliographic data bases. This reference list contains almost 400 references and is summarized in typical journal format in Appendix B. The data base itself includes keyword and area information as well as bibliographic information. This reference list will be available on floppy disks in generic format and in the REF-11 format.

At the present time the map is in the technical editing stage and will go to the draftsman approximately May 1, 1988. A preliminary copy of the map is shown in Figure 1. The complete map will be multi-color and cover North America and surrounding regions at a scale of 1:5,000,000. Only the portion of the map dealing with the United States is illustrated in Figure 1. Figure 1 is half scale (1:10,000,000).

The map will show the heat flow data in terms of symbols graded at 10 mWm^{-2} intervals and as contoured data with a contour interval of 10 mWm^{-2} .

The density of data is sufficient to allow at least preliminary contouring at this interval.

The advantage of contouring heat flow data as opposed to contouring geothermal gradient data is that the geothermal gradients at any site and at any depth can be calculated if the heat flow, and if the thermal conductivity of the portion of the stratigraphic section of interest are known. However, if only a value of local or average geothermal gradient is known, then the actual gradient at any depth, the heat flow, or the temperature at depth cannot be calculated. Therefore, the heat flow map serves the purpose of showing variations in thermal conditions as well as providing information that can be used by interested parties to calculate thermal conditions at depth and can be associated with specific geologic units.

In addition to the thermal data, additional geothermal information are presented such as temperature contours on the Dakota aquifer in the Northern Great Plains (Gosnold, 1988, personal communication 1987). Depth to geopressured horizons in the Gulf Coast is also shown. These data has been compiled as part of DOE Geothermal Resources assessment projects. Depth to geopressure is important because there are low grade geothermal resources within the geopressure zone and because the geopressure zone typically represents a change in mean gradient from 20-25°C/km above geopressure to 35-50°C/km within the upper 0.5-1 km of the geopressure zone. Additional geothermal data shown on the map include the locations of Pleistocene volcanoes and volcanic centers (shown as green asterisks) and major geothermal systems (shown as blue circles). The density of warm and hot springs is too great in the western United States to allow display of every location. Therefore, only "significant geothermal systems" as listed in Circular 790

(Brooks et al., 1979) are shown on the map. In addition a specific category of geothermal systems is shown; i.e., those which have available shallow hole or deep drill hole data which specifically explore that particular geothermal system. These areas are shown by the blue triangles. Reference to the studies in these areas is also included in the data base reference list. These symbols show clearly the extensive geothermal evaluation in the Northern Nevada Basin and Range Province that has been a major component of the DOE Geothermal Programs.

The overall effort in developing this geothermal map has been to compile as complete a list of the available types of information as possible so that this compilation map can serve as a working basis for geothermal evaluations and for additional thermal projects in the future.

GEOHERMAL DATA FROM DEEP HOLES IN THE OREGON CASCADE RANGE

Introduction The Cascade Range in the Northwestern United States and Southwestern Canada is one of the major geothermal resource provinces of North America. It has the largest concentration of Pleistocene and Holocene-age volcanic rocks in the conterminous United States. Demonstrated temperatures in excess of 175°C in geothermal systems exist at Meager Mountain in Southwest British Columbia (Fairbank et al., 1981), Newberry Volcano in Central Oregon, (Sammel, 1981) and Lassen Peak Volcano in Northern California (Beall, 1981). High temperatures probably exist at Medicine Lake Volcano, but industry data there is proprietary. At Lassen Peak and Newberry Volcano, high temperature systems are located in areas not presently available for development. The only Cascade volcano with a significant number of deep drill holes and as yet no demonstrated high temperature system is the Mt. Hood Volcano (Steele et

al., 1982). In addition to the emphasis on locations of young volcanoes as possible sites of high temperature geothermal systems, there is significant evidence for high temperatures throughout much of the province, especially the northern half of the Oregon Cascade Range. Regional temperature gradients there have been demonstrated to be on the order of $65^{\circ}\text{C}/\text{km}$ (Blackwell et al., 1978, 1982; Black et al., 1983). Data are sparse, but temperature gradients are probably similar in the Cascade Range in southern Oregon and northern California. Temperature gradients ($40\text{--}50^{\circ}\text{C}/\text{km}$) are significantly lower, but still above average, in Washington and British Columbia (Blackwell and Steele, 1983; Lewis et al., 1985). Corresponding heat flow values are $100\pm 10 \text{ mWm}^{-2}$ and $75\pm 5 \text{ mWm}^{-2}$.

An elongated zone of high gradients in Oregon (Figure 2) has been interpreted to be related to a shallow heat source in the crust, probably a zone of very high temperatures with pockets of partial melt at a depth of 7-10 km (Blackwell et al., 1982). Interpretation of gravity, depth-to-Curie-point, and electrical resistivity measurements (Connard et al., 1983; Stanley, 1981) are consistent with high temperatures at shallow depths in the crust and suggest that the high temperature gradients and heat flow values observed in shallow holes (see the following discussion) can be extrapolated to depth to calculate regional thermal conditions. At present the area of demonstrated high gradients is still a small part of the Cascade Range (the area demonstrated to have the high gradients is shown by the pattern on Figure 2). This area does not include much of the High Cascade Range. Temperature gradient and heat flow measurements cannot be made in the porous, young volcanic rocks in the High Cascade Range and in the High Lava Plains at their intersection with the Cascade Range (between the Newberry Volcano and the Three Sisters

Volcano) within the depth range of typical shallow exploration holes (150 m). So the deeper thermal conditions are at present unknown except at the site of CTGH-1 (described below) and in the vicinity of the Mount Hood volcano where extensive deeper drilling (greater than 500 m) has taken place.

Thus while high gradients have been demonstrated over part of the area, the total extent of these high gradients and the actual values of gradient along the axis of the Cascade Range (the locus of greatest volcanic activity during the last 0.5 Ma) remain as yet undetermined. Furthermore, the relationship of the hot springs, most of which are concentrated near the boundary between the high heat flow and the Western Cascade Range-Puget Sound-Willamette Valley normal heat flow province, to the regions of high heat flow and high gradient are as yet unexplored. Blackwell et al. (1982) suggested several models for the systems but these models have not been tested except in the vicinity of Breitenbush hot springs (Priest, 1985). The Breitenbush area is one locus of studies of the DOE Cascades geothermal program (Sherrod and Priest, 1988); some of the results are discussed in a following section. Priest and Blackwell (1987) have proposed a drilling program to investigate many of these relationships.

The object of this paper is to present thermal data from several intermediate to deep drill holes in the Oregon Cascade Range, which are new or for which data have recently become available. Data from six drill holes are discussed in this report and compared to existing data. These six holes include three holes at Newberry Volcano, two drilled by Geo-Operator Corporation, and one drilled by Sandia National Laboratories in 1983. Thermal data from two holes drilled in the general vicinity of the Breitenbush Hot Spring area north of Mt. Jefferson are also discussed. These include well CTGH-1, drilled by Thermal Power near Olallie Butte, close to the axis of the Cascade

Range, and a well drilled by SUNEDCO as a deep exploration test 11 km to the southwest at Breitenbush Hot Springs. In addition preliminary results from drill hole CL-1 along the east border of Crater Lake National Park will be mentioned. The results have been published by Blackwell and Steele (1987).

Three of the holes were drilled during 1985-86 with the co-sponsorship of the U.S. Department of Energy/Division of Geothermal and Hydrothermal Technology, and industry on a cost-share program targeted toward intermediate-depth temperature gradient drilling in the Cascade Range. The primary objective of the program was to obtain data from test holes penetrating deeply enough to obtain valid temperature gradient measurements below the surficial cover of porous, young volcanic rocks. The holes drilled so far have succeeded in this objective.

Temperatures were measured in four of the holes in 1986. However, because of the recent completion of drilling, equilibrium temperatures were measured only in hole N-1 (drilled in 1985). Holes N-1, N-3, and CTGH-1 were relogged in 1987. Hole CL-1 could not be relogged due to the fact that the well had boiled dry during the winter. Because the hole is not complete, no samples were available for thermal conductivity measurements.

The locations and preliminary thermal data for these holes are summarized in Table 1. The heat flow data in Table 1 are not corrected for terrain effects. However, these holes are all deep enough that the terrain effects will be insignificant. The locations of five holes are shown on Figure 2; hole CL-1 would be located approximately 50 km south of the southern border of Figure 2.

Detailed thermal conductivity measurements from the three holes for which samples are available are listed in Table 2. Also included are density values

calculated on dry cores and porosity values calculated from the difference between dry and saturated core density. These values are not typical of bulk values because the cores represent the most solid parts of the stacks of lavas and ash flows encountered in each hole. The well logs available for each hole can be used to obtain the best mean density and porosity values for the rocks encountered by the holes (Swanberg and Combs, 1986; Swanberg et al., 1988; UURI open files), with the laboratory values used as calibration data for the log measurements.

Newberry Caldera-Holes Outside Caldera Newberry caldera is situated in central Oregon about 40 km east of the High Cascade Range axis and is the site of extensive Holocene volcanic activity (Macleod and Sammel, 1982) of bimodel type. It is a large shield volcano. The shield is capped by a shallow 4-5 km diameter caldera.

Temperature-depth plots from holes N-1 and N-3 are shown in Figure 3. The temperature profile for N-1 has been discussed in some detail by Swanberg and Combs (1986). The results from N-1 and N-3 have been discussed by Swanberg et al. (1988). Hole N-3 (approximately 5 km north of the north rim of the caldera) shows almost isothermal temperatures to 600 m, an abrupt temperature increase at that point to approximately 50°C, an isothermal section at about 50°C to a depth of approximately 1150 m, and finally a section where temperatures increase rather uniformly to the bottom of the hole at 1220 m. This particular type of temperature-depth curve is generated by intra-hole fluid flow. Water is entering the hole at a depth of approximately 1150 m near the point shown by the arrow. It moves up the hole as artesian flow and exits at another aquifer at approximately 600 m. Because of this behavior it is

difficult to determine the best geothermal gradient for the hole but a reasonable value lies somewhere between $53^{\circ}\text{C}/\text{km}$ (the average gradient over the bottom 46 m of the hole) and approximately $71^{\circ}\text{C}/\text{km}$ (the average gradient from the bottom of the hole to approximately 550 m as shown by the dashed line). This range in gradient, combined with the measured thermal conductivity values (Table 2b) can be combined to calculate a heat flow value for this hole that ranges between 96 and 128 mWm^{-2} .

In contrast, hole N-1, approximately 2 km south of the south rim of the caldera, has a slightly higher temperature in the bottom of the hole, but a temperature-depth curve which may be due to intra-hole downflow. In this case, fluid might enter the hole at a depth of approximately 350-400 m (see arrows) and flow down the hole isothermally to exit between 1000 and 1100 m. In fact, in the period of time between when the hole was completed and logged in late 1985 and when it was logged in 1986, the cold fluid had broken through into a deeper aquifer and 50 additional m of hole were isothermal as compared to the temperature-depth curve published by Swanberg and Combs (1986). The best average gradient for this hole is approximately $84^{\circ}\text{C}/\text{km}$ which, combined with the mean harmonic thermal conductivity from Table 2a gives a the resulting heat flow value of approximately 151 mWm^{-2} .

Swanberg et al. (1988) suggest that the in situ curves for both holes are similar to the one measured for N-1 with very deep sections of isothermal conditions in the rock. This situation is also possible and would be comparable to the Timberline lodge hole at Mt. Hood (Steele et al., 1982, Figure 3) (although that hole is isothermal only to a depth of 250 m). An argument in favor of our explanation is that the 1987 logs, compared to the 1986 logs, show a heating of the hole between 500 and 625 m in N-3 and a cooling of the

hole between 1000 and 1200 m in N-1. These changes with time indicate non-equilibrium thermal conditions associated with the flow, which would not be expected if the flow conditions existed before the holes were drilled.

Hole N-1, closer to the caldera, has a higher average geothermal gradient, heat flow, and bottom hole temperature. The average heat flow is approximately 50% higher than the regional background, suggesting the presence of a local geothermal anomaly associated with the geothermal system and/or with a magmatic heat source beneath Newberry caldera. On the other hand the heat flow in hole N-3 is equal to or only slightly higher than average regional values.

Holes Inside Newberry Caldera Temperature profiles for two holes drilled within the caldera of Newberry Volcano are shown in Figure 4. The first of these holes was drilled by the U.S. Geological Survey in 1981 (Sammel, 1981). The temperature-depth curve in this hole is rather spectacular, showing three areas of negative gradient and a bottom hole temperature of nearly 265°C. In the fall of 1983, a hole was drilled by Sandia National Laboratories to a depth of 424 m approximately 0.3 km south of the NB-2 hole. This hole encountered a non-equilibrium maximum temperature of 158°C at a depth of 350 m at the top of the same aquifer that is about 100°C in the NB-2 well (Black et al., 1984). The Sandia well is slightly closer to the caldera rim and to the 1300-Ya Big Obsidian rhyolite flow so the warm water maybe coming up somewhere south of RDO-1 and flowing northward, cooling off as it passes sequentially the RDO-1 well and the NB-2 well. The presence of very high temperatures at shallow depths and significant lateral flow of warm water within the caldera are clearly demonstrated by these results. The hydraulic

gradient would induce groundwater flow generally westward. There are of present no holes in the public domain west of the caldera although exploratory holes have been drilled by Union, Occidental Geothermal and GEO Operators in that quadrant of the volcano.

Breitenbush Area Based on the hydrogeochemistry (Brooks et al., 1979), Breitenbush may have the hottest geothermal fluid of any of the hot springs occurring along the boundary between the Western Cascade and the High Cascade Range. SUNEDCO completed several of geophysical exploration studies in the area including the drilling of a number of shallow temperature-gradient test holes, one intermediate depth gradient test hole and one deep exploration well (Federal 58-28-1). The results from the shallow gradient test holes have been released in open file form (Blackwell et al., 1986). The deep well temperatures have been summarized recently as well (Priest, 1985). These data are the basis for a detailed thermal analysis of the Breitenbush geothermal system presented elsewhere (Blackwell and Baker, 1988a, 1988b). In addition, as part of the DOE/Industry program, a hole close to the axis of the High Cascade Range, approximately 11 km northeast of the Breitenbush hole, was drilled by Thermal Power in 1986.

Temperature-depth curves from the SUNEDCO deep hole and the Thermal Power hole are shown in Figure 5. Also shown in Figure 5 for comparison is the temperature-depth curve from the deepest hole previously available in the Cascade Range, the Old Maid Flat 7-A hole, approximately 5 km west of the Mt. Hood Volcano (Steele et al., 1982). The temperature gradient in the Thermal Power well (CTGH-1) increases systematically between 300-550 m to a value of approximately 80°C/km between 700 and 1500 m. The gradient is approximately

constant from 700 m to the bottom of the hole at 1465 m. The gradient in the hole is higher than the average gradient along the High Cascade - Western Cascade boundary region ($65^{\circ}\text{C}/\text{km}$, Blackwell et al., 1982; Black et al., 1983). However, in spite of the conductive-looking gradient, there were many fracture zones and evidence for secondary mineralization within this hole. Even on a small sample basis, porosity values were high, averaging 7% (see Table 2c). The core samples have much lower thermal conductivity values than typical of the holes at Newberry caldera and of other Cascade boundary zone drilling. The lower thermal conductivity values suggest thorough alteration of the volcanic rocks to clay rich mineralogies. The clay alteration may explain the low electric resistivity value observed in the general area (J. Iovenetti, personal communication, 1986). Because the average thermal conductivity for this hole is low, the high gradient does not indicate an anomalous heat flow, and in fact the calculated heat flow value is within 10% of the average heat flow for the Western Cascade - High Cascade boundary zone (Table 1).

The results from this hole support the hypothesis that the high gradients and heat flow observed to the west continue eastward to the axis of the High Cascade Range, although based on one hole such a conclusion must obviously be preliminary. The temperature gradient will probably decrease with depth as the rocks become less porous and higher in thermal conductivity. However, even so, the fact that temperatures at 3 km in the well site will exceed 200°C demonstrates that even along the crest of the Cascade Range with the strong hydrologically driven downflow of cold groundwater, temperatures of commercial interest exist within reasonable drilling depths. Such conditions in association with a geothermal system which can be produced have not yet been located, however.

In contrast to the CTGH-1 well, which is at an elevation of 1310 m, the SUNEDCO Federal 58-28-1 was collared at an elevation of only 823 m and drilled to a depth of 2457 m. Several months following completion of drilling, the hole was logged by SMU, although because of viscous mud in the hole, we were not able to log below 1600 m (see Figure 5). The only temperature data at the bottom of the hole are a series of Kuster tool readings made 24 hours after circulation over a period of 50 min. A maximum temperature of 141°C was recorded (Al Waibel, personal communication, 1985). It is a difficult and uncertain procedure to calculate equilibrium temperatures based on such a series of bottom hole measurements, but a plausible minimum equilibrium bottom hole temperature is well in excess of 150°C. The temperature-depth curve for this hole is quite complex, but taking a minimum equilibrium bottom hole temperature of 150°C, and a surface temperature of 10°C, the average gradient for the hole would be 56°C/km. On the other hand, the observed temperature gradient between 250 and 800 m is 148°C/km.

The heat flow values corresponding to these two values of gradient are 106 and 222 mWm⁻² respectively. The lower value is compatible with the average background temperature gradient and heat flow observed throughout this area of the Western Cascade/High Cascade boundary province. The higher value observed for the shallower section of the hole is compatible with results from shallow drilling (100-150 m) in the vicinity of Breitenbush Hot Springs.

The interpretation for the shape of the temperature-depth curve (discussed in detail by Blackwell and Baker, 1988a, 1988b) is as follows. A geothermal aquifer with water at a temperature of approximately 110-120°C was cut by the drill hole at a depth of approximately 800 m. With increase in depth, the thermal effect of this aquifer decays and regional background temperatures were approached below a depth of 2000-2500 m. The temperature

difference at a particular depth between the OMF-7A and Federal 58-28-1 wells may represent the temperature effect of the 800 m aquifer. An interpretation for these types of temperature-depth curves has been described in general by Ziagos and Blackwell (1986) and by Blackwell (1985) for the Long Valley caldera.

The model that is suggested by these results for the geothermal system at Breitenbush is conceptual model 3 of Blackwell et al. (1982). In this model (shown as dotted line numbered 3 in Figure 6), water circulates downward to depths of several kilometers beneath the axis of the High Cascade Range, then returns toward the surface and flows westward along a stratigraphic or quasi-stratigraphic horizon to the site of the hot springs localized along the series of north-south trending structures marking the boundary between the High Cascade and Western Cascade provinces. On the other hand, models 2 and 4, which represent the hypothesis that thermal fluid circulation comes up from great depths beneath the site of the hot springs are not supported by the evidence from Breitenbush. These types of models may represent the situation at some of the other geothermal systems exposed along the Western Cascade/High Cascade boundary, however.

Temperatures in laterally flowing aquifers may change rapidly with distance, but without additional information on the rate of flow through the system, its size, its recharge area, etc., it is impossible to make lateral projections. A more detailed summary of the thermal and geologic data from the general Breitenbush area is in preparation (Sherrod and Priest, ed., 1988). In spite of the data now available, it is not possible to answer some important questions associated with the geothermal evaluation. Reentry of the Federal 58-28-1 well and sampling of the thermal aquifer and/or drilling to the aquifer east of the hole and closer to its presumed source area are needed to complete the evaluation of the geothermal potential of this area.

Crater Lake As part of the DOE/Industry cost-share Program, a hole was drilled by California Energy to a depth of 405 m along the east side of the Crater Lake National Park during the fall of 1986. This hole is approximately 50 km south of the area shown in Figure 2, but its township-range location is given in Table 1. This hole may be deepened sometime in the future if procedural objections can be overcome (see Sammel and Benson, 1987). The results from the hole are quite encouraging in that a temperature of 107.1°C was encountered at total depth making the average gradient over the depth range of the hole at least $250^{\circ}\text{C}/\text{km}$ with a resulting estimated heat flow of 375 mWm^{-2} . A non-equilibrium temperature-depth log for that hole is shown in Figure 7. As mentioned above, the hole could not be relogged in 1987.

Discussion One of the most frustrating situations for thermal exploration in active volcanic terrains is the high permeability typical of the surficial rocks. Certainly this situation is true in the High Cascades. The depth of the "transparent" or isothermal layer in holes drilled so far varies from a few meters to 500-700 m. These results shed light on the possible types of "rain curtain" effects on temperatures at depths of a few hundred meters in the Cascades. In general such effects penetrate to less than 600 m (see temperature depth curves in Blackwell et al., 1982; Steele et al., 1982, for additional examples), although intraborehole fluid flow between fracture zones and stratigraphic horizons may confuse the effects in some holes such as GEO-N-1, GEO-N-3. In contrast in the Western Cascades the volcanic rocks are generally impermeable except along discrete fractures or beds and conductive gradients are generally measured below 20-100 m. In the CTGH-1 hole the transition from the near surface convective regime to the conductive region

occurs over the depth range of 350-550 m. In his analysis of the alteration in the hole Barger (1988) notes that below 480 m smectite occurs ubiquitously. He further notes that most of the original void space is partly to completely filled by secondary minerals. He also concludes that most of the alteration is associated with temperatures of less than 100°C.

In contrast Keith (1988) following work by Waibel (unpublished report) found that the rocks of the Breitenbush Formation in SUNEDCO 58-28 have been exposed to temperatures much higher than those that presently exist, up to 200-250°C below 640-800 m. Effects of present thermal aquifer are not discernable in the alteration analysis. On a regional basis alteration is extensive in the Breitenbush Formation, so most of the alteration is apparently related to post early Miocene relatively deep burial of the section which was subsequently unroofed by erosion between 18 and 12 Ma.

The results of these observations emphasize the conclusion that the transition from surface volcanic rocks with very large permeability to rocks with low permeability is associated with hydrothermal alteration associated with fluids at temperatures of 50°C or higher. This alteration is probably more related to depth of burial than age, but age is a useful site criterion in the Cascades nonetheless. Most of the exposed units that are in the age range 5-10 Ma or older appear to have been buried to a depth of 500-2000 m (and exposed to temperatures and fluids at 50°C or higher) and seem generally impermeable. Rocks in the age range 5-2 Ma appear to have generally been buried to depths of 100's of meters and generally give low to approximately 1/2 regional heat flow values in 150 m holes. Rocks that have never been buried deeper than 500-1000 m (generally less than 2 Ma) seldom have a geothermal gradient in holes 150 m deep except in the immediate vicinity of

geothermal systems. A strict observation of this characteristic assignment of rock properties by selecting only old or visibly altered young rocks as a basis for sites for 150 m gradient tests has resulted in highly successful drilling programs in the Cascades (Blackwell et al., 1982). However, sites in the High Cascades that meet this criterion are rare to nonexistent.

Because the loss of permeability appears to be associated with alteration above 50°C, with the characteristic alteration suite described by Barger (1988), this depth should be detectable using electrical exploration techniques. Wright and Nielson (1986) pointed out the correspondance of units of low electrical resistivity with units that have smectite alteration in hole GEO-N-1 at Newberry volcano. Therefore in a volcanic terrain, the transition from near surface groundwater convective regimes to low permeability-conductive regimes (50°C and greater, past or present) should be characterized by a marked decrease in resistivity. Part of the reasoning for siting the CTGH-1 hole was the presence of a large area of low electrical resistivity at depth (Joe Iovenetti, personal communication, 1986). This electrical resistivity anomaly may be related to the pervasive alteration and vug filling noted in the CTGH-1 core. Therefore a closely coordinated combination of detailed electrical soundings of the upper 1000 m of a prospect area combined with drill holes in the depth range 600-1200 m should furnish the optimum exploration results in terrains such as the High Cascades.

The results from the drill holes discussed in this paper show that average heat flow values within the High Cascade Range exceed 95-100 mWm⁻², that average temperature gradients at depth exceed 55°C/km at all locations so far investigated and that temperatures are 100-125°C at 1000-1500 m. Whatever the significance of the results in terms of local areas, the results from deep

hole 58-28 and from the intermediate depth holes such as CTGH-1 and OMF 7-A verify that the high gradients observed in the shallow holes (150 m) discussed by Blackwell et al. (1982) can often be extrapolated to depths of at least 1-2.5 km. As was discussed earlier, geophysical data suggest such gradients can be extrapolated to depths on the order of 7-10 km. Furthermore the results demonstrate the presence of geothermal systems at several different locations within the Cascade Range and suggest that even given the limitations associated with access and development within the Cascade Range, exploitable geothermal systems may exist in the very large prospective area that remains to be explored.

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Figure 1. Draft version of heat flow map of the United States (excerpt from GSA-DNAG 1:5,000,000 Geothermal Map of North America).

K E Y

See Symbol Key	Land Heat Flow
	Contoured on Observed Data
	In Areas Where the Surface Heat Flow From the Upper Crust Is Known to Be Disturbed by Water Flow in the Color Pattern Is Broken
See Symbol Key	Oceanic Heat Flow
	Contoured on Observed Data - Carribean Sea, Gulf of Mexico, and Artic Ocean
	Contoured on Theoretical Heat Flow for age of lithosphere (Sclater, Jaupart, and Galson, Rev. Geophys., 18, 269, 1980) - Pacific Ocean, Atlantic Ocean, and Labrador Sea.
Grey Scale	Top of Geopressure - Gulf Coast
	Contours on the depth to the top of formations where fluid pressures exceed the hydrostatic value (Bebout et al., 1980). This depth is also a thermal boundary because temperature gradients are generally between 20 and 30 °C/km above that depth and are between 35 and 50 °C/km over 500 or more meters below that depth.
Grey Scale	Aquifer Temperature - Midcontinent
	The Temperature on the Cretaceous Dakota Aquifer in the Great Plains is contoured in Intervals of 10°C
Grey Overprint	Areas Affected by Large Scale Aquifer Flow
	Large areas where conductive heat flow is disturbed by large scale flow of ground water. For example, in the Prairies Basin in Alberta the heat flow values shown are probably do not represent crustal heat flow (Majorowitz et al. 1985).
Blue Circle	Major Thermal Area
	Based on geothermal evidence for high temperature or on large size.
Blue Triangle	High Temperature (>150°C) Geothermal Area
	Area For Which Drill Hole Thermal Data Are Available (Blackwell, Steele, and Carter, 1988).
Blue Triangle	Low Temperature (<150°C) Geothermal Area
	Area For Which Drill Hole Thermal Data Are Available (Blackwell, Steele, and Carter, 1988).
Green Astrick	Pleistocene or Holocene Volcano
Line	Physiographic Boundary

HEAT FLOW SYMBOL KEY

	mWm^{-2}
○	10 to 20
◇	20 to 30
□	30 to 40
x	40 to 50
+	50 to 60
◆	60 to 70
■	70 to 80
▲	80 to 90
●	90 to 100
	100 to 110
+	110 to 120
★	120 to 150
*	> 150

HEAT FLOW CONTOUR KEY

	mWm^{-2}
Purple	10 to 20
Dark Blue	20 to 30
Light Blue	30 to 40
Dark Green	40 to 50
Light Green	50 to 60
Yellow	60 to 70
Light Orange	70 to 80
Dark Orange	80 to 90
Red	90 to 100
Light Pink	100 to 120
Dark Pink	120 to 150
	150 to 200
	> 200

Figure 2. Location map of holes discussed in this paper. Heat flow values and locations of existing holes are given in mWm^{-2} (base after Blackwell et al., 1982).

Figure 3. Temperature-depth curves for Geo-Operator Newberry holes. Selected points are shown.

Figure 4. Temperature-depth curves for USGS-NB2 and Sandia RDO-2. Selected points are shown.

Figure 5. Temperature-depth curves for northern Oregon Cascade Range.
Selected points are shown.

Figure 6. Several models of the relationship of hot springs to the heat flow transition observed at the Western Cascade Range-High Cascade Range boundary. Four curves are shown, corresponding to three different variations in fluid circulation. In curve 1 the observed conductive anomaly is shown. In the other three models the hot spring anomalies are interpreted in terms of various controls on water circulation. Areas of heating of the groundwater corresponding to each circulation model (2-4) and the regional heat source (1) are shown in their appropriate subsurface locations (Blackwell et al., 1982).

Figure 7. Temperature-depth curve. for California Energy Crater Lake test hole. The estimated conductive gradient is shown as a dashed line.

Table 1. Location and thermal data for intermediate and deep holes in the Cascade Range.

Location (Township/Range-Sec)	Hole Name	Hole Depth meters	Maximum Temperature °C	Depth Interval meters	Average Gradient °C/km	Thermal Conductivity Wm ⁻¹ K ⁻¹	* N	Heat Flow mWm ⁻²
8S/8E-28	CTGH-1	1465	96.4	500-1465	82	1.41 ±0.06	7	115
9S/7E-28NESESW	Federal 58-28-1	2457	141**	250-856	148	1.5	5	222
				0-2457	56	1.9	13	>106
20S/12E-24NWSWNW	N-3	1220	57.1	1174-1220	53.2±11.0	1.8		96
				600-1220	71	1.88 ±0.07	18	128
20S/13E-31NESWSW	RDO-1	424	158.3***		-	-		-
22S/12E-25SESENW	N-1	1226	73.9	1146-1226	83.7±4.4	1.8		151
				400-1220	75	1.66 ±0.06	6	125
T31S/R7 1/2 Sec-10	CL-1	405	107.1	0-405	(250)	(1.5)		375

*N = number of thermal conductivity measurements within depth interval

Not equilibrium *Not equilibrium, measured at 350 m

TABLE 2a. Cascade DOE Drill Hole Thermal Conductivity Samples, GEO N-1.

SAMPLE #		T.C. WET	DENSITY DRY	POROSITY %
meters	feet	$\text{Wm}^{-1}\text{K}^{-1}$	gm/cm^3	
595.6	1954	1.32	2.06	7
626.7	2056	1.87	2.70	3
685.8	2250	1.63	2.71	7
718.4	2357	1.54	2.68	2
747.1	2451	1.41	2.73	2
776.0	2546	1.87	2.60	2
810.8	2660	1.57	1.68	18
842.2	2763	1.83	2.74	6
900.4	2954	1.34	2.32	5
930.6	3053	1.52	2.63	1
1053.7	3457	1.71	2.74	4
1082.0	3550	1.42	2.39	2
1111.9	3648		2.65	1
1129.6	3706			1
1143.6	3752	1.94	2.45	4
1157.9	3799	1.76	2.81	2
1174.7	3854	1.83	2.39	7
1191.2	3908	1.94	2.42	5
1202.6	3945.5	2.03	2.24	13
1217.1	3993	1.83	2.41	1

TABLE 2b. Cascade DOE Drill Hole Thermal Conductivity Samples, GEO N-3.

SAMPLE #		T.C. WET	DENSITY DRY	POROSITY %
meters	feet	$\text{Wm}^{-1}\text{K}^{-1}$	gm/cm^3	
488.0	1601	2.32	2.42	5
522.1	1713	1.68	2.64	5
822.4	2698	1.73	2.61	1
847.3	2780	1.85	2.58	8
947.0	3107		2.27	10
977.2	3206	1.74	2.72	1
1098.5	3604	1.94	2.48	2
1127.8	3700	2.11	2.34	4
1174.1	3852	1.95	2.35	5

TABLE 2c. Cascade DOE Drill Hole Thermal Conductivity Samples, TP-CTGH-1.

SAMPLE #		T.C. WET	DENSITY DRY	POROSITY %
meters	feet	$\text{Wm}^{-1}\text{K}^{-1}$	gm/cm^3	
366.1	1201	1.63	2.60	1
428.5	1406		2.54	1
456.3	1497	1.72	2.66	1
519.7	1705	1.47	2.48	11
553.7	1816.5		2.59	5
582.5	1911		2.70	1
731.2	2399	1.67	2.32	1
762.0	2500	1.52	2.48	12
960.7	3152	1.30	2.01	20
964.2	3163.5	1.31	2.04	14
1157.3	3797	1.37	2.19	16
1281.7	4205	1.30	2.25	1
1374.6	4510		2.06	5
1418.2	4653		2.59	2
1461.5	4795		2.65	12

APPENDIX A**Description of GSA-DNAG Geothermal Master File
Data Base System**

GEOHERMAL MASTER FILE DATABASE SYSTEM

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PURPOSE

This section is a description of the data base used for the North American Geothermal Map project. The compilation of this map is for the GSA-DNAG Series. This description relates specifically to the U.S. data.

ORGANIZATION

The database basic unit is composed of "hole information" - a summary of resulting work from a single hole location or from several closely spaced hole locations (usually less than 1 km apart).

Information about each site is divided into five basic groups. These groups are:

Location	- Hole location and date of temperature measurement
Information/Status	- Minimum and maximum values of hole
Results	- Gradient and heat flow results per depth interval
Geology	- Lithologic information of the hole
Comments	- General notes and comments as needed

Each basic information group is composed of an 80 column "card image" with each variable in the group assigned a specific location on the "card".

Table 1 is a display of the card image" pattern.

Each of the five basic data groups has its own data area on the Database. Each data area is composed of four lines (except for (G)eology) in Table 1. An example of the printout of one hole as it would appear in the database is shown in Table 2.

These lines are as follows:

- (a) Title of the data group
(i.e., Location, Results, etc.)
- (b) Data access line
- (c) Template reference line for the parameters
(i.e., shows format and location of parameters)
- (d) Parameter list line
(i.e., shows the parameters of the data group)
The data groups - "Geology" and "Comments" share a common parameter list line - "Free Format".

The parameters of the template are described in the section on Description of the Parameters.

RULES OF THE TEMPLATE

(1) The pattern similar to >>>< or } } } { { { indicates a floating point value in which the change of direction of the related symbol is an implied decimal point.

Ex. 2356 is 23.56 and 1005 is 100.5
 } } } { >>><

(2) Where integers are used, they are right-justified in the template (i.e., == or ---). These patterns do not have reversing symbols, but each field has a common pattern.

Ex. 1 is 1 and 1 is 100
 --- ---

(3) The @ symbol is used for special symbol notation associated with the number to its left.

Ex. 35* is (3.5) (an estimate or average)
 >><@

Ex. 275 < is < 27.5 (less than 27.5)
 >>><@

Allowed symbols are as shown in Table 3. In some cases the @ location may be used as a number location.

Ex. 3567 is 35.67
 >>><@

(4) Special combination patterns are used for such parameters as date, township/range-sec, latitude, longitude, and others.

Ex. 5/ 6/85 is May 6th, 1985
 ==/==/==

Ex. 2N/15E- 2AAC is Township/Range-Section information
 ---@---x-----

(5). Where numbers are used (floating or integer) a blank is the same as the number zero.

The Input/Output thermal units are in "CGS" units. All values are stored in the database file in the "CGS" System.

The parameter names and type patterns for each basic group are described in the following paragraphs. Refer to the template display in Table 1 for an overview.

"Card" 1 - (L)OCATION CODES

The Location data consist of only one "card" per site.

AMS MAP AMS Sheet Identification <Character Type>

An AMS sheet (1:250,000 scale map) is used to give a consistent map location for the hole site. This map scale is the most detailed available for all the U.S.

-----		template pattern
1	2	columns 1 thru 24
	4	

Ex. STEFFORD HILL AMS, ILL.

HOLE	Drill Hole Name	<Character Type>
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
20	20	20
21	21	21
22	22	22
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31
32	32	32
33	33	33
34	34	34
35	35	35
36	36	36
37	37	37
38	38	38
39	39	39
40	40	40
41	41	41
42	42	42
43	43	43
44	44	44
45	45	45
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47	47	47
48	48	48
49	49	49
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53	53	53
54	54	54
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56	56	56
57	57	57
58	58	58
59	59	59
60	60	60
61	61	61
62	62	62
63	63	63
64	64	64
65	65	65
66	66	66
67	67	67
68	68	68
69	69	69
70	70	70
71	71	71
72	72	72
73	73	73
74	74	74
75	75	75
76	76	76
77	77	77
78	78	78
79	79	79
80	80	80
81	81	81
82	82	82
83	83	83
84	84	84
85	85	85
86	86	86
87	87	87
88	88	88
89	89	89
90	90	90
91	91	91
92	92	92
93	93	93
94	94	94
95	95	95
96	96	96
97	97	97
98	98	98
99	99	99
100	100	100

This parameter is a name related to the identification of the hole (i.e., by owner, company, or project). It also is used to differentiate a hole from a set of holes in the same area.

```

===== template pattern
2      3  columns 25 thru 32
5      2

```

Ex. WIFE-3

DATE	Measured Date	<Integer Type>
------	---------------	----------------

This parameter is the date of the temperature measurement from which the thermal results were determined. It is in the form MM/DD/YY.

```
==/==/==  template pattern
4          4  columns 41 thru 48
1          8
```

Ex. 5/ 6/85 is May 6th, 1985
 ==/==/==

(TS-RN-SEC) Township/Range-Section-Sub <Char/Integer Type>

This parameter is the break-down of the hole location by township, range, and section numbers. The section is sub-divided from 1/4 section down to as small as 1/32 of a section. The sub-section divisions are indicated by a combinations of the letters

A,B,C,D, as follows:

A = NE corner

B = NW corner

C = SW corner

D = SE corner

Thus, if a hole was in the SE 1/4 section of the SW 1/4 section of section 16, then this parameter would read

16CD

and the position of the hole would be

If the township or range number is larger than 2 digits, then the @ symbol of the template indicates that a special symbol was used to indicate the value. Instead of a / to separate the township/range specification, an * is used. The full specification of the township/range-sec-sub is then given in the Comments Data Group.

---@---x----- template pattern
 4 6 columns 49 thru 62
 9 2

Ex. 2N/15E- 2AAC
 ---@---x-----

Ex. 12S*18E-14B * This hole is really
 ---@---x----- 12S/18.5E-14B

The * indicates to see note in Comment Group

ST

State/Country

<Integer Type>

This parameter is a numeric code for the state or foreign country where the hole is located. It follows the alphabetic order of

the states for the U.S. Some countries are also included. This code is given in Table 4.

P Physiographic Province <Integer Type>

The physiographic province is a tectonic division of a region and is given by a two digit code. For the North American Geothermal Map Project, the list of codes used is shown in Table 5.

LAT Latitude <Integer Floating Type>

The latitude is expressed in degrees and minutes North of the equator.

-->><< template pattern
6 7 columns 67 thru 72
7 2

Ex. 424324 is 42 degrees 43.24 mins
 -->><<

LONG Longitude <Integer Floating Type>

The longitude is expressed in degrees and minutes west of the Greenwich meridian.

--->><< template pattern
7 7 columns 73 thru 79
3 9

Ex. 1121230 is 112 degrees 12.30 mins
 --->><<

"Card" 2 - (I)NFORMATION/STATUS CODES

The Information/Status data group is allowed only one line (card) per site.

ELEV Collar Elevation <Floating Type>

Elevation of the surface location of the hole is given in meters above sea level.

>>>>< template pattern
1 6 columns 1 thru 6

Ex. 2100 is 2,100 meters elevation
 >>>><

DMAX Measured Depth <Floating Type>

Measured depth is the total depth of temperature measurement in meters.

}}}}{ template pattern
7 1 columns 7 thru 11
 1

Ex. 8005 Temperature was measured to depth of
 }}}}{ 800.5 meters

DWAT Water Table Depth <Floating Type>

Water table depth in the hole.

>>><@ template pattern
1 1 columns 12 thru 16
2 6

Ex. 100 * is approximately 100 meters
 >>><@ water table depth.

TSUR Surface Temperature <Floating Type>

Calculated or inferred (from least-squares fit of temp. vs depth) surface temperature of the hole.

Unit is Deg C.

}}}}{ template pattern
1 2 columns 17 thru 21
7 1

Ex. 2721 is 27.21 Deg C surface temperature
 }}}}{

TMAX Maximum Hole Temperature <Floating Type>

Maximum measured temperature in Deg C.

```
>>><<  template pattern
2      2  columns 22 thru 26
2      6
```

Ex. 1005 is 100.5 Deg C maximum temperature
>>><<

TMIN

Minimum Hole Temperature <Floating Type>

Minimum measured temperature in Deg C.

```
}}}{ template pattern
2      3  columns 27 thru 31
7      1
```

Ex. 72 is 7.20 Deg C minimum temperature
}}}{

JOBDATE

Drill Date <Integer Type>

Date drilling of hole was completed. It is
in the form MM/DD/YY.

```
==/==/==  template pattern
3          3  columns 17 thru 21
2          9
```

Ex. 1/ 4/78 is Jan 4th, 1978
==/==/==

BHT

Bottom Hole Temperature <Floating Type>

Temperature at bottom of hole in Deg C.

```
>>><<  template pattern
4      4  columns 40 thru 44
0      4
```

Ex. 3 5 is 30.05 Deg C bottom temperature
>>><<

PAGE

Province Age <Floating Type>

Estimated age of tectonic province in Ma.

```
}}}{ template pattern
4      4  columns 45 thru 49
5      9
```

Ex. 145 is 14.5 Ma province age
}}}{

BAGEBasement Age

<Floating Type>

Estimated age of basement rock in Ma.

```
>>>><  template pattern
5      5  columns 50 thru 54
0      4
```

Ex. 25 is 25 Ma basement age

>>>><

PUBPublished Reference

<Character Type>

Publication code if data have been published.

```
-----==  template pattern
6          7  columns 65 thru 72
5          2
```

The code is composed of 3 parts:

(1). Author

This code is the first four letters of the name of the first author. If author's name is less than four characters, then the remaining spaces are left blank.

(2). Year published

This code consists of the last two digits of the year published.

(3). Number of authors on paper

If there is only one author then column is blank, if nine or more authors 9 is used.

(4). Sub-Year code

If more than one paper was published with identical Author, Year code and number of authors, then letters starting with A are used to identify each paper.

Ex. BLAC78B refers to the second
 -----== paperpublishedin 1978
 by Blackwell.

"Card" 3 - (R)ESULTS CODES

The (R)esults Data Group is allowed a maximum of six "cards" per site.

RNG1 Depth Beginning <Floating Type>

Starting depth of the temperature interval in meters

>>>>< template pattern
1 5 columns 1 thru 5

1 is 10.0 meters start depth of
>>>>< temperature interval.

RNG2 Depth Ending <Floating Type>

Ending depth of the temperature interval in meters

}}}}{ template pattern
6 1 columns 6 thru 10
0

21 5 is 2100.5 meters end depth of
}}}}{ temperature interval.

TCU Average Thermal Conductivity <Floating Type>
SE Standard Error <Floating Type>

Laboratory or estimated in situ thermal conductivity measurement for the depth interval RNG1 to RNG. If an estimate is used, then the appropriate symbol is used in the place of the @ template symbol (i.e., <, >, or *). See Rules of the Template section above.

If a statistical mean is used, then the standard error (SE) of the mean is included.

The units (TCU) are milli-cal/cm-sec-deg C

>><@}{ template pattern
1 1 columns 11 thru 17
1 7

Ex. 35> is > 3.5 TCU (greater than 3.5)
>><@}{

Ex. 35 12 is 3.5 TCU

>><@}{ plus/minus 0.12 TCU s. e.

Ex. 35* is (3.5) TCU (estimate)

>><@}{

N

Number of Conductivities

<Floating Type>

This parameter is the number of measured values of conductivities used to derive the TCU value. If an estimate was made from surrounding area or from some other information, then no number is given, and the * symbol in the @ position of the template is used with the TCU value.

-- template pattern

11 columns 18 thru 19

89

Ex. 5 5 values were used to calculate TCU

--

UNGR
SE

Uncorrected Gradient
Standard Error

<Floating Type>

<Floating Type>

Calculated or estimated uncorrected thermal gradient measurement for the depth interval RNG1 to RNG2. The units are Deg C/Km.

Uncorrected refers to non-terrain corrected gradient.

If an estimate is used, then the appropriate symbol is used in the position of the @ template symbol (i.e., <, >, or *). See the Rules of the Template section.

If a statistical mean estimate is used, then the standard error (SE) of the mean is included.

>>><@}{ template pattern

2 2 columns 20 thru 27

0 7

Ex. 35 > is > 35.0 Deg C/Km
>>><@}{ (greater than 35.0)

Ex. 35 2 is 35.0 Deg C/Km
>>><@}{ plus/minus 2.0 Deg C/Km s. e.

Ex. 35 * is (35.0) Deg C/Km (estimate)
>>><@}{

COGR
SE

Corrected Gradient
Standard Error

<Floating Type>

<Floating Type>

Calculated or estimated corrected thermal gradient measurement for the depth interval RNG1 to RNG2. The units are Deg C/Km.

Corrected generally refers to terrain corrected gradient.

If an estimate is given, then the appropriate symbol is used above the @ template symbol (i.e., <, >, or *). See the Rules of the Template section.

If a statistical mean estimate is used, then the standard error (SE) of the mean is included.

```
>>><@}{ template pattern
2      3  columns 28 thru 35
8      5
```

Ex. 35 2 is 35.0 Deg C/Km
>>><@}{ plus/minus 2.0 Deg C/Km s. e.

The other codes are the same as for Uncorrected Gradient

UNHF
SE

<u>Uncorrected Heat Flow</u>	<Floating Type>
<u>Standard Error</u>	<Floating Type>

Calculated or estimated uncorrected heat flow value for the depth interval RNG1 to RNG2. The units are HFU (microcal/square cm-sec).

Uncorrected generally refers to non-terrain corrected heat flow.

If an estimate was used, then the appropriate symbol is used above the @ template symbol (i.e., <, >, or *). See the Rules of the Template section.

If a statistical value was calculated, then the standard error (SE) of the mean is included.

```
>><@}{ template pattern
3      4  columns 36 thru 43
6      3
```

Ex. 21 2 is 2.1 HFU
>><@}{ plus/minus .20 HFU s. e.

The other symbols are the same as used in the Uncorrected Gradient section.

COHF
SE

Corrected Heat Flow
Standard Error

<Floating Type>
<Floating Type>

Calculated or estimated corrected heat flow value for the depth interval RNG1 to RNG2. The units are HFU (microcal/square cm-sec).

Corrected generally refers to terrain corrected heat flow.

If an estimate was used, then the appropriate symbol is used above the @ template symbol (i.e., <, >, or *). See the Rules of the Template section.

If a statistical value was calculated, then the standard error (SE) of the mean is included.

```
>><@}{[ template pattern
4      5  columns 44 thru 51
4      1
```

Ex. 21 2 is 2.1 HFU
 >><@}{[plus/minus .20 HFU s. e.

The other symbols are the same as used in the Uncorrected gradient section.

Q

Quality of Heat Flow

<Integer Type>

This parameter is a single digit code that indicates the quality (or degree of confidence) of the gradient or heat flow value presented in the interval RNG1 to RNG2.

```
-- template pattern
55 columns 52 thru 53
23
```

Ex. 1 is high quality heat flow value
 --

HP
SE

Heat Production
Standard Error

<Floating Type>
<Floating Type>

Calculated value from K,U,Th elements for an interval or for a drill hole (if only first card has a value).

The units are 10^(power of -13) cal/cubic cm-sec (HGU).

```
>><@}{ template pattern
5      6  columns 54 thru 60
4      0
```

Ex. 21> is > 2.1 HGU
 >><@}{ (greater than 2.1)

Ex. 21 2 is 2.1 HGU
 >><@}{ plus/minus .20 HGU s. e.

Ex. 21* is (2.1) HGU (estimate)
 >><@}{

N

Number of Heat Production Samples <Integer Type>

This parameter is the number of measured values of heat production used to derive the HGU value.

If an estimate was made then no number is given, and the related * symbol is used in the @ template of the HP value.

```
-- template pattern
66 columns 61 thru 62
12
```

Ex. 5 indicates 5 values were used to
 -- calculate HPU.

AQU
SD

Aquifer Temperature <Floating Type>
Standard Deviation <Floating Type>

Measured, calculated or inferred from temperature logging. Assumes that the interval RNG1 to RNG2 is part of the aquifer when a number is given. This is a special code set only used for the Snake River Plain aquifer in Idaho.

```
>><@}{ template pattern
6      7  columns 63 thru 70
3      0
```

Ex. 451 2 is 45.1 Deg C
 >><@}{ plus/minus .20 Deg C st. dev.

0

Porosity <Floating Type>

Calculated or inferred conductivity porosity of samples from the interval RNG1 to RNG2. Used to calculate in situ TCU from cuttings measurements.

Unit is percentage of 100

>><< template pattern
7 7 columns 71 thru 74
1 4

Ex. 272 is 27.2 % porosity
 >><<

"Card" Type 4 - (G)EOLOGY CODE

The (G)eology data group is allowed a maximum of six "cards" per hole set.

FREE-FORMAT

Lithology Information

<Character Type>

This group is used to indicate the lithologic information known in or around the hole.

The first part of the pattern is grouped into two 12 space blocks used in a special printing routine as indicated below:

-----	=====		template pattern
1	11	2	columns 1 to 24
	23	4	

Ex. Quartz Monzonite is printed
----- as:

Quartz
Monzonite

"Card" Type 5 - (C)OMMENTS CODE

The (C)omments data group is allowed a maximum of six "cards" per hole set.

FREE-FORMAT

Comments/Information

<Character Type>

This parameter is used to indicate general information about the hole, about the corrections that were applied or need to be applied to the thermal values. There is a maximum of six lines of 79 characters in free format that can be used.

Table 1 Key to "card image" pattern

```

-----LOCATION-----
=====XXXXXXXXXX==/==/=---@---X-----><---->\<
AMS MAP              HOLE    (BLANKS) DATE   ( TS-RN-SEC )ST P LAT      LONG
                        INFORMATION-STATUS

>>>><|||||{>>><@}|||{|>>><|}|{|={}/=/{=>>><|}|{|}>>><XXXXXXXXXX-----XXXXXXX
ELEV DMAX DWAT TSUR TMAX Tmin JOBDATE BHT PAGE BAGE (BLANK) PUB
                        RESULTS

>>>><|||||{>>><@}{|-->>><@}|>>><@}|>>><@}|{|>>><@}{|-->>><@}|{|>>><@}|{|>>><XXXXXX
RNG1 RNG2 TCU SE N UGR SE COGR SE UNHF SE COHF SE Q HP SE  N AQU SD 0
                        GEOLOGY

-----COMMENTS-----
=====
FREE - FORMAT
```

Table 2 Example data set

OKANOGAN AMS, WASH	DDH-K-5	7/17/7140N/27E-	6BDC	484448597411929191
4634 18 3 < 1 75 1531 1152 1/	/71 1531	BLAC74		
6 18 755 2 19 252 1 223	19 1 168 1			
GREENSTONE SCHIST				
0-180 M PALMER MOUNTAIN GREENSTONE (PERMIAN TO TRIASSIC)				
OROVILLE 15'				
OKANOGAN AMS, WASH	DDH-702	7/15/7140N/33E-	2ACD	486548597111835911
11476 2 5 3 < 63 1 82 67 1/	/71 1 82	BLAC74		
75 2 5 757 3 22 252 6 227	191 11 171 1			
MESOZOIC GREENSTONE				
0-205 M MESOZOIC GREENSTONE				
CURLEW 15'				

Table 3. Data base symbol key

Symbol	Meaning
>	Greater than
<	Less than
* = ()	Estimate
!	Unexpected value
?	Questionable value
\$ = (-)	The SE value is treated as part of a range estimate.

Ex. 35 \$45
 >>><@}}{ (25.0 - 45.0)

Table 4. State codes

01 = Alabama	21 = Maryland	41 = South Carolina
02 = Alaska	22 = Massachusetts	42 = South Dakota
03 = Arizona	23 = Michigan	43 = Tennessee
04 = Arkansas	24 = Minnesota	44 = Texas
05 = California	25 = Mississippi	45 = Utah
06 = Colorado	26 = Missouri	46 = Vermont
07 = Connecticut	27 = Montana	47 = Virginia
08 = Delaware	28 = Nebraska	48 = Washington
09 = District of Columbia	29 = Nevada	49 = West Virginia
10 = Florida	30 = New Hampshire	50 = Wisconsin
11 = Georgia	31 = New Jersey	51 = Wyoming
12 = Hawaii	32 = New Mexico	52 = Canada
13 = Idaho	33 = New York	53 = Costa Rica
14 = Illinois	34 = North Carolina	54 = Egypt
15 = Indiana	35 = North Dakota	55 = Mexico
16 = Iowa	36 = Ohio	56 = Panama
17 = Kansas	37 = Oklahoma	57 = Colombia
18 = Kentucky	38 = Oregon	
19 = Louisiana	39 = Pennsylvania	
20 = Maine	40 = Rhode Island	

Table 5. Province codes

01 = ATLANTIC COASTAL PLAINS	39 = SALINIA-W. OF SAN ANDREAS
02 = GULF COASTAL PLAIN	40 = SOUTH CASCADE RNG - WEST WASH
03 = FLORIDA PENN	41 = WESTERN CASCADE RNG - ORE/CAL
05 = SUPERIOR UPLAND	42 = HIGH CASCADE RANGE - ORE/CAL
06 = INTERIOR LOWLANDS	43 = SOUTH CASCADE - EAST WASH
08 = GREAT PLAINS	44 = NORTH CASCADE RANGE - WASH
10 = APPALACHIAN HIGHLANDS	45 = WESTERN-HIGH CAS RNG - ORE/CAL
11 = PIEDMONT PROVINCE	50 = COLUMBIA BASIN
12 = BLUE RIDGE	51 = YAKIMA FOLDS
13 = VALLEY AND RIDGE	52 = PASCO BASIN
14 = APPALACHIAN PLATEAUS	53 = UMATILLA BASIN
15 = NEW ENGLAND PROVINCE	54 = DESCHUTES-UMATILLA PLATEAU
16 = ADIRONDACK PROVINC	55 = OWYHEE UPLANDS
20 = COLORADO PLATEAU	56 = WESTERN SNAKE RIVER PLAINS
21 = MIDDLE ROCKY MTNS.	57 = EASTERN SNAKE RIVER PLAINS
22 = WYOMING BASIN	58 = CAMAS P. - MT. BENNETT HILLS
23 = SOUTHERN ROCKY MTNS.	59 = YELLOWSTONE/ISLAND PARK
25 = BASIN AND RANGE	62 = CHALLIS SUBDIVISION
26 = HIGH LAVA PLAINS	63 = CENTRAL IDAHO BASIN AND RANGE
30 = COAST RANGE-WILLAPA HILLS	64 = NORTHERN IDAHO BATHOLITH
31 = WILLAMETTE VALLEY-PUGET LOWLANDS	65 = NORTHERN ROCKY MTNS.
32 = KLAMATH MTNS.	66 = SOUTHERN IDAHO BATHOLIT
34 = OLYMPIC MTNS.	67 = WALLOWA-SEVEN DEVILS
36 = SIERRA NEVADA MTNS.	68 = BLUE MOUNTAINS
37 = GREAT VALLEY/CALIFORNIA	
38 = FRANCISCAN-EAST OF SAN ANDREAS	90 = BAJA CALIFORNIA

Table 6. The Table of Heat Flow Quality Codes.

Publish Code	Data Code	Error +%	Description
A	01	5	High Quality Data: Deeper than 100 m, at least a 50 m linear gradient
B	02	10	Medium Quality Data: Deeper than 50 m Some problems
C	03	25	Poor Quality Data: Shallow; Isothermal
G	04		Geothermal System
D	05		Gradient may be useful
X	06		No Hope-large scale aquifer

Table 7. Conversion of Units

CGS units	SI units
1 HFU = micro-cal/square cm-sec	= 41.84 milli-Watts/square meter
1 TCU = milli-cal/cm-sec-deg C	= 0.4184 Watts/meter Kelvin
1 HGU = 10 ^(power of -13) cal/cubic cm-sec	= 0.4184 microWatts/cubic meter

APPENDIX B**GSA-DNAG United States Geothermal Map Bibliography**

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