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INTERPRETATION OF GEOTHERMAL GRADIENT AND HEAT FLOW DATA FOR BASIN AND RANGE GEOTHERMAL SYSTEMS

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Abstract

Simple conceptual models have been developed to explain the nature of many geothermal systems in the Basin and Range physiographic province. Models are characterized by range bounding normal faults which separate high thermal conductivity bedrock from low thermal conductivity valley fill, and along which geothermal fluids may circulate. Modeling results suggest that information on the temperature of the fluid, dip of the fault, and vertical extent of the fluid circulation is contained in the heat flow anomaly pattern. Such information is valuable for exploration decisions. The models will be illustrated for geothermal anomalies at Vale Hot Springs KGRA, Oregon, and Roosevelt Hot Springs KGRA, Utah.

Most hot springs in the Basin and Range physiographic province are located on or near the major range bounding normal faults that block out the mountains and valleys. These faults usually juxtipose widely contrasting rock units such as unconsolidated and semi-consolidated silt, clay and sand or volcanic rocks against Paleozoic and/or Mesozoic sedimentary rocks or Mesozoic and Cenozoic volcanic and intrusive rocks. In such a setting electrical resistivity data are difficult to interpret with respect to their geothermal significance due to the widely contrasting intrinsic electrical resistivity of the different units. Geothermal gradient and heat flow surveys can be used to great advantage in such situations and, combined with other geophysical data, can furnish the information needed for exploration decisions.

Simple conceptual models applicable to Basin and Range settings are shown in Figure 1. These models are amenable to numerical solution using heat conduction theory in two dimensions. In each model the subsurface is divided into two regions: bedrock having higher thermal conductivity is separated from lower thermal conductivity valley fill by a normal fault of arbitrary dip and displacement. A typical Basin and Range heat flow of 2.0 μcal/cm^2 s (HFU) is assumed so that the thermal gradient in the bedrock is 29 ^{o}C/km and that in the valley fill alluvium is 57 ^{o}C/km.

Model 1 describes a non geothermal area where the isotherms from the valley and range connect

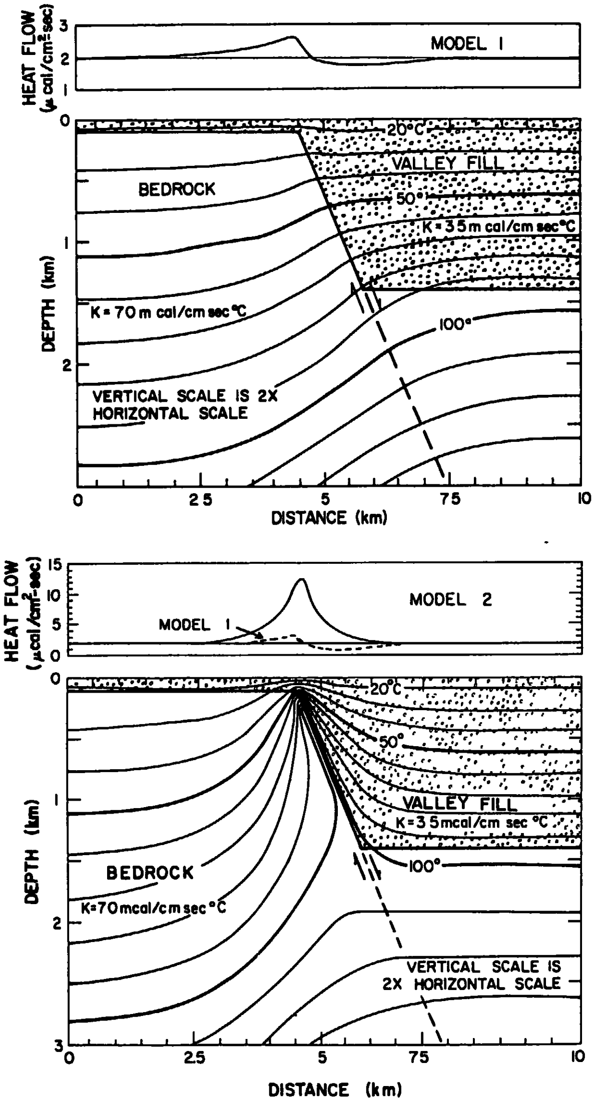

Figure 1. Thermal models for a Basin and Range setting. Model 1: Configuration of isotherms and heat flow pattern across a range bounding fault using typical Basin and Range background heat flow. Model 2: Thermal spring is modeled by hot water circulation along the range bounding fault. A distinctive isotherm and heat flow pattern is seen.

smoothly across the fault zone. The warping of the isotherms results from refraction of heat caused by the thermal conductivity contrast. A small heat flow anomaly results from this refraction (see Figure 1). Model 2 describes a similar Basin and Range setting but with the addition of a thermal spring. Water heated by the natural geothermal gradient to about 100°C at 1.5 km depth moves up along a range bounding fault to a depth of 100 to 200 m. We model the thermal source as a sheet of fluid circulation up along the fault. The heat flow anomaly associated with this thermal spring can be substantial as is shown in Figure 1.

Heat flow surveys in the Basin and Range Province demonstrate that many hot springs are associated with this latter type of anomaly. An anomaly may be several kilometers long even though only one or two hot springs are observed. Thus the area of fluid upflow is much more extensive than indicated by the surface manifestations. In contrast some areas have no upflow except along a small area around the spring and a pipe model may be applicable to such systems. Finally some systems are more complicated than the simple model illustrated.

Obviously it is of great interest in geothermal exploration to identify the nature of the system associated with a surface hot spring or a concealed geothermal resource. The heat flow data (heat flow must be used here due to the contrasting thermal conductivities of the rocks) contain information on the nature (sheet, pipe, other) and extent of the circulation system. If detailed data are available on a cross section across the anomaly information on the temperature of the fluid, dip of the fault, and vertical extent of fluid circulation is contained in the anomaly pattern in the same way that density contrast and fault geometry are contained in a gravity anomaly. All these parameters cannot be independently determined, but if other information is available, such as fault geometry from resistivity or gravity surveys, temperature from geochemistry, etc., then detailed interpretations are possible. Even lacking these other data a series of self consistent models for the circulation system can be developed for testing by additional exploration or deep drilling.

The application of the interpretive techniques are illustrated by theoreticical and actual examples. Heat flow anomalies from Vale Hot Springs KGRA, Oregon, and Roosevelt Hot Springs KGRA, Utah are examples of the kinds of anomalies discussed. At the Vale KGRA the anomaly is caused by circulation along a steeply dipping normal fault. The length of the anomaly is about 10 km although the only surface manifestation is at the Vale Hot Springs. At Roosevelt KGRA the anomaly is consistent with one control on the system being a basin dipping normal fault. However the width of the anomaly is greater on the range side of the surface fault trace than is predicted by the single fault model, indicating that the system is more complex and larger than a single fault zone. Deep exploration drilling has verified that the reservoir is in fact inside the range block in fractured Miocene granite.