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IMPLICATIONS OF FACIES MODELS ON GEOTHERMAL SYSTEMS IN THE BASIN AND RANGE PROVINCE

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INTRODUCTION

The nature of geothermal systems in the Basin and Range has been the subject of much discussion. The question is a important one as there is significant development of geothermal energy in the Basin and Range province and the question arises as to the possibility of additional resources being developed. In 1993 there was over 190 MW of installed capacity in Nevada (Garside and Hess, 1994) and 40 Mw (gross) of capacity is developed in Utah (Blackett and Ross, 1994). In addition, the thermal nature of the Basin and Range is intimately related to the hydrocarbon and mineral potential as was documented in GRC Special Paper 13. The object of this paper is to briefly investigate the present information on some of the thermal characteristics of the "typical" Basin and Range geothermal system in the northern part of the province. As part of this discussion some recent advances in the understanding of the sedimentary facies relationships in active rift basins will be compared to the results of drilling in Basin and Range geothermal systems.

THERMAL SETTING

The background thermal setting of the Basin and Range province has been discussed by Lachenbruch and Sass (1978) and by Blackwell (1983). Little regional thermal data have been collected since the early 1980's, so the regional setting is still as described in those papers. The major thermal systems in the northern Basin and Range province were briefly compared by Benoit and Butler (1983). At that time there was little deep drilling in the systems described. Although most of the electrical power production has been developed since that paper and deep wells have been drilled in most of the systems, the results have not been much discussed nor the original views modified.

A general thermal model of a Basin and Range geothermal system was given by Blackwell and Chapman (1977). The circulation was envisioned to be dominated by a master range bounding fault and the heat transfer to be dominated by conduction away from the fault in both the range and basin blocks. This model is a cartoon that does not address the question of where the heat in the system is derived. The source of the heat is not generally considered to be upper crustal magmatic in origin since there is little silicic Quaternary or Holocene volcanism in the Great Basin. While there may be significant magmatic crustal underplating of basalt (Jarchow et al., 1993), it is so remote from the circulation of fluid in the brittle upper crust that such intrusion must appear as only regional changes in the background heat flow (Lachenbruch and Sass, 1978). Thus in general the heat is thought to be derived from deep circulation in fractures and stratigraphically controlled aquifers. This model is presented in Figure 1 in a general form with no specific area in mind for comparison.

Becker and Blackwell (1993) investigated the heat transfer in the case of the Roosevelt geothermal system (where the heat is magmatically related, in contrast to the statement in the previous paragraph). In developing a flow model of the system, they concluded that cross range flow was unlikely to be a significant factor in the heat transfer because the resulting thermal pattern would not be anything like the actual pattern seen at the Roosevelt system. However, in other systems longer range flow seems to be required. For example the Desert Peak geothermal system (Benoit et al., 1982) must either have topographically driven cross range flow or thermally driven flow from one of the adjacent basins (Yeamans, 1983). In the case of the Socorro geothermal system, Barroll and Reiter (1990) reached a similar conclusion.

Models have also been proposed that source the high temperature fluid flow in the fault zone itself. Welch et al. (1981) investigated the energetics of this class of models. They concluded that such systems, if they exist, cannot transfer as much energy as is usually seen in the larger Basin and Range systems.

Thus in fact we may view geothermal systems as natural experiments that illuminate the large scale geographic distribution of the permeability of the crust in the Basin and Range. The shallow and deep drilling in these areas and in areas of lower heat flow around the hot areas can be used to put constraints on the fluid flow patterns.

RIFT VALLEY FACIES MODELS

A typical sedimentary facies model that has been developed for rift basins is shown in Figure 2. In this model there is general development of a coarse alluvial facies along the hanging wall of the range bounding faults. The evidence for this alluvial facies is based on geologic observational and geophysical reasoning. First, alluvial fans are a prominent part of the topography in the Basin and Range province. Second, the seismic data typically do not image the range bounding faults very clearly and coarse diffracting layers have been envoked to explain lack of resolution of the seismic data (Okaya and Thompson, 1985).

Gravel is one of the most porous and permeable geologic materials so the presence of a gravel zone near the range bounding fault could have a dominating effect on the circulation of both cold and hot fluid. In fact this is just what has been postulated. For example Steckler et al. (1993) argued that fission-track ages on apatites from the area around the bounding fault of the Triassic Newark basin have an age pattern that can be explained by extensive circulation of cold fluid in the arkosic wedge in the foot wall of the normal fault. They infer that the isotherms were depressed 2 km or more along a 2 to 4 km wide zone along the fault compared to the interior of the basin (Figure 3).

Similarly, Person and Graven (1994) discussed fluid flow modeling of hypothetical rift basins. They developed models that involve extensive fluid movement in a laterally continuous alluvial fan facies. They even envision cases of free, thermally driven, convection confined to the alluvial facies in the late stages of rift development. During the active rifting phase they infer that topographically driven groundwater flow develops ubiquitously in the range bordering alluvial facies. They infer that the isotherms are deeply depressed along the valley margin in the hanging wall of the fault. Barroll and Reiter (1990) presented thermal evidence for moderate temperature cross-basin fluid flow in one of the Rio Grande rift basins. Such regional thermal data are rare, however.

The drilling experience in the Basin and Range represents some problems if the model envisaged by Steckler et al. (1993) and Person and Garven (1994) is applied to this area. The geothermal systems in northern Nevada are either associated with the fault zone or are in fracture permeability within the range (bedrock) block. Extremely low heat flow values are not common in the valley fill (see Sass et al., 1979) and the heat flow above the fault zone geothermal systems is usually conductive. How can this conflict between the observations and model predictions be resolved?

Recently Leeder and Gawthorpe (1987) presented a new model for the sedimentary facies associated with rift valley formation when the drainage is internal. They postulate that in a situation in which active faulting is forming the basin and subsidence is rapid, the shape of the basin is such that the deepest part is adjacent to the fault scarp. In this case the subsidence is faster than clastic deposition and the lacustrine basin is located against the fault scarp. In this model the lithology in the hanging wall block close to the foot wall during active faulting would be composed in significant part of fine-grained clastics. When faulting slows down, coarse-grained erosive products in the hanging wall block prograde into the basin and alluvial deposition becomes more dominant adjacent to the footwall with the lacustrine facies pushed toward the center of the valley. Hence large, extensive, clastic wedges may be more likely to form in times of tectonically quiescence rather than times of active faulting. Similarly the presence of lacustrine facies rocks at or near the fault may indicate times of most active faulting. Gordon and Heller (1993) have presented field evidence for this model of rift valley sedimentation from Pine Valley, in central Nevada. They argue that the times of gravel progradation may in fact represent times of reduced tectonism rather than the intuitive conclusion that they represent times of most active faulting.

SIGNIFICANCE TO GEOTHERMAL EXPLORATION

This sedimentological model is significant to the understanding of, and exploration for, Basin and Range geothermal systems. For high temperature systems to exist, water must be heated to temperatures equivalent to those at depths of 8 to 10 km. For the hot water to return to drillable depths, the valley sediments overlying the fault may have to be low in permeability so that the hot fluid is not diluted. In Dixie Valley the basin fill does not participate in a significant way in the fluid flow in the geothermal system (Benoit, 1992), in spite of the arguments from the seismic data that a clastic wedge exists (Okaya and Thompson, 1985). The only significant geothermal flow encountered in the valley is in basalts. The apparent impermeability of the valley fill relative to the fault zone is not consistent with the models of Steckler et al. (1993) and Person and Garven (1994) that assume a continuous formation of an extensive, high permeability, clastic wedge.

Clearly the development of facies and of flow systems in the basins is complex and probably strongly time dependant. During times when major geothermal systems form, in the case of northern Basin and Range at least, the valley fill may act more as an aquitard than an aquifer. Because the heat transfer appears to be dominated by conduction in many cases, shallow geothermal gradient/heat flow drilling has proved (perhaps surprisingly based on the theoretical models proposed) to be a successful way to explore for Basin and Range geothermal systems.

This does not mean that there is no fluid movement within valley sediments, only that it does not disturb the fracture or fault-controlled thermal regime in a major way. The primary exception to this situation is in the case of the shallow groundwater aquifer. In many cases the upflow from the geothermal system is discharged into the watertable aquifer, and large and sometimes confusing shallow thermal anomalies result (Benoit et al., 1982; Blackwell, 1985; Benoit and Stock, 1993). This situation causes results from most geophysical measurements to be difficult to interpret and even in this case drilling below the shallow aquifer has proved the most practical way to develop a picture of deeper thermal conditions related to the geothermal system. The difficulty in interpreting the seismic data may be related to either the inherent difficulty of imaging a steeply dipping irregular fault surface or to diffraction of energy by boulders dispersed in a fine-grained matrix supported lithology.

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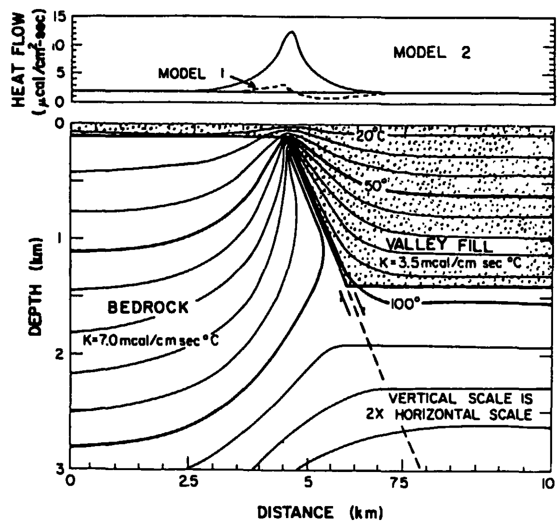

Figure 1. Schematic thermal model for a Basin and Range geothermal system (Blackwell and Chapman, 1977). Isotherm depths away from range bounding fault are constructed for a typical Basin and Range background heat flow.

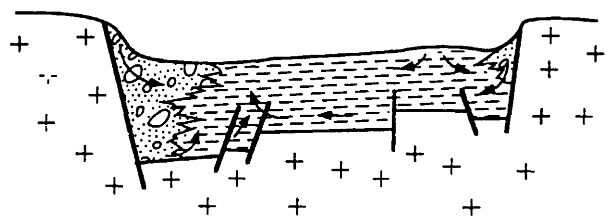

Figure 2. Schematic model of fluid flow in an active rift basin (Person and Garven, 1994).

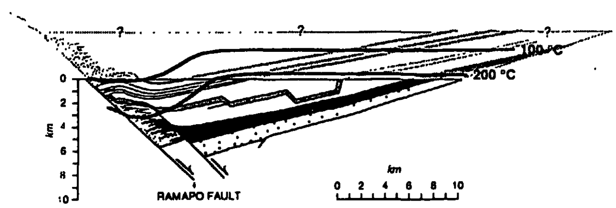

Figure 3. Schematic cross section of Newark basin. Solid lower half shows the present day cross section. Upper half is reconstructed, from Steckler et al. (1993).