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Comparison and Discussion of the 6 Km Temperature Maps of the Western US Prepared by the SMU Geothermal Lab and the USGS

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ABSTRACT

Interpretations of temperature-at-6 km depth maps for the western US are compared and three areas of difference are discussed in detail. These three areas are critical for EGS resource evaluation yet they are quite different between the two maps. The data in these three areas (the northern Oregon Cascade Range, the Snake River Plain, and the northern Great Basin) bearing on the interpretations are discussed. There is a large body of published information that documents high temperatures at depth in the Oregon Cascade Range and in the Snake River Plain. For the northern Basin and Range, and in general, the data distribution is discussed and it is clear that there are large areas with probable hydrothermal and EGS potential with no subsurface thermal information. Therefore both resource maps are preliminary in at least this critical area, while in the other two areas the thermal regimes as depicted on the SMU map are well established and documented.

Introduction

As part of the DOE sponsored Future of Geothermal Energy report, (Tester et al., 2006) temperature at depth maps were prepared for the conterminous US by the Southern Methodist University (SMU) Geothermal Laboratory (western US section shown in Figure 1a) The maps are published separately in Blackwell et al. (2007) and are reproduced on the web at www.google.org/egs. As part of the DOE sponsored USGS geothermal resource evaluation project, a 6 km temperature map of the western US was prepared by Williams (2010). While the resource numbers are similar, predicted temperatures in the two maps are significantly different in several areas that are relevant to understanding the location of important enhanced geothermal systems (EGS) resource targets and the characteristics of the thermal regime at depth. Three of these areas of difference, the northern Oregon Cascade Range, the Snake River Plain, and the northern Great Basin are discussed in this paper. Figure 1b is a subset of Figure 1a comparing the parts of both maps discussed.

General Similarities and Differences

The two maps of heat flow and temperature at 6 km (Williams, 2010) and Blackwell et al. (2007) have similar overall patterns and
appear to have used similar data sets. The heat flow data used by Blackwell and Richards (2004a, 2004b) to generate the Tester et al. (2006) and Blackwell et al. (2007) maps are available on the web at www.smu.edu/geothermal. In addition some bottom-hole temperature (BHT) data were converted to heat flow and used to help contour the northeastern Nevada Basin and Range and for areas in the US east of the Rocky Mountains. These data are probably not represented on the Williams (2010) map.

However, the calculated temperatures are significantly different at several places between the two analyses (see Figure 2). Two of the largest, hottest areas on the Blackwell et al. (2007) maps and emphasized as major potential geothermal resource areas in Tester et al. (2006) are the northern Oregon Cascade Range and the Snake River Plain. Neither area is particularly hot on the USGS map. In contrast an extensive, continuous area of very high temperature is shown on the USGS map in northeast Nevada and northwest Utah that has a variable temperature pattern on the Blackwell et al. (2007) 6 km temperature map (see Figure 2). Thermal data within these two areas will be discussed in an attempt to understand the reasons for these differences.

Temperature-Depth Curve Characteristics in Volcanic Terrains

Fundamental understanding of temperature data in volcanic terrains is vital to the interpretation of the deeper thermal regimes. Areas of young volcanics generally have high near surface permeabilities and consequently copious ground water flow. Drilling in such terrains has proved that when the volcanic rocks have been altered when subjected to temperatures in the range of 60 to 100 °C the permeability is generally drastically reduced and thermally conductive behavior dominates, except in fracture zones (Blackwell et al., 1982). This upper zone of high permeability with low gradients is sometimes referred to as the “rain curtain” effect (Swanberg et al., 1988). The transition to thermally conductive behavior is often associated with a decrease in electrical resistivity due to the presence of clays and zeolites in the altered volcanics. Examples of such temperature-depth curve types seen in these situations are shown in Figure 2. Alteration conditions were utilized to successfully locate thermal gradient wells and estimate required drill depths to reach conductive behavior in the Oregon Cascades projects carried out by the Oregon Department of Geology and Mineral Industries.

Northern Oregon Cascade Range

The Cascade Range of northern California, Oregon, and Washington should be the preeminent area in the conterminous US for hydrothermal geothermal development based on comparative geology to global geothermal systems. However, most of the attractive areas for conventional geothermal development are on National Forest land and many are in Wilderness set asides. At present the only area accessible for conventional and EGS geothermal development is the Newberry volcano in central Oregon (Osborn et al., 2010). According to Blackwell et al. (2007) the area directly west of the northern Oregon High Cascades in the Western Cascade Province is one of the hottest large areas in the US with projected temperatures of over 250 °C at 6 km over an area at least 200 km North to south by 50 km east to west. At least part of this region includes less restricted access areas than around the volcanic systems themselves. Thus this area is one of the premier EGS resource areas in the US (Tester et al., 2006). In contrast, according to the USGS (Williams, 2010) the same area has temperatures of ~200 °C at 6 km with higher temperatures to the north and east in less accessible areas.

The documentation for the Blackwell et al. (2007) interpretation is published in several journal reviewed papers (Blackwell et al., 1982, 1990b; Blackwell and Priest, 1996a, 1996b). A cross section for the Northern Oregon Cascade Range valid from about latitude 43.5° to 45° N from Blackwell et al. (1982) is shown as Figure 3. Somewhat similar results are also found in

![Figure 2](image)

**Figure 2.** Deep wells at the edge of the High Cascades/Western Cascades boundary (modified from Blackwell et al., 1990a, Figure 4).

![Figure 3](image)

**Figure 3.** Heat flow geothermal gradient, and temperature along the High/Western Cascades boundary (modified from Blackwell et al., 1982, Figure 8).
the Washington Cascades, although with more variability and somewhat lower temperatures (Blackwell et al., 1990a). Along the east side of the northern Oregon Cascade there is an extensive basaltic lava flow terrain (Deschutes) similar to the Eastern Snake River Plain where the shallow water wells available give essentially zero heat flow because they do not penetrate to the conductive region at depth (see previous section). Ingebritsen et al. (1992, 1993) proposed that the shallow temperatures in the High Cascades are a fundamental effect and not a shallow effect and that the background heat flow values in the Western Cascade Range are typical of the outer arc to the west (~50 mWm⁻²) based on no additional significant information (their conclusion is critiqued by Blackwell and Priest, 1996a; 1996b). Nonetheless they concurred on a regional heat flow of about 100 mWm⁻² for the High Cascade Range and much of the Western Cascade Range.

The deepest well in the area is the Breitenbush Federal 58-28 well at almost 2500 m with a nonequilibrium bottom-hole temperature of 142 °C (see Figure 4). The projected temperature at 3 km is approximately 200 °C. This well was drilled through a shallow hydrothermal system that is related to the nearby hot springs before approaching the background geothermal gradient at depth measured in all of the surrounding regional holes (indicated by the dot-dash line). That gradient (60 °C/km) is similar to or slightly less than the thermal gradients in intermediate depth wells in the Western Cascades and the edge of the High Cascades also illustrated in Figure 4.

A geophysical corroboration of these results and projections is that the Curie point depths in the High and Western Cascades are at 5 to 7 km as compared to greater than 10 km depths west of the thermal anomaly (Foote, 1985). Gravity data also outline the shape of a low density region associated with the thermal anomaly. Thus it seems quite strongly indicated that, allowing for variations in thermal conductivity with depth, temperatures of greater than 200 °C can be expected at depths of ~4 to 5 km over a very large region.

**Eastern Snake River Plain, Idaho**

The thermal regime in the Snake River Plains has been extensively studied and discussed in the literature (e.g. Brott et al., 1976, 1978, 1981; Blackwell, 1988). The shallow thermal pattern (above 150 to 500 m) is complicated and variable, but reasonably well understood. The deeper thermal regime is controlled by the time translation of the Yellowstone hot spot to the east and the track of geological and thermal features in its wake (Brott et al., 1976). Heat flow is high in the eastern Snake River Plain below the shallow Snake River Plain aquifer (105±5 mWm⁻²) and grades into typical Basin and Range values (75±5 mWm⁻²) in the western Snake River Plain (see Blackwell, 1988). In the Snake River Plain aquifer (occupying the eastern half of the Snake River Plains) the temperature is generally near the mean annual temperature because of the rapid fluid flow in the aquifer. There are subregional, low-temperature geothermal systems along most of the margin of the Snake River Plains. Prominent ones are the Bruneau-Grandview thermal aquifer along the southwest margin, the thermal aquifer used to heat parts of Boise, Idaho and the warm artesian aquifers near Twin Falls, Idaho.

Example temperature depth curves for regions of the Snake River Plains are shown in Figure 4 (modified from Blackwell, 1988, Figure 10). The INEL-GT1 well is in the eastern Snake River Plain and has only a very thin section in the aquifer. The thermal gradient from 1 to 3 km averages 35 °C/km and the BHT is 135 °C. Thus temperatures will reach 200 °C at 5 to 6 km. The well was drilled into the upper part of a large granite pluton. The Anderson Camp (ANDCAPWW), Mountain Home Air Force Base, and Bostic 1A wells are in the central portion of the Snake River Plains and have higher gradients but lower heat flow values (because of lower thermal conductivity since the wells are in volcanic rocks) and could have temperatures as high as 200 °C at 3 km. The Ore-Ida 1 well, at the west end of the Snake River Plain, has a relatively modest heat flow, but the gradient is relatively high because of the low thermal conductivity of the western Snake River Plain Basin sediments. So even though the gradient will decrease with depth, temperatures in the area of the Ore-Ida well are projected to be over 200 °C by a depth of about 4 km.

The only deep thermal regime in Idaho south of the Snake River Plains is tested by one well, the Anschartz Federal 60-13 well. The well is located south of the western Snake River Plains immediately north of the northern margin of the Great Basin. In this well the moderate temperature Bruneau/Grandview aquifer dominates the first 1 km of the temperature log (see Figure 4). However, the temperatures at 3 km are slightly less than in the eastern Snake River Plains (INEL-1) and the heat flow is lower, so the projected temperatures will be still lower at greater depths. The Bruneau/Grandview aquifer was extensively prospected in the 1970’s because of the high shallow heat flow values, but the temperatures were ultimately found to be less than 100 °C.

In contrast to the measured temperatures of 150 to 200 °C at about 3 km described above, Williams (2010) shows an area of less than 175 °C at 6 km in the eastern and central Snake River Plains. Further, the Williams (2010) map has a very large area of temperature greater than 250 °C at 6 km south of the Snake River Plains in much of the northeastern Great Basin. As a result, on the margins of the Snake River Plains there are high heat flow values due to the relatively shallow-flowing, moderate temperature aquifers and apparently not due to deep thermal anomalies. South
of the Snake River Plains in the northern part of the Great Basin, shown uniformly hot by Williams (2010) there are very little published data and the published values are not of high quality and generally are in shallow holes. Blackwell et al. (2007) supplemented the published data there with BHT data in northeastern Nevada because very limited thermal gradient data exist for this region. The pattern interpreted there is similar to the remainder of the Basin and Range and is quite variable with both high and low temperatures at 6 km.

Effect of Data Density

In spite of the better knowledge of the thermal regime in the western US compared to the eastern US, in terms of number of data points, there are still many data gaps. A map of the density of heat flow/thermal gradient data in the western US is shown in Figure 5. The areas of the temperature map in Figure 1 are black in this figure in areas where there are no data points over a 120 km² area (an area about 40 km in diameter). These data gaps can lead to some of differences between the SMU and USGS maps as contouring is some what subjective. In areas such as the Cascade Range and the Snake River Plains sparse data can be used to interpolate temperature regimes between data points in similar thermal settings with some confidence.

The data density is not impressive when the size of commercial hydrothermal systems in the Basin and Range is considered. Since geothermal development sites are generally only a few square km in size, and about half the area has no data at all, there must be large undiscovered geothermal resources as predicted by the recent assessment of undiscovered resources (Williams, 2010).

The two maps differ significantly in the northern Great Basin. The USGS map has an continuous area of over 5,000 km² with temperature over 250°C at 6 km. However, such a large area of consistently high heat flow and temperature does not seem reasonable. The limited data from in this area deep oil wells and geothermal tests show variable temperatures. The high heat flow area in northeast Utah has essentially no data and heat flow contours in this area are controlled by the southern margin of the Snake River Plain and some very low quality data in the southern part of the hot area. Some other important areas have essentially no information. Consequently, even though the two maps differ in these two areas, there is in fact no right answer, as there is for the Cascade Range and the Snake River Plain. Data are especially needed from the Northern Great Basin as the implications of the two maps have major resource location and size differences.

Acknowledgements

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