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Targeting of Potential Geothermal Resources in the Great Basin from Regional Relationships Between Geodetic Strain and Geological Structures

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ABSTRACT

We report on an initial assessment of a new method to target potential geothermal resources on the regional scale. The method is based on seeking relationships between geologic structures and geodetic observations of regional tectonic strain. The working hypothesis is that geothermal plumbing systems might in some regions be controlled by fault planes acting as conduits that are continuously being stressed apart by tectonic activity. Specifically, this type of model would predict that geothermal activity would be spatially correlated with areas of high interseismic strain accumulation, especially when faults are favorably oriented with respect to the strain-rate tensor field. We tested these predictions in the Great Basin using tectonic velocity gradients derived from a network of Global Positioning System (GPS) sites, producing a regional strain-rate map with precision approaching a few parts per billion per year in some regions. Our initial conclusions are that regions of high interseismic strain accumulation correlate significantly with high geothermal well temperatures and the locations of geothermal power-producing sites. The next step is to test the prediction that fault orientation is also important, and that this information can be used to enhance the predictive capability of regional geodetic strain to target potential geothermal resources.

Background

A major key to targeting regions with potential geothermal resources is to understand the role of faults in controlling fluid flow in the crust. There is evidence that critically stressed fractures and faults can play an important role in geothermal fields (Barton, *et. al.*, 1995; Hickman, *et. al.*, 1997). We hypothesize that the continuous regional accumulation of tectonic strain acts to open faults and develop fractures as conduits for fluid flow, hence acting to sustain geothermal systems. This model would predict an enhancement of this effect if the regional tendency of fault strikes is favorably oriented in the ambient strain field. In particular, maximum effect would be predicted for fault strikes oriented perpendicular to the direction of maximum extensional strain. In reality many other factors, such as rock type, are important in controlling fluid flow. Nevertheless, if our hypothesis holds, it should be possible to detect some correlation between geothermal activity, the regional strain-rate tensor field, and regional tendency of fault orientations. The motivation behind this study is that if the predicted effect were confirmed, it should lead to better regional-scale predictive tools to identify potential targets for geothermal resources. Such developed tools would then not only rely on tectonic strain and fault orientations, but would comprehensively incorporate as many correlative factors as possible. We therefore seek to add an important piece to the puzzle of geothermal resource targeting.

The Great Basin appears to be an optimal natural laboratory for testing our working hypothesis, as its dominant structural features are major normal-fault systems set within an extensional strain field. High strain rates are accommodated episodically by earthquakes, and therefore high strain rates correlate with active faults. Many of these normal fault systems are active, are oriented sub-perpendicular to the current minimum horizontal stress (Zoback, 1989), and are accommodating significant present-day extensional crustal strains (Thatcher, *et. al.*, 1999; Bennett, *et. al.*, 1999; Wernicke, *et. al.*, 2000). The density of Quaternary faults in the Great Basin (Fig. 1) is such that it is possible to define the general tendency of fault strike orientation at almost any point as a continuous variable. Moreover, Global Positioning System (GPS) data have been collected at many stations in the Great Basin for several years, thus allowing for precise (but not necessarily high resolution) determination of strain accumulation at the level of several parts per billion (10^{-9} meters/meter) in some locations.

Methodology

Using GPS data taken continuously from a worldwide network of sites for several years, we have solved for the geometrical configuration of the global network every week with several millimeter precision (Davies and Blewitt, 2000). This in turn was used to produce a global site velocity map, which was then combined with regional-scale GPS velocity solutions. Importantly for our study, the regional solutions included data from the BARGEN network in the Great Basin (Wernicke et al., 2000; Bennett et al., 1999) and from epoch GPS campaigns traversing the Great Basin (Thatcher et al., 1999). The regional stations used in our analysis are shown in Fig. 1 (which represents a small subset of the entire global solution).

By spline interpolation, the horizontal velocities were used to compute a strain-rate tensor map (which is equivalent to a velocity gradient tensor field) (Kreemer et al., 2000). The strain-rate tensor has four horizontal components at every point on the map. These can either be expressed as cartesian components, or decomposed into components of rotation (the antisymetric part), and deformation (the symmetric part). In turn the deformation can be decomposed into one component of dilitation (increase in surface area), and two components of shear (oriented at 45° to each other). Alternatively, the three components of deformation can be represented by a direction and magnitude of maximum extension, and an orthogonal magnitude of minimum extension (which is typically negative, hence compression). The relative magnitudes of these components indicate the style of strain, hence the style of faulting. For example, within a strike slip regime, maximum extension and maximum compression are of similar magnitudes. In a normal-fault regime, most of the deformation is extension approximately normal to the fault strike. Hence, given a GPS-determined strain-rate tensor map, our plan is to investigate how the style of regional strain might interact with the regional tendency of fault orientation to produce favorable conditions for geothermal activity.

In preparation for investigating the role of fault orientation, a database of Quaternary faults was provided by C.M. dePolo of the Nevada Bureau of Mines and Geology (personal communication), an update of which is currently nearing completion for seismic hazard assessment purposes. This database was incorporated into a GIS database along with the strain tensor data, site positions, and various geothermal parameters (Coolbaugh, *et. al.*, 2002).

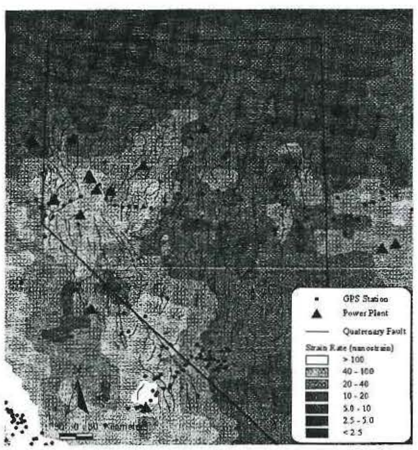

Figure 1. Map of the magnitude of strain rates in the Great Basin study area (Nevada border shown for reference) based on site velocity data from GPS stations shown. Higher strain rates are indicated by lighter shades. Superimposed are geothermal power-producing sites. Quaternary faults have been digitized and are superimposed to illustrate the potential for defining a continuous field of favorable orientations with respect to the strain tensor field. Note that strain rate can only be interpreted with resolution at the same spatial scale as the distance between neighboring GPS stations, which varies considerably with location.

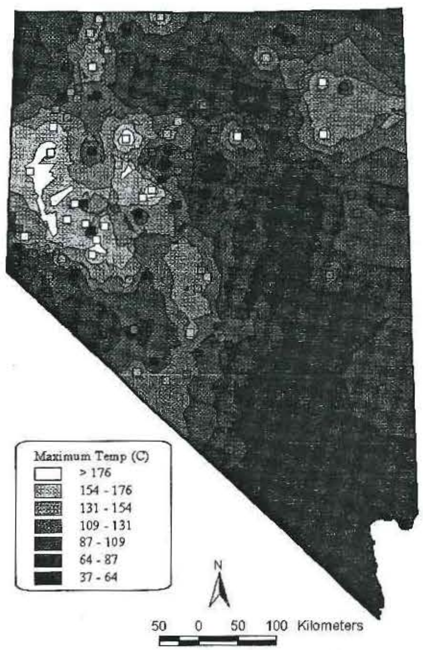

Figure 2. Trend surface of maximum geothermal temperatures. Locations of geothermal systems used for contouring are shown with squares. Method of surface interpolation was inverse distance weighting, with power of 1, using nearest 5 neighbors.

Initial Results

The magnitude of the resulting strain rate tensor is shown for the Great Basin in Figure 1. The magnitude here is the second invariant, defined as the square root of the sum of squares of the four tensor components. As such, in this initial analysis there is no indication of orientation, or style of strain. Knowing that much of the strain in the Great Basin is extensional, we therefore are testing the prediction of our working hypothesis that the magnitude of strain should correlate with other favorable indicators of geothermal activity.

Figure 1 shows that areas of relatively high strain tend to correlate with the location of existing power-producing geothermal plants. As an alternative indicator of geothermal activity, Figure 2 shows an independent map of maximum geothermal temperatures sampled in each region, then interpolated. There is a compelling visual correlation between the magnitude of strain (Figure 1) and geothermal temperatures (Figure 2).

Conclusions

We have initial evidence to support our working hypothesis that geothermal plumbing systems might in some regions be controlled by fault planes acting as conduits that are continuously being stressed apart by tectonic activity. The promising correlation shown between geodetic measurement of tectonic strain accumulation and geothermal activity strongly suggests that further investigations be made into testing predictions that geothermal fluid flow is also controlled by the relative orientation of faults within the ambient regional strain field.

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