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

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**Abstract.** The objective of the proposed research is to assess 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 (1) geothermal activity would be spatially correlated with areas of high inter-seismic strain accumulation, (2) especially when faults are favorably oriented with respect to the strain-rate tensor field. We aim to test 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.

## 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 maintain faults and 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., 2000; Wernicke et al., 2000]. The density of Quaternary faults in the Great Basin (Figure 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 in some locations.

## Methodology

(1) Using GPS data taken continuously from a worldwide network of sites for several years, we have already solved for the geometrical configuration of the global network every week since 1995 with several millimeter precision [Davies and Blewitt, 2000]. This is turn will be used to produce a global site velocity map with ~1 mm/yr precision, which will then be combined with regional-scale GPS velocity solutions. Importantly for our study, the regional solutions will include data from the BARGEN network in the Great Basin [Wernicke et al., 2000; Bennett et al., 2000] and from epoch GPS campaigns traversing the Great Basin [Thatcher et al., 1999]. The regional stations that will be used in our analysis are shown in Figure 1 (which represents a small subset of the entire global solution).

(2) By spline interpolation, the horizontal velocities will be 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. Based on preliminary data in hand, the magnitude of the 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 have a promising correlation 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).

(3) Given the above 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 (private communication), an update of which is scheduled for completion in September 2002 for seismic hazard assessment purposes. This database was incorporated into a GIS database along with

preliminary strain tensor data, site positions, and various geothermal parameters [Coolbaugh et al., 2002]. This preliminary database is shown superimposed on Figure 1. We propose to use the digital fault database to construct the extensional component of strain that is normal to fault strike. This together with other explorative studies will lead us to determine the most favorable strain-fault characteristics that correlate with geothermal activity.

## References

Barton, C.A., M.D. Zoback, and D. Moos, Fluid flow along potentially active faults in crystalline rock: Geology, v. 23, p. 683-686, (1995).

Bennett, R.A., J.L. Davis, and B.P. Wernicke, B.P., Present-day pattern of Cordilleran deformation in the western United States: Geology, v. 27, p. 371-374, (1999).

Coolbaugh, M.F., J.V. Taranik, G.L. Raines, L.A. Shevenell, D.L. Sawatzky, T.B. Minor, and R. Bedell, A geothermal GIS for Nevada: defining regional controls and favorable exploration terrains for extensional geothermal systems, (this volume), (2002).

Davies, P., and G. Blewitt, Methodology for global geodetic time series estimation: A new tool for geodynamics, Journ. Geophys. Res., Vol. 105, No. B5, pp. 11,083-11,100 (2000).

Hickman, S., C.A. Barton, M.D. Zoback, R. Morin, J. Sass, and R. Benoit, In situ stress and fracture permeability along the Stillwater fault zone, Dixie Valley, Nevada: International Jour. of Rock Mechanics and Mining Science, v. 34, p. 414, (1997).

Kreemer, C., J. Haines, W.E. Holt, G. Blewitt, and D. Lavallée, On the determination of a global strain rate model, Earth, Planets and Space, 52, 765-770, (2000).

Thatcher, W., G.R. Foulger, B.R. Julian, J. Svarc, E. Quilty, and G.W. Bawden, 1999, Present day deformation across the Basin and Range province, western United States: Science, v. 283, p. 1714-1718, (1999).

Wernicke, B., A.M. Friedrich, N.A. Niemi, R.A. Bennett, and J.L. Davis, Dynamics of plate boundary fault systems from Basin and Range geodetic network (BARGEN) and geologic data: GSA Today, v. 10, no.11, p. 1-7, (2000).

Zoback, M.L., State of stress and modern deformation of the northern Basin and Range province: Jour. Geophys. Res., v. 94, p. 7105-7128, (1989).

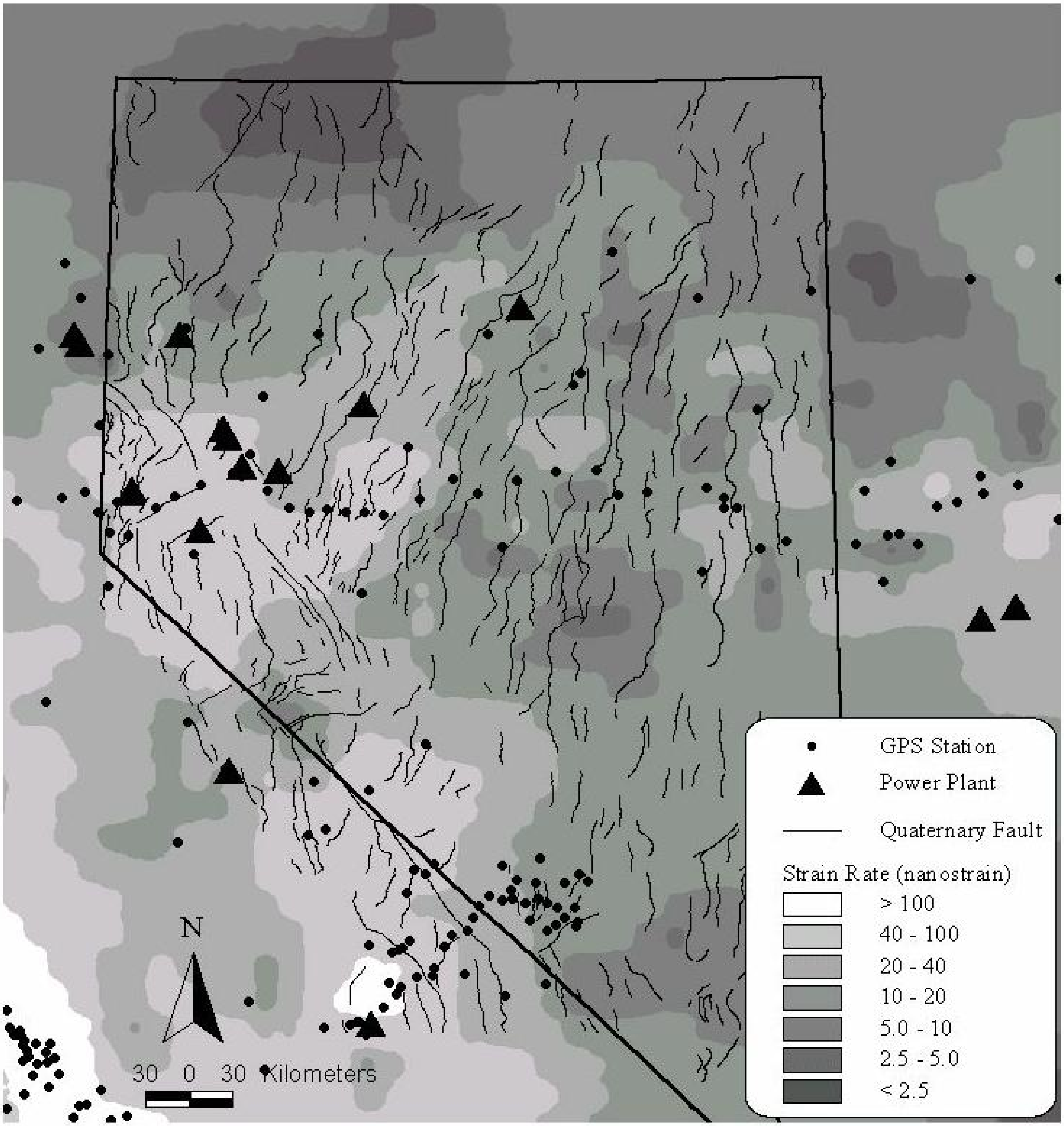

**Figure 1.** Map of the magnitude of strain rates in the Great Basin study area (Nevada border shown for reference) based on preliminary site velocity data from GPS stations shown. Higher strain rates are indicated by lighter shades. Superimposed are geothermal power-producing sites. A preliminary map of quaternary faults has 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.

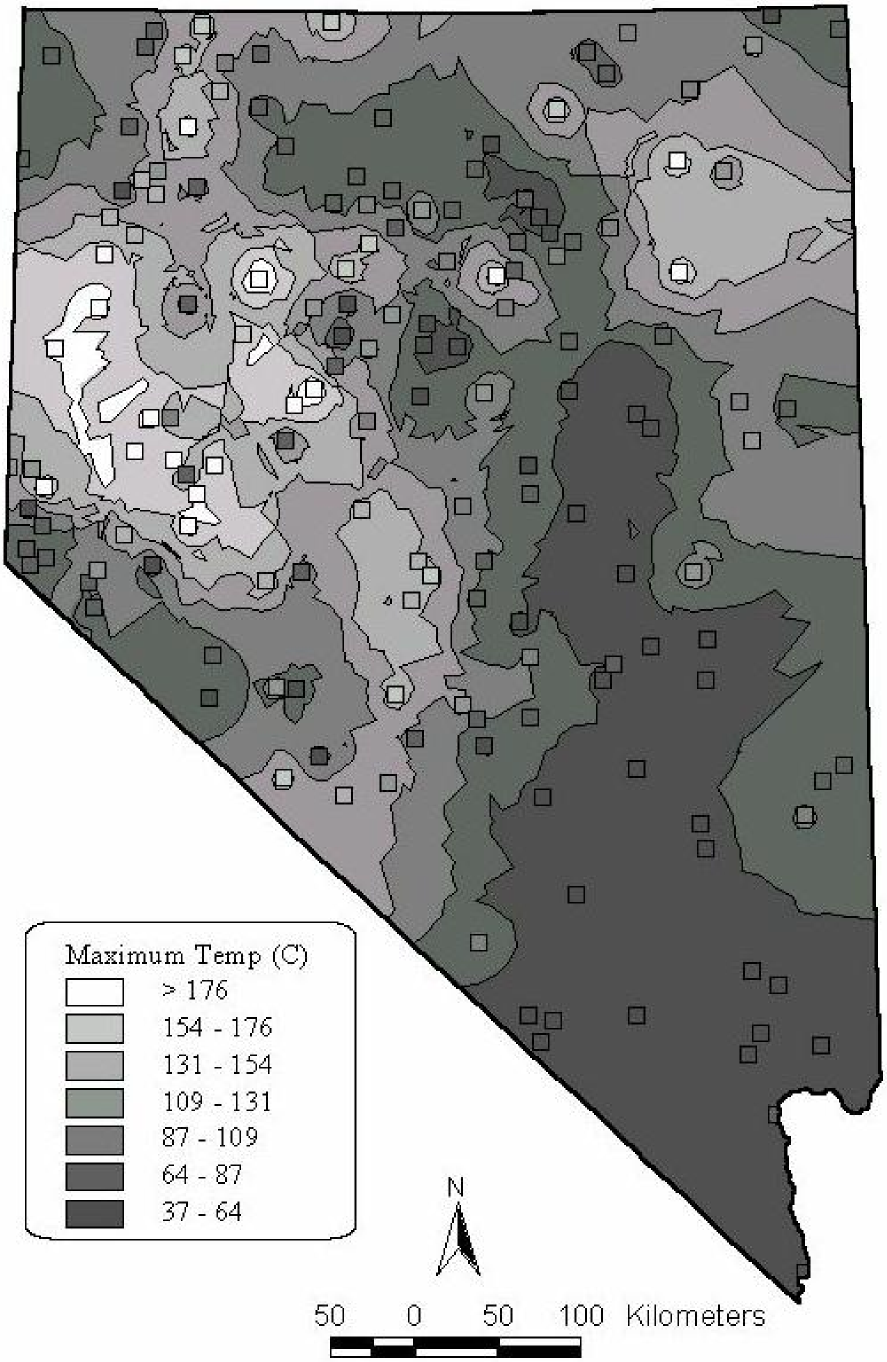

**Figure 2.** Trend surface of maximum geothermal temperatures. Locations of geothermal systems used for contouring are shown with squares. Method of surface interpolation was inverse distance weighting, with power of 1, using nearest 5 neighbors.

## Work Plan and Schedule

The work will be conducted by the P.I. together with a Graduate Research Assistant (to be hired), and with input from two subcontracts noted below.

| Task | Regional Relationships between Geodetic Strain and Geological Stuctures | Completion |
|---|---|---|
| 01 | Compilation of GPS velocity data[1] | 06/30/2002 |
| 02 | Hire graduate research assistant[2] | 06/30/2002 |
| 03 | Construction of tensor strain rate field[3] | 08/31/2002 |
| 04 | Presentation of preliminary results at GRC | 09/24/2002 |
| 05 | Inclusion in GIS database/Coordination w/Taranik-GIS | 10/30/2002 |
| 06 | Strike-normal extensional strain analysis using GIS[2] | 11/31/2002 |
| 07 | Presentation of updated results at AGU | 12/10/2002 |
| 08 | Updated map showing favorable geothermal targets | 03/19/2003 |
| 09 | Preparation of final report and journal article | 03/19/2003 |

[1] An essential component of the regional GPS velocity compilation in the Great Basin will be solutions from the BARGEN array. These will be provided under a sub-contract by Jim Davis' group at the Harvard Smithsonian Center for Astrophysics.

[2] A Graduate Research Assistant will be hired for one year on this project and will be tasked with conducting sub-task 06, "Strike-normal extensional strain analysis using GIS."

[3] Bill Holt at the State University of New York, Stonybrook will be sub-contracted to produce a strain-rate tensor map of the Great Basin using as input a compilation of GPS velocities, including regional velocities in the Great Basin, and

## Budget: $86,917