

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

**Short Title:** Geothermal Targeting from Strain and Structure

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**Abstract.** This is a follow-on proposal from last year's funded project "Targeting of Potential Geothermal Resources in the Great Basin from Regional Relationships between Geodetic Strain and Geological Structures," which assessed a new method to target potential geothermal resources on the regional scale by seeking relationships between geologic structures and GPS-geodetic observations of regional tectonic strain [Blewitt *et al.*, 2002]. From the current project it was discovered that, on a regional scale, the locations of existing power-producing plants together with the spatial pattern of geothermal well temperatures is strongly correlated with GPS-measured rates of tectonic extension normal to the strikes of faults in the Great Basin, indicating 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 [Blewitt *et al.*, 2003a].

Here we propose to both continue this regional-scale study, but to add a significant new component of the study to investigate the relationship of the pattern of strain accumulation on the basin scale at two locations already targeted by the regional-scale studies (hence the slight modification to the title of this project). We propose that one basin-scale site to be investigated is Buffalo Valley (near Battle Mountain), which is currently unexploited. As a control area, the second would be the Desert Peak and Brady's Hot Springs geothermal area which last year was investigated using geophysics and structural tectonics methods by the Great Basin Center for Geothermal Energy (GBCGE) (P.I., Jim Faulds). The basin-scale studies would test the hypothesis that the controlling tectonic features are abrupt changes in the strike of faults within the regional strain field. Examples of this include step-over geometries in strike-slip faults which create pull-apart tectonics, or trans-tensional systems.

The GPS measurements would need to be of sufficient accuracy (~1 mm) and of sufficient density (station distances of ~5 to 15 km) to resolve the strain field associated with such basin-scale structures. We therefore propose to install approximately 10 stations at each of the two basin-scale areas. These will be monitored by 10 GPS receivers which will be rotated to cover all sites, so that each station records data regularly throughout the year. After 2 years of data collection, strain rates of sufficient accuracy and spatial resolution are predicted to be at the level required to discriminate hypotheses from each test area regarding which structures are tectonically active, and to invert for tectonic parameters that are relevant to geothermal models (such as the depth of locking and 3-d slip-rate vectors on active fault planes, which theoretically can be used to model volumetric dilatation around fault zones which might be accommodated by fracturing). The outcome of this project will be identification at the basin-scale of specific structures which might be targeted for geothermal exploitation, with a level of confidence that is commensurate with our demonstrated ability to positively identify active structures at the Desert Peak-Brady's control area.

## Description of Project

### Background: Results from Current Project (2002-2003)

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].

In the currently funded project (starting March 2002) it was hypothesized 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, significant correlation was observed between geothermal activity (Figure 1) and the regional tendency of fault orientations (Figure 2a), and also the direction of extensional strain as measured by GPS (Figure 2b), and the magnitude of fault-normal extensional strain as inferred by both GPS and digitized Quaternary fault maps (Figure 3). The stated motivation behind last year's study was that if the predicted effect were confirmed, it should lead to better regional-scale predictive tools to identify potential targets for geothermal resources. In this proposal, based on a detection of an anomalous high in fault-normal extensional strain, Buffalo Valley (SW of Battle Mountain) is identified as a potential geothermal target to be further explored using GPS on the basin scale (Figure 4). We propose a 2-year GPS measurement project to explore Buffalo Valley as a candidate for geothermal targeting.

### Objectives

(1) The primary objective of this project will be to characterize strain accumulation with basin-scale resolution at the target site, Buffalo Valley, Nevada. The resolution and accuracy will be sufficient to determine specific active faults that might act as geothermal fluid conduits.

(2) As a control experiment, a similar basin-scale GPS survey in the region of the Brady's and Desert Peak geothermal power plants will be used to assess the validity of the methodology and to provide a quantitative measure of confidence in the interpretation of strain at Buffalo Valley.

(3) Provide a basin-scale interpretation that is guided by and is consistent with the regional-scale pattern and style of strain accumulation and faulting.

(4) The outcome of this 2-year project will be an assessment of the geothermal potential of Buffalo Valley. If Buffalo Valley proves to be particularly promising (by comparative study with the Brady's-Desert Peak area), an optimistic outcome will be identification of specific geological structures and recommended locations for test drilling. (Even if not achievable in 2 years, the optimistic outcome is more likely to be achievable in 3 to 4 years, given the very low strain rate signals typical of active structures in the Great Basin).

### Proposed Methodology

(1) Use GPS to determine the velocities of a 10-station network both in the Buffalo Valley region, and also of a 10-station control network around the Brady's and Desert Peak geothermal producing region.

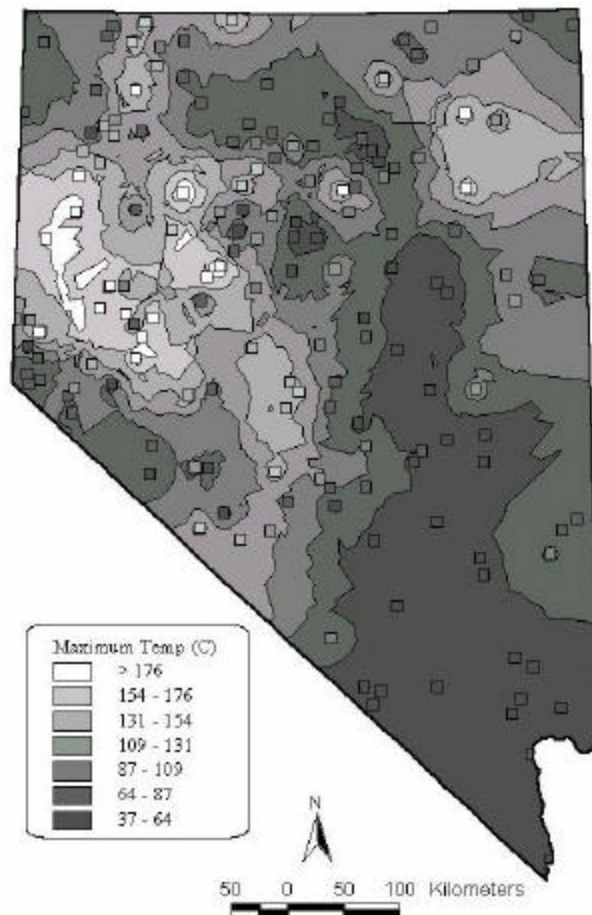
(2) Survey each point with 1-mm positioning precision at least once every month for 2 years. This strategy will allow for the mitigation of known seasonal signals/errors associated with GPS positioning which can significantly bias velocity estimates [Blewitt and Lavallee, 2002]. Achieve these requirements by deploying 10 GPS receivers to rotate around the 20-station network, by fieldwork every 2 weeks.

(3) To minimize station set up error and to improve repeatability of daily-repeating multipath errors, use force-centered antenna mounts based on bolts drilled and secured by epoxy into either exposed bedrock, or concrete pillars.

(4) Process the basin-scale networks in relative positioning mode, then rigorously integrate the solutions with regional-scale solutions in Year 2 of the project.

(5) Follow an identical strategy of the previous year's work to produce a regional-scale strain map of the Great Basin, including (a) GPS global velocity solutions from UNR [Davies and Blewitt, 2000], (b) GPS station velocity solutions in the Great Basin by a subcontract with Smithsonian Astrophysical Observatory (SAO) [Wernicke et al., 2000; Bennett et al., 2000], (c) modeling of strain rates based on both UNR global solutions, SAO regional solutions, and other regional campaign solutions [Thatcher et al., 1999] by a subcontract with State University of New York [Kreemer et al., 2000], (d) integrate the basin-scale solutions into the velocity and strain analysis. This regional-scale study is only required in Year 2 of this project to place the basin-scale study in context.

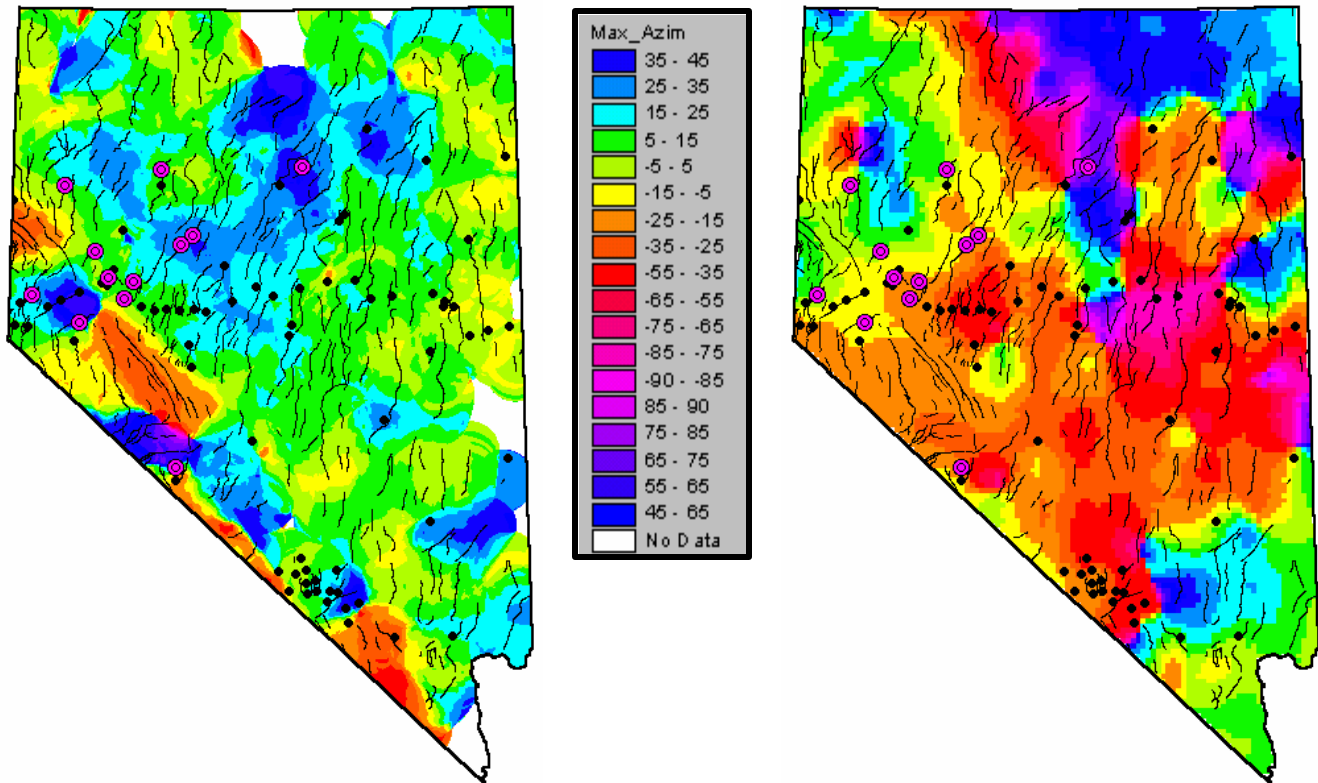
(6) Given the strain-rate tensor map, investigate how the style of strain might interact with the tendency of fault orientation to produce favorable conditions for geothermal activity. Perform all spatial analyses within an established GIS framework with assistance of Mark Coolbaugh at the GBCGE.



**Figure 1.** 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. Note that geothermal temperatures tend to follow both the NE-SW trending Humboldt structural zone intersecting with the NW-SE trending northern Walker Lane.

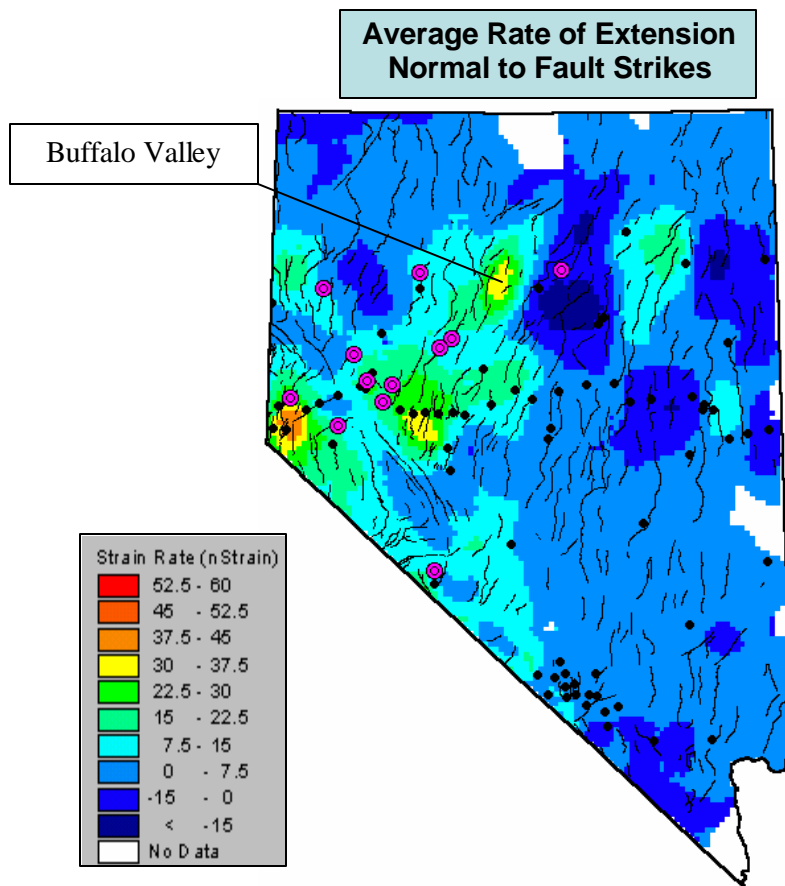
**Direction of Regionally-Averaged Fault Strike**

**Direction of Shear Strain  
(Azimuth of Maximum Extensional Rate)**

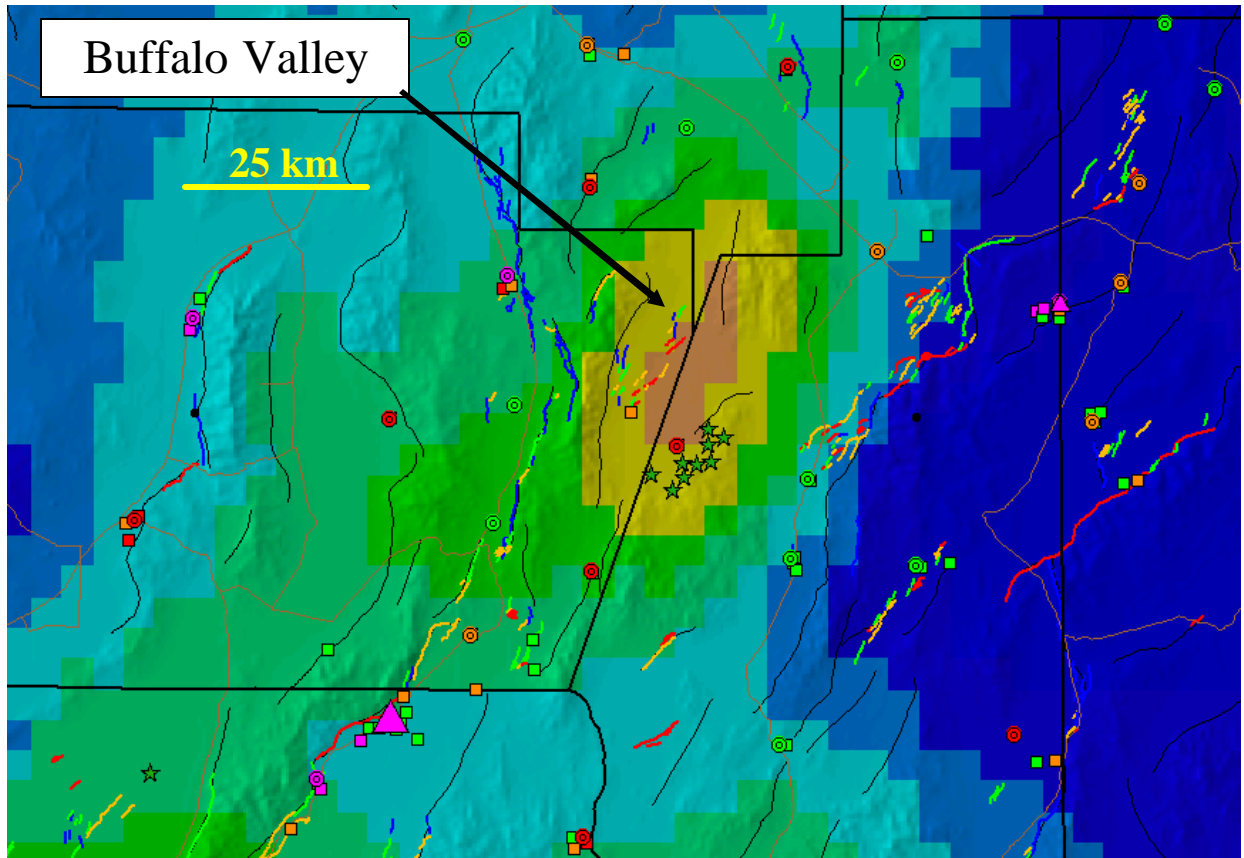


**Figure 2a: (left)** Azimuth map of regionally-averaged Quaternary fault strikes using the statistics of bi-directional data, where the average is computed in 30 km circular areas [Blewitt *et al.*, 2002, 2003a, 2003b]. Azimuth is measured in degrees, clockwise from North. The original Quaternary fault data is from Craig DePolo (private comm., 2002). Note the NW-SE trend of the Walker Lane (red), in contrast to the NE-SW trend of the Humboldt structural zone (blue). Geothermal power plants tend to fall in either of these two distinct zones. The Humboldt structural zone can be characterized as a directional anomaly in the broader regional N-S trend of fault strikes. For reference purposes, black dots show the location of GPS stations, and purple circles show the location of current geothermal power plants.

**Figure 2b: (right)** Azimuth map of the direction of regionally-averaged shear strain rates as determined entirely by GPS station velocity data (stations shown by the black dots) [Blewitt *et al.*, 2002, 2003a, 2003b]. Note that the trace of geothermal power producing plans following the Humboldt structural zone, trending NE-SW, falls on a linearment corresponding to an abrupt change in the direction of shear. This change in direction of shear might have some correlative cause with the change in azimuth of fault strikes in Fig. 2a. One hypothesis that appears to be supported by evidence from seismic surveying is that the crust is thinner along the Humboldt structural zone, leading to a change in alignment between the strain and stress fields [Blewitt *et al.*, 2003b]. A thinned crust would also explain the trend in location of power producing plants. This model would predict an anomalous increase in strain along the Humboldt structural zone. This was in fact confirmed by our GPS measurements, as shown in Figure 3.



**Figure 3:** Strain rate map derived from GPS velocities (stations shown as black dots) [Blewitt *et al.*, 2002, 2003a, 2003b]. Specifically, this is the average rate of extension normal to Quaternary fault strikes, and so also depends on the fault database. There is an increase in the magnitude of this style of strain rate along the Humboldt structural zone trending NE-SW, correlating with the trend of geothermal power plants. Note also the NW-SE trending fault-normal extensional strain along the Walker Lane. Thus the approximate “X” shape pattern approximates the pattern of geothermal temperatures show in Fig. 1. The basin-scale region, Buffalo Valley, is indicated as a local high in fault-normal extensional strain, and thus is identified as a potential target for geothermal exploitation.



**Figure 4:** Regional-scale strain-rate map zoomed in on Buffalo Valley, taken from the results of last year's GBCGE project based on velocity data from GPS station (black dots) [Blewitt *et al.*, 2003a, 2003b]. Background color relates to the magnitude of extensive strain rates perpendicular to fault strike. Warmer colors indicate larger strain rates; the smallest being close to zero, and the largest at approximately 40 nanostrains (parts per billion) per year. The spatial sparseness of GPS stations means that the local concentration of strain at the basin scale is not well known, hence the need for a basin-scale GPS survey. The apparent basin-scale spatial variation in fault-normal strain rate is largely due to the anomalous orientation of faults in Buffalo Valley, which leads to the possibility of locally enhanced opening of fractures. Light black lines are digitized faults from Craig DePolo (private comm., 2002). Colored lines are faults published by Dohrenwend. Brown lines are roads. Purple triangles are geothermal power plants. Circles and squares are geothermal systems and hot springs. Heavy black lines are county lines. The stars at the southern end of Buffalo valley indicate ~1 Ma cinder cones, which may be associated with crustal extension and thinning. Crustal thinning in Buffalo Valley is also indicated by smaller depths to Moho in the seismic data of John Louie of the GBCGE [Blewitt *et al.*, 2003b].

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## Work Plan, Deliverables, and Schedule

The work will be conducted by the P.I. together with a technician, and with input from two subcontracts in Year 2 as noted below.

Task	Geothermal Targeting from Strain and Structure	Completion
01	Presentation of poster at Joint IRIS-UNAVCO workshop, Yosemite, CA.	06/21/2003
02	Complete purchase order of required GPS station equipment	06/30/2003
03	Receive and test station equipment & download procedures	07/31/2003
04	Site reconnaissance, selection, & 20 stations installed at Desert Peak	08/31/2003
05	Site reconnaissance, selection, & 20 stations installed at Buffalo Valley	09/30/2003
06	Every 2 weeks visit sites to download data and relocate receivers	ongoing
07	Quarterly report	09/30/2003
08	Presentation of paper at GRC Meeting, Morelia, Mexico	10/15/2003
09	Initial benchmark solutions for both 20-station basin-scale networks	12/31/2003
10	Quarterly report	12/31/2003
11	Update basin-scale network solutions	03/31/2004
12	Quarterly report	03/31/2004
13	Submit paper to annual GRC conference	05/31/2004
14	Update basin-scale network solutions	06/30/2004
15	Quarterly report	06/30/2003
16	Secure subcontract with SAO to compute regional-scale velocities	09/30/2004
17	Secure subcontract with SUNY to compute tensor strain-rate solution	09/30/2004
18	Initial assessment of basin-scale network velocity solution	09/30/2004
19	First fiscal-year annual report	09/30/2004
20	Presentation of initial results at annual GRC conference	09/30/2004
21	Update basin-scale network velocity solution	12/31/2004
22	Quarterly report	12/31/2003
23	Submit abstract to AGU Joint Assembly	02/28/2005
24	Compute regional-scale velocity solution for Great Basin (SAO) <sup>1</sup>	02/28/2005
25	Update basin-scale velocity solutions and combine with regional solution	03/31/2005
26	Quarterly report	03/31/2005
27	Compute regional- & basin-scale tensor strain rates (SUNY) <sup>2</sup>	04/30/2005
28	Presentation of paper at AGU Joint Assembly, New Orleans, LA	05/27/2005
29	Submit paper to annual GRC conference	05/31/2005
30	Update basin-scale velocity solutions and combine with regional solution	06/30/2005
31	Quarterly Report	06/30/2005
32	Compute regional- & basin-scale tensor strain rates (SUNY) <sup>2</sup>	07/31/2005
33	Prepare and submit journal article reporting results and interpretation	09/30/2005
34	Presentation of results at annual GRC Conference	09/30/2005
35	Second fiscal-year annual (final) report	09/30/2005

<sup>1</sup>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. This regional solution will provide the reference frame and regional context for the interpretation of basin-scale solutions.

<sup>2</sup>Bill Holt at the State University of New York, Stony Brook 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 from SAO, additional velocity data from GPS campaigns by other groups, including USGS, and also the basin-scale velocity data produced at UNR.