

## **Great Basin Center for Geothermal Energy**

Proposal for DOE Geothermal Funding for Research to Increase Utilization of  
Geothermal Resources in the Western United States

### **Continuation Project: Assembling Crustal Geophysical Data for Geothermal Exploration in the Western Great Basin**

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#### **ABSTRACT**

This project will survey additional regions of the western Great Basin of Nevada and eastern California for evidence of the thin crust found by the previous project below the Battle Mountain heat-flow high. Exploration for hidden resources requires a realistic three-dimensional crustal model to understand the deep sources of geothermal heat in the crust. Current data suggest extensional tectonic geothermal fields are associated with thin crust (<30 km), while thicker crust hosts only magmatic fields. Crustal properties and thickness are known only at wide spacing, so new surveys are needed from the mines hosting blasts that we have been able to record at distances exceeding 450 km.

We will compile as well additional velocity information from sources in the literature, results of previous seismic experiments and earthquake-monitoring projects, and data donated from mining, geothermal, and petroleum companies. The two new crustal seismic refraction profiles will cross the central Walker Lane, and central Nevada. The central Walker Lane shows nearly the level of geothermal resources of the northern Walker Lane, but central Nevada (Carlin to Las Vegas) has very few. Our three surveys resulting from the continuing project will thus sample the full range of occurrence of geothermal resources in the Great Basin.

The resulting seismic velocity model will be contributed to the associated projects, if funded, to assemble geographic databases of geothermal indicators. With the proposed more complete sampling of the crustal geophysical characteristics of geothermal resources in the Great Basin, these measures can contribute to quantitative analyses of the associations between different indicators. Under the Center's goal "(1) Geothermal Resource Assessment and Exploration: B. Identification and Characterization of New Potential Geothermal Resource Targets," this project will contribute critical data toward the effective exploration for new geothermal resources.

# **Continuation Project: Assembling Crustal Geophysical Data for Geothermal Exploration in the Western Great Basin**

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## **Project Description**

### **PREVIOUS PROJECT OBJECTIVES**

This project assembled a three-dimensional reference seismic velocity model for the western Great Basin region of Nevada and eastern California (figure 1). This model is rule-based and distributed as software on the Internet (<http://shake.seismo.unr.edu:8081/lv/share/ma3>), similar to the SCEC Community Velocity Model (CVM) of Magistrale et al. (2000). These qualities make the model useful for multidisciplinary research activities including geothermal exploration, mineral exploration, earthquake-hazard assessment (work coordinated with a project on the Las Vegas Valley funded by LLNL), high-precision microearthquake location and source-parameter estimation, and crustal-structure imaging.

A faculty geophysicist and students assembled this model almost entirely from existing results. The project both included literature review and examination of gray literature and data donated by the geothermal, mining, petroleum, and geotechnical industries. We assembled especially detailed information on Nevada's major sedimentary basins. We also conducted in May 2002 an inexpensive, 5-day seismic refraction survey, 500 km long, between mine blasts and crossing the northern Sierra Nevada and Walker Lane.

### **PREVIOUS PROJECT DELIVERABLES**

(1) Delivered September 30, 2002: a brief report outlining the sources of existing velocity information mined to date (figures 2, 3, 4), reporting on the acquisition and performance of the new Reftek "Texan" instruments (figure 5), and preliminary data from the refraction experiment (figures 1, 6).

(2) Presented March 2003: a brief report outlining and referencing all data sources (figures 2, 3). In addition, we described the form of the velocity database and its transmission to cooperating GIS projects (figure 7). We presented an interpretation of this crustal model to industry at the 2002 GRC meeting.

(3) In progress for September 2003: technical papers detailing the features of the assembled seismic velocity model (figure 6), and their implications for the distribution of geothermal resources (figure 7), will be submitted for publication in peer-reviewed scientific journals. At present, a web site accessing the database and all results is available (<http://www.seismo.unr.edu/geothermal>). A complete copy will be delivered to the GBCGE on CD-Rs or DVD-R disc. The new Reftek recorders have been placed in a Seismo Lab facility, maintained for use by UCCSN geophysicists.

(4) Quarterly DOE Reports: for quarters 1-4 completed by the PI.

(5) Apr. 26, 2002 GRC Meeting abstract: showed samples of sources of velocity data, and appealed to the industry for donations of data to help fill gaps in coverage.

### **BACKGROUND**

Exploration for hidden resources requires a realistic three-dimensional crustal model to understand the deep sources of geothermal heat in the crust of the western Great Basin. The type of rule-based representations developed by the Southern California Earthquake Center (SCEC) are very appropriate to defining velocity on the spatial scales of this application, particularly for the western Great Basin (Louie, 2002). Crustal properties and thickness are known only at wide (100 km) spacing, but the structure of the urban basins (Concha-Dimas et al., 2002) and some geothermal regions (e.g., Coso, Dixie Valley) is known at some detail (0.2 km spacing).

Crustal thickness and velocity are closely related to a region's thermal and tectonic history. Known geothermal resources in north-central Nevada are closely associated with thin crust and an uplifted Moho (figures 3, 7; Thelen et al., 2002; Savage and Sheehan, 2000; Ozalaybey et al., 1997; Fliedner et al., 1996; Humphreys and Dueker, 1994). By assembling a velocity model for the entire western Basin and Range (figures 1, 2, 3), we will be able to look for crustal features, similar to those

under known geothermal resources (Thelen et al., 2002; figures 3, 4), that may be closer to Southern California power markets.

The acquisition under the previous project of 20 Reftek RT-125 "Texan" seismic recorders will assist our effort to acquire an additional 500-km-long refraction profile each project year, across the central Walker Lane and across central Nevada (figure 1). An additional 200 recorders we will again borrow from the IRIS/PASSCAL Instrument Center for each experiment, for the cost of shipping and batteries.

## RESEARCH PLAN

Velocity information will continue to be compiled from sources in the literature, results of previous and cooperating, on-going seismic experiments and earthquake-monitoring projects, and data donated from mining and petroleum companies. Figure 7 shows that our previous Northern Walker Lane survey was aligned along a northeasterly trend of extensional geothermal fields termed the "Humboldt Trend," and that we found a striking feature of the northeast end of this zone to be a crustal thickness of only 19 km. To better define the limits of this thin crust, we propose to collect one new crustal refraction profile each year. Both new profiles will originate at the mine near Battle Mountain, Nev. (fig. 1) that proved to have daily blasting work that we could record to long distances with Texan arrays in the previous project (Louie et al., 2002). Mine blasts could be identified in the No. Walker Lane survey recordings to 400-km distances, producing the new crustal velocity results of figures 6 and 7.

In year 1 of the continuation project, the profile will extend from these large daily sources in Barrick's GoldStrike mine (often >40,000 kg ANFO) southwest across Beowawe, Austin, and Mina, Nevada, the central Walker Lane Belt, the Long Valley, Calif. volcanic area, and after a 10-20 km gap at the Sierra crest down the west-central Sierra to quarries near Fresno, Calif. Even if a large enough reverse shot cannot be obtained from a Fresno-area quarry, earthquake activity in the Long Valley area is common enough that a reversing event is likely there during the four days of the survey. The previous project recorded several earthquakes off-profile, including one in Bridgeport, Calif. (figure 1).

The third year's profile will extend south-southeast from the GoldStrike mine across Carlin, Eureka, and Alamo to a quarry in the Las Vegas area, where we can have a blasting consultant set off a large reverse shot. This profile will assess crustal velocities across central-eastern Nevada, where some crustal geophysical constraints exist from receiver-function work (Ozalaybey et al., 1997). Unlike the Northern and Central Walker Lane surveys, this Central Nevada survey will cross a region of no known geothermal production (figure 7). We seek to validate the correlations of crustal geophysical properties against the occurrence of economic geothermal resources (as in figures 4 and 7) with additional data coverage. The survey results will be embedded in a 3-d crust over a variable-depth Moho, as developed by the previous project, and contributed to the associated projects if funded, to assemble geographic databases of geothermal indicators.

Aside from the refraction surveys, the remainder of the proposed effort will be to assemble additional velocity information of several types and at several scales to define the model at different depths:

*Upper mantle*— The tomographic image of Humphreys and Dueker (1994) provides a starting framework for mantle velocity in the western Great Basin; although their coverage north and east of Reno (figure 1) is poor.

*Pn velocities*— Thompson et al. (1989) review regional constraints on Pn velocities. Our proposed profile across the northern Sierra and Walker Lane will provide some of the constraints available for the southern Sierra and Death Valley from Fliedner et al. (1996).

*Crustal thickness*— Mooney and Braile (1989) and Kaban and Mooney (2001) reviewed all available constraints on Moho depth for the western Great Basin (figure 1). For the central Great Basin constrained receiver-function analyses are available from Ozalaybey et al. (1997), but these are constrained to >30 km thicknesses to some extent from 1960s recording of nuclear tests. Refraction experiments in the 1980s found crustal thicknesses as low as 22 km in the eastern Great Basin (Mooney and Braile, 1989), so our 19 km depths from the No. Walker Lane are not unprecedented.

*Middle & lower crustal velocities*— Mooney and Braile (1989), Thompson et al. (1989), and Fliedner et al. (1996) provide reviews of crustal velocity information that form a basis for a 3-d crustal velocity model. Our survey results (figure 6; Louie et al., 2002) will be integrated with the pre-existing

data. Ozalaybey et al. (1997) constrained crustal velocity profiles at several locations in the central Great Basin, establishing low-velocity zones exist at very few.

*Upper crust*—In addition to crustal thickness, much of the work reviewed by Kaban and Mooney (2001) constrains P velocities well to 5-10 km depth. Additional constraints are reviewed by Thompson et al. (1989) and Fliedner et al. (1996); many of them come from long COCORP surveys extending from the northern Sierra to the Ruby Mountains, and in the Death Valley region (figure 1). We will continue to compile all available information from reflection stacking velocity analyses, and seek to examine copies of commercial spec surveys, abundant in eastern Nevada.

*Basin depths and velocities*— Honjas et al. (1997), Chavez-Perez et al. (1998) and Abbott et al. (2001) estimated basin depths and velocities for Death Valley and Dixie Valley (figure 1) from the first-arrival times recorded in reflection surveys. Jachens and Moring (1990) summarize relations between density and depth in Nevada basins from oil-well logs, mostly from Railroad Valley (figure 1). Langenheim et al. (2001) and Abbott and Louie (2000) used these relations together with some borehole and seismic data to detail the depths and density profiles of Nevada's urban basins in Las Vegas, Reno, and Carson (figure 1).

We are in the second year of a LLNL-sponsored project to characterize the Las Vegas basin (Concha-Dimas et al., 2002), and parallel efforts to characterize the Reno basin. USGS-funded work by UNLV colleagues on this project has resulted in detailed basin structure and geotechnical characterization. All of this has been integrated with the results of this project into a rule-based model code available on the Internet at <http://shake.seismo.unr.edu:8081/lv/share/ma3>.

## DESCRIPTION OF DELIVERABLES

(1) September 30, 2003: a brief report will be delivered to the GBCGE outlining the integration of the No. Walker Lane survey results with pre-existing data, and progress on making the integrated, rule-based crustal model available for viewing on the Web.

(2) April 2004: GRC Meeting abstract, on statistical significance of new crustal data.

(3) June 2004: a brief report will be delivered to the GBCGE on the level of success with recording the Central Walker Lane survey.

(4) September 30, 2004: a brief report will be delivered to the GBCGE outlining the integration of the Central Walker Lane survey results with pre-existing data, and evidence for limits the area of thin crust below Battle Mtn.

(5) April 2005: GRC Meeting abstract, comparing the northern and central Walker Lane crust.

(6) June 2005: a brief report will be delivered to the GBCGE on the level of success with recording the Central Nevada survey.

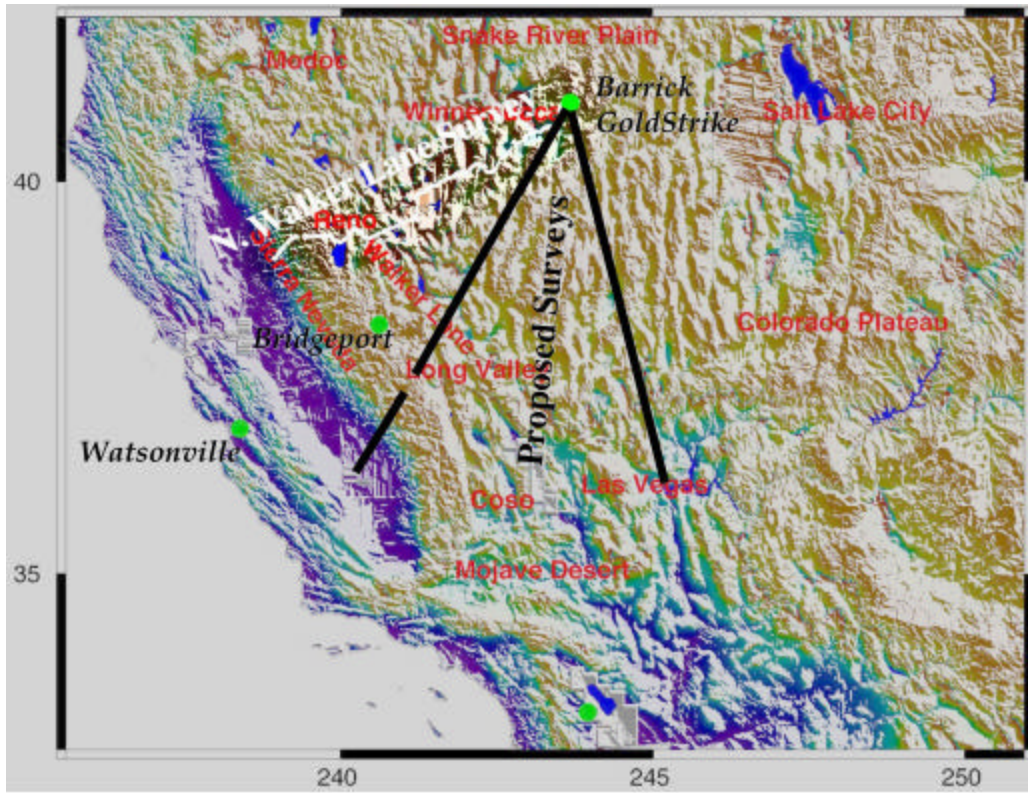
(7) At the completion of the project: technical papers detailing the features of the assembled crustal seismic velocity model, and their implications for the distribution of geothermal resources throughout the western Great Basin, will be submitted for publication in peer-reviewed scientific journals. In addition, a web site accessing the updated database and all new results will be available, and a complete copy delivered to the GBCGE on CD-Rs or DVD-R disc. The Reftek recorders will continue to be maintained for use by UCCSN geophysicists.

(8) Quarterly DOE Reports: will be completed as required by the PI.

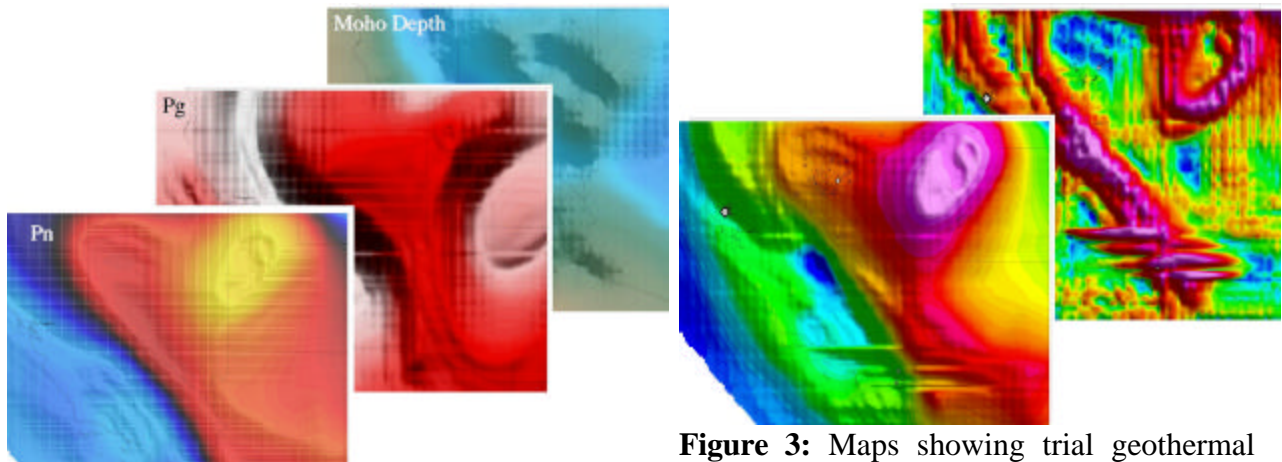
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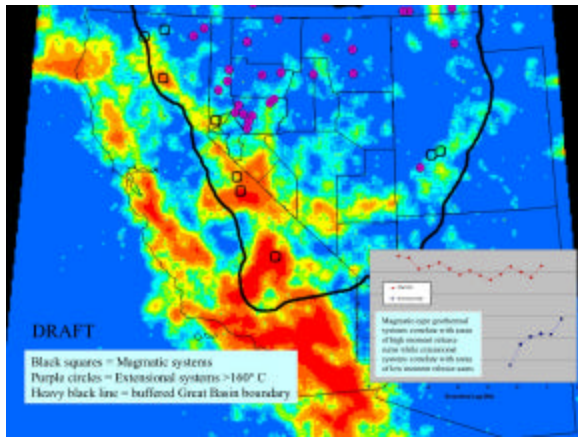


**Figure 1:** Map of Great Basin physiography, with the completed and proposed crustal refraction surveys shown by the white and black lines, respectively.



**Figure 2:** Maps showing crustal geophysical properties across the Great Basin, compiled by IRIS from previous studies.

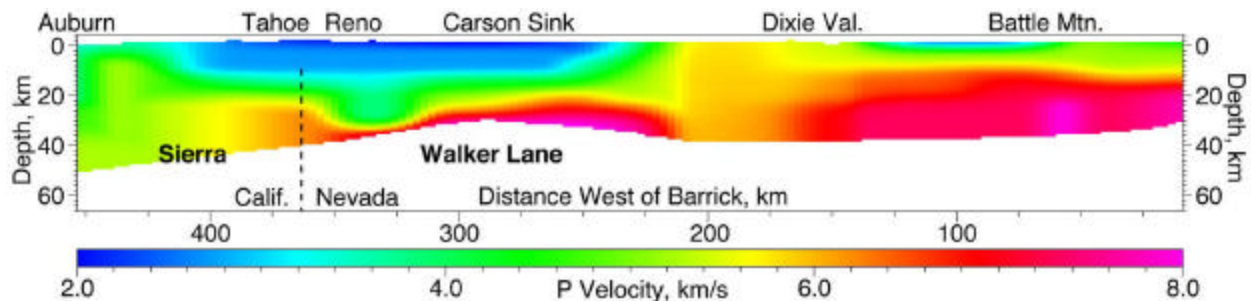
**Figure 3:** Maps showing trial geothermal index values across the Great Basin (front), and a spatial gradient of the index (back). Diamonds show geothermal power sites, sized according to production.



**Figure 4:** Earthquake moment release in the Great Basin, which correlates spatially with magmatic geothermal systems (squares) but not with extensional tectonic systems (purple circles). Mapping by M. Coolbaugh.



**Figure 5:** Compact 20-channel Reftek RT-125 “Texan” crustal refraction recording system acquired under the previous year of this project (front). 199 Texans owned by the NSF during deployment on the No. Walker Lane Refraction Survey, May 2002 (back).



**Figure 6:** Crustal cross section resulting from the May 2002 No. Walker Lane Refraction Survey from Auburn Calif. to the Barrick GoldStrike mine in Nevada (figure 1). Mantle velocities, purple, are unexpectedly shallow (20 km) below the Battle Mountain heat-flow high, and more than 45 km deep below the Sierra, suggesting the range has a thick crustal root.

**Figure 7:** Addition of No. Walker Lane Refraction Survey crustal-thickness results to pre-existing data. Figures give the difference in depth between the pre-existing, extrapolated depths and our new, localized measurements. The more precise depths allow clean separation of magmatic (thick crust) from extensional geothermal systems (thin crust). The proposed surveys will fill remaining data gaps to better define the extent of thin crust under northern Nevada. Mapping by M. Coolbaugh.

