

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

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

### **Assembly of a Crustal Seismic Velocity Database for the Western Great Basin**

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#### **ABSTRACT**

This project will assemble a three-dimensional reference seismic velocity model for the western Great Basin region of Nevada and eastern California. Exploration for hidden resources requires a realistic three-dimensional crustal model to understand the deep sources of geothermal heat in the crust. 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. Crustal properties and thickness are known only at wide spacing, but the structure of the urban basins and some geothermal regions is known at some detail.

We will compile 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. We will also collect one new crustal refraction profile between mine blasts across the northern Walker Lane, poorly characterized at present. The proposed seismic recording equipment will capitalize Mackay's ability to continue to gather such basic information.

The resulting seismic velocity model will consist of simplified rule-based representations of some of the region's sedimentary basins. Shallow velocities will be constrained by geotechnical data; seismic receiver-function and refraction analyses will constrain Moho depths. The model will be specified in a form compatible with computer codes developed for SCEC; and contributed to the associated projects by Shevenell and Garside, UNR-NBMG, if funded, to assemble geographic databases of geothermal indicators.

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## **Project Description**

### **PROJECT OBJECTIVES**

This project will assemble a three-dimensional reference seismic velocity model for the western Great Basin region of Nevada and eastern California (figure 1). This model will be rule-based and distributed as software on the Internet, similar to the SCEC Community Velocity Model (CVM) of Magistrale et al. (2000). These qualities will make the model useful for multidisciplinary research activities including geothermal exploration, mineral exploration, earthquake-hazard assessment, high-precision microearthquake location and source-parameter estimation, and crustal-structure imaging.

A faculty geophysicist and a graduate student will assemble this model almost entirely from existing results. The project will both include literature review and examination of gray literature and data donated by the geothermal, mining, petroleum, and geotechnical industries. We will assemble especially detailed information on Nevada's major sedimentary basins. We will also conduct an inexpensive, 3- to 5-day seismic refraction survey, 500 km long, between mine blasts and crossing the northern Sierra Nevada and Walker Lane.

### **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. Crustal properties and thickness are known only at wide (100 km) spacing, but the structure of the urban basins 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 (Savage and Sheehan, 2000; Ozalaybey et al., 1997; Fliegener et al., 1996; Humphreys and Dueker, 1994). By assembling a velocity model for the entire western Basin and Range (fig. 1), we will be able to look for crustal features, similar to those under known geothermal resources, that may be closer to Southern California power markets.

The acquisition under this project of 25 Reftek RT-125 "Texan" seismic recorders will assist our effort to acquire the 500-km-long refraction profile across the northern Sierras and Walker Lane. An additional 150 recorders we will borrow from the IRIS/PASSCAL Instrument Center for the experiment, for the cost of shipping and batteries. However, these instruments are in great demand, and scheduling of our experiment will be constrained by other projects. We have used the PASSCAL Texans at the UNR Seismo Lab several times in the past two years, and feel certain that we will be able to borrow the instruments and complete the experiment within the project year. The 25 instruments we propose to acquire will enable UCCSN geophysicists to continue smaller-scale refraction experiments regardless of the PASSCAL schedule.

### **RESEARCH PLAN**

Velocity information will be compiled from sources in the literature, results of previous seismic experiments and earthquake-monitoring projects, and data donated from mining and petroleum companies. We will also collect one new crustal refraction profile between mine blasts near Auburn, Calif., and Battle Mountain, Nev. (fig. 1). This new profile will assess crustal velocities across the northern Walker Lane, poorly known at present.

The resulting seismic velocity model will consist of simplified rule-based representations of some of the region's sedimentary basins (e.g., Las Vegas, Reno, Carson Sink, Dixie Val., Railroad Val., Indian Wells Val., Death Val.). Available basins will be embedded in a 3-d crust over a variable-depth Moho, as

developed by SCEC for southern California. Shallow velocities will be constrained by geotechnical data; seismic receiver-function and refraction analyses will constrain Moho depths. The model will be specified in a form compatible with computer codes developed for the SCEC Community Velocity Model; and contributed to the associated projects by Shevenell and Garside, UNR-NBMG, if funded, to assemble geographic databases of geothermal indicators.

Harder and Keller (2000) demonstrated that a 150-km-long deployment of 300 PASSCAL Texan instruments could be completed in a single day, with the efforts of seven crews of 2 or 3 people. They observed crustal P, Pg, PcR, PmP, and SmS phases from a single ripple-fired mine blast. The proposed profile is three times as long as Harder and Keller's (2000), and will be reversed between mines in the western Sierra Nevada and west of Carlin (figure 1). However, the profile is centered on Reno and entirely accessible from Interstate 80. Thus, the proposed budget only needs include wages for three undergraduate helpers in addition to the PI and graduate assistant, and funds for 5 vehicles for the 3-5 days we anticipate for layout and pick-up. The profile will use 150 Texans; the PI as well as students have been trained in their use during two completed experiments.

Aside from the single inexpensive refraction survey, most of the proposed effort will be to assemble 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. Dueker and Sheehan (1997) tracked upper-mantle discontinuities across the Snake River Plain (figure 1) with long-period receiver functions.

*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).

*Moho depth*— Mooney and Braile (1989) and Kaban and Mooney (2001) reviewed all available constraints on Moho depth for the western Great Basin (figure 1). We will find out if Dueker and Sheehan (1997) also made shorter-period receiver functions more suitable for estimating mantle depths in the northern Great Basin. For the central Great Basin constrained receiver-function analyses are available from Ozalaybey et al. (1997). The proposed refraction survey between mine blasts will provide Moho depth information across the northern Sierra and Walker Lane (figure 1), where constraints are poorer than to the south near Death Valley.

*Middle & lower crustal velocities*— Mooney and Braile (1989), Thompson et al. (1989), and Fliedner et al. (1996) provide reviews of crustal velocity information that will form a basis for a 3-d crustal velocity model. This model will be parameterized as functional profiles at the locations of control points, with interpolation extending the model laterally between controls. In the northern and eastern Basin and Range control may be sparse enough that we will need to employ the CRUST 5.1 global model of Mooney et al. (1998). Ozalaybey et al. (1997) constrained crustal velocity profiles at several locations in the central Great Basin, establishing low-velocity zones exist at very few. We will assemble as well published and unpublished studies of joint aftershock relocation and velocity inversion such as by Asad et al. (1999) for the Eureka Valley sequence north of Death Valley (figure 1).

*Upper crust*— Louie and Qin (1991) and Louie et al. (1997) used surface waves and COCORP reflection surveys to constrain upper-crustal velocities west of Death Valley (figure 1). The optimization methods of Pullammanappallil and Louie (1993; 1997) have proved effective in obtaining velocities to 5 km depth from reflection surveys. We will pick and optimize first-arrival and reflection times where needed from available COCORP and industry data. 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 compile all available information from reflection stacking velocity analyses, and seek to examine copies of commercial spec surveys, abundant in the Carlin gold trend.

*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 have already developed rule-based velocity models for the Las Vegas and Reno basins, from the published depth and density data, and viewable at <http://www.seismo.unr.edu/ftp/pub/louie/reno/basinseis.jpg>. These models are expressed in Java code. One measurement of shear velocity to the basement has been done in Reno (Louie, 2001), using the method of Horike (1985), Liu et al. (2000), and Satoh et al. (2001a). COCORP stacking velocities from basins will provide a few P-velocity constraints for basins between Reno and Carlin, and near Death Valley; spec seismic data we are able to view will gain us some data for the central Great Basin.

Unlike how Magistrale et al. (2000) created the SCEC CVM with rules for formation depths and velocities gained from oil wells, Nevada's urban basins have far too few deep boreholes. However, SCEC's CVM must be accurate for basins under compression, with kilometers of thrust deformation. All of Nevada's urban basins are principally extensional, and still receiving sediment. We propose to form the western Great Basin model using instead rules for depth within a basin, and possibly the basin's proximity to Tertiary volcanic centers, and its age and subsidence rate. Controlling for these factors, as far as is possible, will enable us to predict velocities within the Las Vegas and Reno basins from the Railroad Valley density profiles, and the Death Valley and Dixie Valley velocity optimizations.

*Geotechnical*— Louie (2000) published some shallow geotechnical velocity information on the Reno basin. We have continued to apply the refraction microtremor technique in and around this basin, resulting in measurements at a dozen rock sites around the basin. Many of these measurements were made at borehole sites with assistance from local engineering consultants. During both project years we will seek out geotechnical data from consultants working in both Las Vegas and Reno. We will seek out as well shallow geophysical data such as the study between Death Valley and Las Vegas (figure 1) by Shields et al. (1998).

## **DESCRIPTION OF DELIVERABLES**

(1) September 30, 2002: a brief report will be delivered to the funder outlining the sources of existing velocity information mined to date, reporting on the acquisition and performance of the new Reftek "Texan" instruments, and preliminary data from the refraction experiment.

(2) February 2003: a brief report outlining and referencing all data sources will be delivered to the funder. In addition, we will describe the form of the velocity database and its transmission to cooperating GIS projects. We intend to present an interpretation of this crustal model to industry at the 2003 GRC meeting.

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

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

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

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**Figure 1:** Map of Great Basin physiography, with the area of the proposed Western Great Basin Model enclosed by the dashed line.

## Biographical Sketch of John N. Louie

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### Professional Experience

**Associate Professor of Seismology**, Seismological Laboratory and Department of Geological Sciences, The University of Nevada, Reno; since January 1992. Responsibilities include undergraduate and graduate instruction, supervision of M.S. and Ph.D. degree candidates, and conducting a research program in seismology.

**Assistant Professor of Geosciences**, The Pennsylvania State University, University Park, Pennsylvania; Sept. 1987 to Jan. 1992. Responsibilities included undergraduate and graduate instruction, supervision of M.S. and Ph.D. degree candidates, and research in high-resolution seismology.

### Recent Graduate Theses Directed

Ph.D. Thesis in Geophysics by Robert E. Abbott on "Geophysical constraints on seismic hazard and tectonics in the western Basin and Range" defended on 23 Aug. 2001.

Ph.D. Thesis in Geophysics by Abu M. Asad on "Linearized and nonlinear travel time tomography for upper crustal velocity structure of the western Great Basin" defended on 23 Jan. 1998.

M.S. Thesis in Hydrogeology by Ken Mela on "Interpretation of stochastic hydrogeologic properties from seismic data" defended on 14 Nov. 1997.

Ph.D. Thesis in Geophysics by Sergio Chavez-Perez on "Enhanced imaging of fault zones in southern California from seismic reflection studies" defended on 4 Aug. 1997.

M.S. Thesis in Geophysics by Zakir Kanbur on "Seismic reflection study of Upheaval Dome, Canyonlands National Park, Utah" defended on 17 July 1997.

### Selected Recent Sponsored Research

Evolution of the Sierra Nevada - Basin and Range boundary — tephrochronologic and gravity constraints on the record in Neogene basin deposits, sponsored by the National Science Foundation 6/00-5/02 for \$55,182 between 3 PIs.

Analysis of shallow site response to LARSE-2 blasts at precarious rock sites near the San Andreas fault, sponsored by the Southern California Earthquake Center 7/99-3/02 for \$37,270 between 3 PIs.

Geophysical test of low-angle dip on the seismogenic Dixie Valley fault, Nevada, sponsored by the National Science Foundation 9/97-8/99 for \$91,313 between 3 PIs.

Seismic hazards in the vicinity of Las Vegas and Reno, sponsored by the U.S. Geological Survey 4/99-3/01 for \$100,000 between 4 PIs.

Reflectivity structure below San Fernando Valley from Northridge aftershock recordings, sponsored by the National Science Foundation 9/94-2/96 for \$46,978.

Geophysical constraints on extensional models for the Death Valley region of California and Nevada, sponsored by the National Science Foundation 8/94-8/97 for \$70,256.

### Graduate Education

California Institute of Technology, Pasadena, California. Degrees: Ph.D. Geophysics, June, 1987; M.S. Geophysics, June, 1983.

### **Relevant Publications**

- J. N. Louie, 2001, Faster, better: shear-wave velocity to 100 meters depth from refraction microtremor arrays: *Bull. Seismol. Soc. Amer.*, 91, no. 2 (April), 347-364.
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### **Other Important Publications**

- J. N. Louie, S. Chavez-Perez, S. Henrys, and S. Bannister, 2002 in press, Multi-mode migration of scattered and converted waves for the structure of the Hikurangi slab interface, New Zealand: accepted for *Tectonophysics* Aug. 17, 2001.
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### **Current External Support — John N. Louie**

- National Science Foundation/Tectonics: Evolution of the Sierra Nevada - Basin and Range Boundary — Tephrochronologic and Gravity Constraints on the Record in Neogene Basin Deposits, \$55,182, 6/1/2000 - 5/30/2002, Cashman, Louie (0.25 summer month), Trexler.
- National Science Foundation/SCEC: Site Response Investigations at Critical Precarious Rocks Near the San Andreas Fault, \$20,000, 4/01/2001 - 3/31/2002, Louie (0.5 summer month), Anderson, Brune, Anooshehpour.