The crustal thickness of the Great Basin: using seismic refraction to assess regional geothermal potential

Heimgartner, Michelle$^{1,2}$, John N. Louie$^{1,2}$, James B. Scott$^{1,2}$, Weston Thelen$^3$, Christopher T. Lopez$^1$, and Mark Coolbaugh$^4$

1. University of Nevada, Reno, Department of Geological Sciences and Engineering
2. Nevada Seismological Laboratory
3. University of Washington, Department of Earth and Space Sciences
4. Great Basin Center for Geothermal Energy, University of Nevada, Reno

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Abstract

When assessing the geothermal potential of the Great Basin, crustal thickness provides valuable regional-scale information: if the crust is thin, Earth’s mantle is closer to the surface, heat flow can be higher, and the potential for geothermal energy may be greater. In addition, crustal thickness when combined with temperature gradient, gravity, fault location, and strain rate data sets, can allow us to better understand the factors that control the occurrence of geothermal activity. In order to assess the crustal thickness of the Great Basin in poorly constrained areas, we have completed three long-range seismic refraction transects. Our Northern Walker Lane (NWL) refraction experiment, completed in 2002, confirms the presence of a thin crust ranging from 19-23 km-thick in a 100 km-wide region near Battle Mountain, Nevada (Louie et al., 2004) with a southern extent defined by our 2004 Idaho-Nevada-California (INC) transect. Both tomography model sections show an unexpectedly deep crustal root (>50 km) beneath the northern and central Sierra Nevada. Our third experiment, the 2005 Northern-Nevada-Utah transect (NNUT) will provide crustal thickness data in an area with geothermal potential and where no refraction data currently exist. We have also compiled a contoured crustal thickness map for the Great Basin from current results of the INC and NWL experiments, as well as other previous work in the region.

Figure 1: Location map of the Northern Walker Lane (NWL), Idaho-Nevada-California (INC) and Northern-Nevada-Utah transect (NNUT) seismic refraction experiments. The yellow stars indicate the earthquake locations and the orange stars represent mine blasts used as seismic sources for the three experiments. The dotted yellow line is the location of the PASSCAL 1986 refraction survey.
1. Introduction

Since 2002, we have completed three, long-range seismic refraction experiments: Northern Walker Lane (NWL) in 2002; Idaho-California-Nevada (INC) in 2004; and most recently Northern-Nevada-Utah transect (NNUT) in 2005 (Figure 1). The purpose of these refraction experiments is to obtain basic information about crustal thickness and seismic velocity over a region that had not yet been extensively characterized, as well as to show that the use of commercial mine blasts as a seismic source is cost-effective. Regional assessments of geothermal potential can benefit from a general understanding of crustal properties, including thickness and seismic velocity. When crustal thickness and crustal velocity are compared with other crustal properties such as temperature gradient, gravity, fault location, and strain rate data sets, we are able to better understand the relationships that control geothermal activity. The commencement of new seismic refraction experiments (NWL, 2002; INC, 2004; NNUT, 2005) in northern Nevada (Louie, 2002; Louie et al., 2004; Heimgartner et al., 2005) adds to the crustal thickness data available, which were summarized by Braile et al. (1989).

2. Crustal thickness map

We have compiled a contoured crustal thickness map (Figure 4) based on the NWL (Louie et al., 2004) and INC seismic refraction results presented in this paper, as well as previous geophysical studies within the Great Basin (literature cited in the comprehensive Braile et al., 1989; and from Catchings and Mooney, 1991; Hauge et al., 1987; Jones and Phinney, 1998; Krishna, 1988; Mangio et al., 1993; Özalaybey et al., 1997; Potter et al., 1987; Valasek et al., 1987; and Wernicke et al., 1996). We extracted information concerning crustal thickness from the crust-mantle (Moho) refraction velocities and arrival times, crossover distances, and from models presented in the literature. In areas where refraction results are not available, we used compilations of seismic reflection and telesismic receiver-function results (Hauge et al., 1987; Jones and Phinney, 1998; Mangio et al., 1993; Özalaybey et al., 1997; Potter et al., 1987; and Valasek et al., 1987). Also, a preliminary version of this map was used in assessing areas for future refraction experiments, such as our NNUT experiment completed in August 2005 (Figure 1). The contours were created using a kriging algorithm with little smoothing. On a first-order basis, the contoured crustal thickness data (Figure 4) correlate well with heat flow observations for the Great Basin, as illustrated by the temperature gradient map in Figure 5 (Coolbaugh et al., 2005).

3. Northern Walker Lane (NWL) refraction experiment

In May 2002, 199 portable seismographs, Ref Tek RT-125, “Texan” instruments, connected to 4.5 Hz geophones were laid out across the 450 km-long Northern Walker Lane transect. The Texans recorded an 84,000 lb (38,000 kg) blast from Barrick’s GoldStrike gold mine near Battle Mountain, NV. We also caught a rare blast at the Logan granite-aggregate quarry in Watsonville, CA on the San Andreas fault (near San Francisco, CA; Figure 1) that registered magnitude 2.2 on the regional seismograph network. This refraction survey detected an unexpectedly deep crustal root under the northern Sierra Nevada range, over 50 km in thickness and possibly centered west of the topographic crest (Figure 2; Louie et al., 2004). Our observations of Moho refraction delays of 4-6 seconds support this interpretation. At Battle Mountain, Nevada, we observe
anomalously thin crust over a limited region approximately 100 km-wide, with a crustal thickness of 19-23 km as presented in our NWL tomography model (Figure 2). Crustal refraction crossover distances of less than 80 km support this anomaly, which is surrounded by observations of more typical, 30 km-thick crust (Figure 2; Louie et al., 2004).

4. Idaho-Nevada-California (INC) refraction experiment

Along the 600 km-long INC transect, we deployed 411, 24-bit Texans connected to 4.5-Hz geophones to record mining blasts and small earthquakes. Our initial tomography inversions (using Pullammanappallil and Louie, 1994) for the INC refraction transect include one 169,000 lb (77,000 kg) blast from the Barrick’s GoldStrike mine near Battle Mountain, NV and a magnitude 2.8 earthquake occurring in Paso Robles, CA. Future inversions will include three more GoldStrike blasts of similar size, a blast at the Round Mountain Mine (Figure 1) and several more small magnitude earthquakes from within the interior of our line, located in Tom’s Place, CA and Tokop, NV. The earthquakes range in magnitude from 1.5-2.0.

The preliminary INC transect tomography model (Figure 3) shows relatively normal, 30 km-thick crust just south of the Battle Mountain region, possibly defining the southern limit of the very shallow-Moho region near Battle Mountain, NV identified by the NWL transect (Louie et al., 2004). This 30 km-thick crust concurs with the 1986 PASSCAL refraction experiment (Figure 1). Near Battle Mountain, NV, our initial tomography model was not able to confirm the extremely thin crust defined by the NWL transect; however, Moho crossover distances of less than 95 km in both the NWL and INC records support the thin crust model (Heimgartner et al., 2005; Louie et al., 2004). Future inversion models from the INC data should provide more accurate crustal thickness estimates within the Battle Mountain region. The INC inversion model also shows a 50 km-deep crustal root beneath the Sierra Nevada Mountains, now adding evidence for an inferred continuous crustal root from Auburn, CA to Fresno, CA. The crustal thickness map of Figure 2 does not interpolate along the root between the NWL and INC results, where few constraints exist.

5. Northern Nevada Utah transect (NNUT) refraction experiment

We located the Northern-Nevada-Utah transect (NNUT) across an area west of the Wasatch Front (Figure 1) that lacked previous refraction data. This northeastern Nevada and northern western Utah area is also of interest for its geothermal potential (Figure 4). We completed the 600 km-long transect in August 2005. The transect extends east of Battle Mountain, NV, across the Wasatch Front, south of Salt Lake City, Utah and ends just west of the Utah-Colorado border (Figure 1). Like the INC experiment, we deployed 400 Texans connected to 4.5 Hz geophones. The Texans recorded for a total of 58 hours and captured blasts from Barrick’s GoldStrike (117,000 kg), Kennecott’s Bingham Canyon, and Simplot’s phosphate mines (Figure 1), as well as a magnitude 4.0 earthquake on the Wasatch range-front fault. During the experiment, Kennecott’s Bingham Canyon mine was rearranging the approach to ore and had to bring down a large portion of one of the pit walls, requiring a ~300,000 lb (136,000 kg) blast, one of their largest ever. Data from this transect should constrain the eastern extent of thin crust near Battle Mountain, NV. It will also clarify the transition between the Basin and Range and the Wasatch front, adding to our understanding of the tectonic processes in the Great Basin.
6. Conclusions

The Northern Walker Lane, Idaho-Nevada-California and Northern-Nevada-Utah transects are contributing to our efforts to understand regional geophysical properties and their relationships to the occurrence of geothermal resources. Our refraction experiments will help provide a more accurate crustal model for the northern Great Basin where little previous seismic refraction control exists. From our Northern Walker Lane and Idaho-Nevada-California transects, we observe an unexpectedly deep crustal root (>50 km) beneath the northern Sierra Nevada range. Near Battle Mountain, Nevada, we observe anomalously thin crust over a limited region approximately 100 km-wide, with a crustal thickness of 19-23 km and a southern extent limited by the INC transect. To first order, our crustal thickness map correlates well with heat flow in the Great Basin as illustrated in the temperature gradient map (Figure 5). Once processing is complete, our NNUT refraction experiment will better constrain crustal thickness and provide insight into the crustal-scale tectonics of the northeastern Great Basin.

These experiments are a successful demonstration that crustal refraction profiles can be obtained using mine blasts and a dense array of portable seismographs. Costly refraction shots were not needed to model crustal thicknesses where mine blasts could be recorded. Acquiring refraction data in poorly constrained areas also contributes to regional tectonic and geologic models. A detailed resolution of crustal thickness makes it possible to quantitatively evaluate the role that crustal-scale processes play in controlling the location of geothermal systems, and that evaluation is in progress.

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References


Figure 2: Tomography (velocity section) model for the Northern Walker Lane refraction experiment. Seismic sources for the model include a 38,000 kg (84,000 lb) blast at Barrick Goldstrike near Battle Mountain, NV and a quarry blast in Watsonville, CA (near San Francisco, CA; Louie et al., 2004). To compute this tomography model, an optimized simulated-annealing inversion was used (Pullammanappallil and Louie, 1994). The dotted line shows an interpretation of depth to the Moho across the section. Since there were no NWL receivers west of Auburn, shallow velocities are not constrained in that part of the section. 2x vertical exaggeration.

Figure 3: Tomography (velocity section) model for the Idaho-Nevada-California refraction experiment. Seismic sources for this model include a magnitude 2.8 earthquake in Paso Robles, CA and a 77,000 kg (169,000 lb) mine blast at Barrick Goldstrike near Battle Mountain, NV (see Figure 1). To compute this preliminary section, an optimized simulated-annealing inversion was used (Pullammanappallil and Louie, 1994). White areas have no tomography ray coverage; in this result there is no constraint on crustal thickness north of GoldStrike mine. West of Fresno, CA there are no receivers; therefore, shallow velocities are not constrained in that part of the section. 2x vertical exaggeration.
Figure 4: Kriged crustal thickness map for the Great Basin. Colored circles with black centers are data compiled from the INC and NWL (Louie et al., 2004) refraction experiments presented in this paper, as well as previous geophysical studies within the Great Basin (literature cited in the comprehensive Braile et al., 1989, and Catchings and Mooney, 1991; Hauge et al., 1987; Jones and Phinney, 1998; Krishna, 1988; Mangio et al., 1993; Özalaybey et al., 1997; Potter et al., 1987; Valasek et al., 1987; and Wernicke et al., 1996).
Figure 5: Temperature gradient map for the Great Basin after David Blackwell, Southern Methodist University (Coolbaugh et al., 2005). The colored circles with black centers are the same crustal thickness data as in Figure 2, with the same color coding for thickness. The crustal thickness data are presented here to show the correlation between crustal thickness and heat flow within the Great Basin.