An Idaho-Nevada-California refraction experiment: utilizing large mine blasts for long-range profiles
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Summary
Utilizing commercial mine blasts and local earthquakes, as well as a dense array of portable seismographs, we have achieved high-resolution crustal refraction profiles across northern Nevada and the central Sierra Nevada Mountains. Using a dense spacing of 411 portable seismographs and 4.5 Hz geophones, the instruments were able to record events ranging from large mine blasts, small local earthquakes (approximately magnitude 2), as well as two larger earthquakes (magnitudes 2.8 and 3.8). Our instruments sensed blast first arrivals out to a distance of approximately 400 km. We have obtained 99% data recovery and clear refractions across the Sierra Nevada and the northern Great Basin regions.

Introduction
In August 2004, we completed a 600 km-long refraction transect extending from the Idaho-Nevada border, through Battle Mountain, Nevada and western Nevada, across the Long Valley caldera and the central Sierra Nevada, and into Fresno, California (Figure 1). The high-resolution refraction profiles will contribute not only to our ongoing exploration of the Basin and Range Province, but this experiment is also a successful example of the recording methods employed. The motivation for this research stems from an ongoing collaboration to create a Great-Basin-wide crustal thickness profile to assess the regional potential for geothermal resources. The Idaho-Nevada-California (INC) refraction experiment will provide important information on crustal thickness, where few constraints currently exist. The transect’s continuous crossing over the Sierra Nevada will also supply pertinent information in evaluating the depth of the central Sierra crustal root, as well as contribute to our understanding of Basin and Range tectonics.

Methods
Along the 600 km-long transect, we deployed 411, 4.5-Hz geophones connected to 24-bit single channel portable seismographs to record mining blasts and small earthquakes. The portable seismographs, known as RefTek “Texans,” were programmed to record for a total of 96 hours (four 24-hour periods) on the dates of August 16, 17, 19, and 20. Although mine blasts are triggered only during daylight hours, we wanted to insure the instruments would gather earthquakes occurring at night. In our previous 2002 experiment, instruments were only programmed to record during working hours. Valuable earthquakes that would have served as refraction reversals were missed (Louie, 2004).

The recorder array consisted of instruments with 64 or 32 megabytes of memory. The 32 Mb instruments were retrieved halfway through the experiment for a 24-hour period to download data and change batteries. We programmed the seismographs to sample at 50 Hz, slower than commonly used in refraction recording. The recovery rate for instrument hardware was 99.5%. The data recovery rate was over 99%.

During the deployment, the instruments were buried at least one foot (0.3 m) beneath the ground surface to help

Figure 1: Map indicating the location of the Idaho-Nevada-California (INC) transect and locations of previous refraction experiments including the Louie et al. (2004) Northern Walker Lane refraction experiment.
diminish noise and insulate instrument clocks from changes in temperature. Noise such as traffic and industrial operations played a minimal role, as the transect only crossed three highways (395, 50, 80) in this undeveloped region. In addition, two teams hiked fifteen of the 411 instruments into the John Muir Wilderness and over the Sierra Nevada crest, recording at 11,500 ft (350 m) in elevation. This is now the first continuous refraction experiment to cross the Sierra Nevada. The success rate deploying instruments at assigned sites was 100%.

Modeling our experiment after Harder and Keller (2000), we utilized blasts from Nevada gold mines: Barrick GoldStrike; Round Mountain; and Cortez, as seismic sources for this experiment. However, our experiment tested the limitations of the original experiment; Harder and Keller (2000) used one mine blast to record a high-density profile out to a distance of 150 km. This experiment takes the original idea a step further by looking at first arrivals out to a distance of at least 400 km, and by recording earthquakes.

In disseminated gold deposits, high revenues and levels of production depend on crushing large quantities of rock. Our experiment reaped the benefits of 200,000 lb ANFO blasts (90,000 kg). Explosives were detonated within arrays of 40-ft (12 m) holes, providing a nicely controlled source. The shot holes were ripple-fired, but video recording shows all firing is within a 0.5 second interval.

We also employed earthquakes located by the California Integrated Seismic Network and the Western Great Basin Seismic Network. These earthquakes provided reversals from the Barrick GoldStrike blasts, as well as crustal refraction values along the interior of the transect.

**Seismic Data**

Preliminary results show clear and detailed crustal refractions, including reversed profiles made possible by a magnitude (M) 3.8 Lake Nacimiento, CA earthquake on August 16, 2004, and a M 2.8 Paso Robles, CA event on August 20, 2004.

First arrivals from the Barrick GoldStrike blast can be picked to a distance of approximately 400 km to the southwest and out to the Idaho border in the Owyhee plateau. Initial first-arrival picks exhibit 5.9 km/s Pg and 7.4 km/s Pn apparent velocities (Figure 2). A crossover distance of only 95 km is apparent. A similar short crossover at only 72 km in the Battle Mountain, Nevada area was noted by Louie et al. (2004).

We observe a 6.0 km/s Pg apparent velocity and a possible 7.2 km/s Pn apparent velocity from a M 2.8 Paso Robles, CA earthquake (Figure 3). The earthquake’s first arrivals are present in our records out to 435 km, almost 600 km from the epicenter. The Lake Nacimiento earthquake (M 3.8) was also visible, but the larger earthquake provided more difficult first-arrival Pn picks. Although Pg picks were clear, the complicated nature of the earthquake provided more emergent Pn arrivals.

![Figure 2](image_url)  
Figure 2: Barrick GoldStrike blast on August 19, 2004. The blast occurs 8 seconds before the origin time of this profile. The transect extends from Fresno, CA (SW) to the Idaho-Nevada border (NE), an approximate 600 km distance.
An Idaho-Nevada-California refraction transect

Small M 1-2 local earthquakes, such as those at Tom's Place, CA (Figure 4) show pickable first arrivals to distances of 100 km. Later phases are observable to 400 km distances. The crustal apparent velocities range from 5.7 to 6.4 km/s.

The pronounced detail of the profiles is in part due to the 1.5 km spacing of the receivers in a continuous crossing through northern and central Nevada, as well as across the central Sierra Nevada. This detail is evident in the crispness of the first arrivals and shows lateral velocity changes apparent as undulations in the travel-time curves.

Conclusions

The INC transect is a successful demonstration that crustal refraction profiles can be achieved using mine blasts and a dense array of portable seismographs. Costly refraction shots may not be needed to model crustal thicknesses. This experiment will also provide a crustal model for the central Walker Lane and Sierra Nevada tectonic provinces, for which little seismic refraction control exists. In addition, it will contribute to efforts correlating regional geophysical properties and the occurrence of geothermal resources. Acquiring refraction data in poorly constrained areas also contributes to global data-gathering efforts such as the Crust 2.0 model (Mooney et al., 1998; Mooney et al., 2004).

Figure 3: Paso Robles, CA Earthquake (M 2.8), August 20, 2004. The approximate 600 km long transect extends from Fresno, CA (SW) to the Idaho-Nevada border (NE). The earthquake occurred 13 seconds before the start of this record.

Figure 4: Tom's Place, CA earthquake, August 19, 2004. The earthquake initiated 5 seconds after the start of this record. The INC transect covers an approximate distance of 600 km.
An Idaho-Nevada-California refraction transect

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References


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