# Annual Report

**Project Title**: Advanced High Resolution Seismic Imaging, Material Properties Estimation and Full Wavefield Inversion for the Shallow Subsurface :

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**RESEARCH OBJECTIVE**: Develop and test advanced near vertical to wide-angle seismic methods for structural imaging and material properties estimation of the shallow subsurface for environmental characterization efforts.

## RESEARCH PROGRESS AND IMPLICATIONS:

In 2000 we conducted 3-D seismic reflection, tomography, and downhole seismic studies at Operable Unit 2 (OU2) at Hill Air Force Base (HAFB) in Ogden, Utah. OU2 has been the subject of ongoing remediation efforts to remove dense nonaqueous phase liquids (DNAPLs) that contaminate a shallow (less than 20 m) aquifer. This study builds on initial results from our 2-D survey (Dana et al, 1999) that successfully demonstrated the capability of seismic techniques to image a buried paleochannel that acts as a contaminant trap for DNAPLs within the near surface area of the site.

### Background

The basic premise of our research is based on the observation that the shallow subsurface, subject to hydrologically enhanced chemical and mechanical weathering processes, is geophysically an exceedingly complex environment, with the result that conventional seismic imaging methods can break or produce misleading results if applied blindly. Our results from seismic surveys at Hill Air Force Base have confirmed this premise.

Hill Air Force Base, Ogden, Utah, has proven to be an excellent test site for acquisition of high resolution seismic data and development of processing algorithms for imaging the shallow subsurface. Operable Unit-2 at HAFB is a ground water contamination site, where trichloroethene (TCE) was dumped into unlined trenches dug into Quaternary alluvium on the side of a mesa. The mesa borders and stands above an agricultural area. About 4-15 meters of poorly consolidated Quaternary alluvium rests on a clay unit known as the Alpine formation. The top of the clay layer was incised by paleo-streams, leaving a paleochannel crossing the OU-2 site. The base of the paleochannel is now at 5-15m depths beneath the surface. The TCE, a DNAPL, has ponded at the base of the shallowest groundwater in the lowest points of the paleochannel, complicating remediation efforts. For complete remediation, the extraction wells have to be located at the low points in the buried paleochannel. Despite drilling over 270 wells in an area ~50 by 100 meters, the site is still not characterized well enough to complete cleanup.

### Methods

The success of the 2-D survey at HAFB led us to conduct a 3-D survey in 2000 on a grid roughly 40m by 90m, spanning a significant fraction of the OU-2 site. The 2000 experiment suite consisted of a 3-D reflection experiment, a 3-D tomography experiment, 6 check shot surveys, and 2 VSP's combined with surface seismic recording. The 3-D reflection survey was designed with help from the Western Geophysical 3-D group, at no cost to DOE, and involved extensive analysis of the pilot 2-D reflection data. Analysis and processing of the large 3-D reflection dataset is ongoing, but it appears that the survey has been quite successful. The 3-D tomography experiment consisted of a single deployment of all ~600 receivers. Analysis of these has been completed and the resulting sub-surface model is shown in Figure 1. Approximately 200,000 picks from 350 shots were been inverted using a 3-D tomographic algorithm that has been further developed as part of this DOE grant (Zelt et al. 1999).

The VSP (vertical seismic profile) recordings were made in 2 wells separated by 21m. Surface data were also collected between the 2 wells. This double VSP-surface seismic experiment was designed to estimate material property variations as well as image the subsurface . Both traveltime topography and full waveform methods are being applied to the VSP/surface dataset, and preliminary results of this work are presented in Figure 2.

**Results**

The results from 3-D seismic tomography experiment have been completed (Figure 1). The surface velocity is ~120 m/s and increases smoothly to water velocity (1500 m/s) at ~10m depth. The horizontal slices through the model between 10 and 12 m depth (Figure 1) most clearly show the paleochannel structure running roughly north-south in the middle of the model as a low-velocity anomaly, as expected for a channel feature. To test the spatial resolution and reliability of the final 3-D tomographic velocity model, we have applied a series of checkerboard tests.

The double VSP-surface seismic experiment was designed to estimate material property variations as well as image the subsurface (Figure 2). First arrival traveltimes from the data were picked for use in 2-D traveltime tomography. The 2-D velocity model obtained form the traveltimes was then used as a starting model in the inversion of the first arrival waveforms using the method of Pratt (1999) producing a considerably more heterogeneous velocity model than the traveltime tomography. Significant velocity fluctuations occur on the 2-3 m scale throughout the image, and particularly at relatively shallow depths.

**Future Work**

Over the next year we plan to complete our analysis of the 3-D reflection data and VSP data, and this should provide an adequate picture of the paleochannel in three dimensions to support remediation activities.

**Information Access**

Center for Computational Geophysics homepage:

http://terra.rice.edu/department/ccg/

CCG members homepages:

http://terra.rice.edu/department/faculty/alan.html
http://terra.rice.edu/department/faculty/czelt.html
http://www.trip.caam.rice.edu/txt/bios/symes/william_symes.html
http://terra.rice.edu/department/students/azaria/
http://terra.rice.edu/department/students/dana/
http://terra.rice.edu/department/students/fcgao/

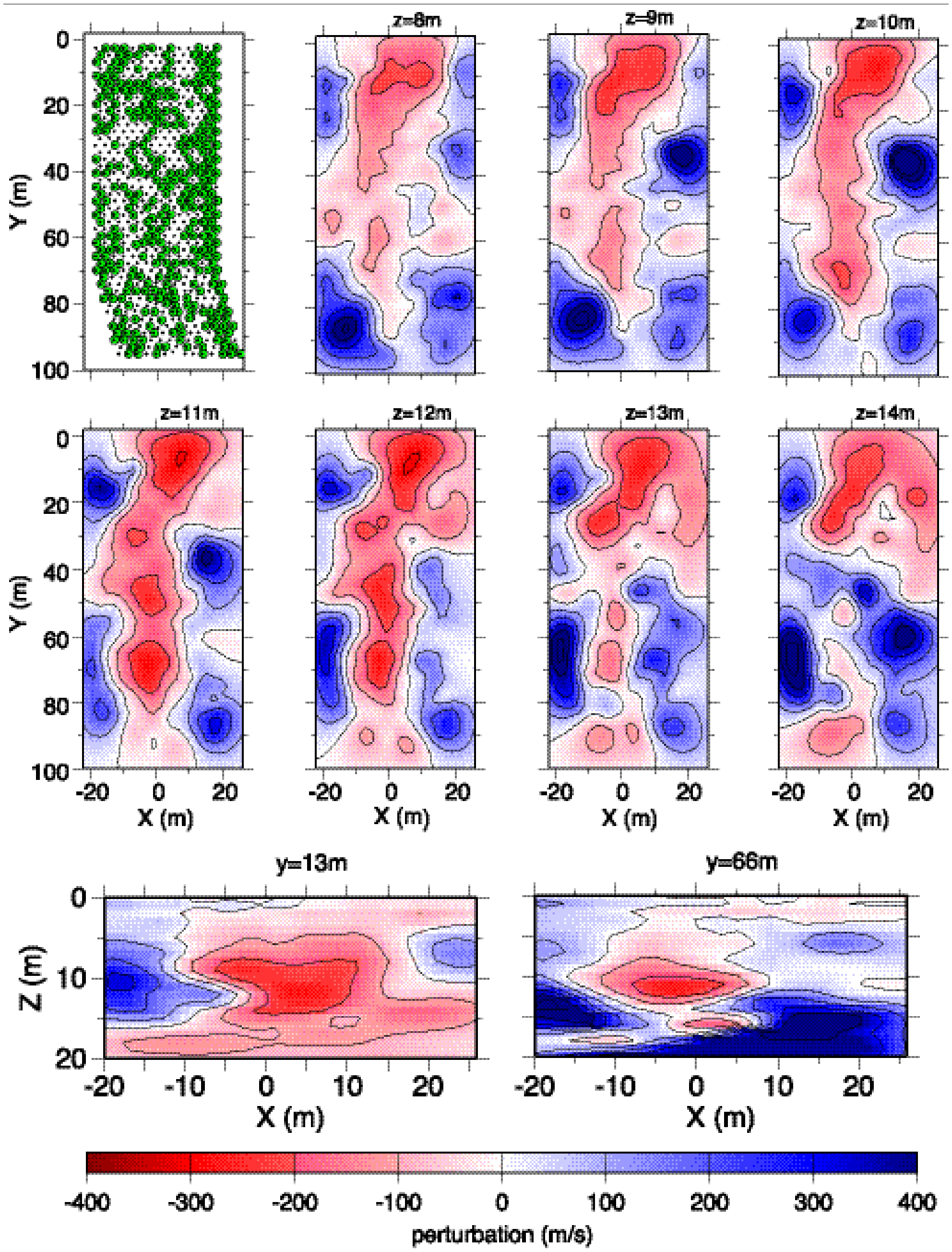


Figure 1. Horizontal (top) and vertical (below) slices through the final 3-D velocity model obtained from 3-D travel tomography. The slices are presented as perturbations with respect to the 1-D starting model. The depth (z) and north-south position (y) is indicated above each horizontal and vertical slice. The top left diagram shows the 349 shots (green dots) and 618 receivers (black dots) used in the 3-D traveltime tomography.

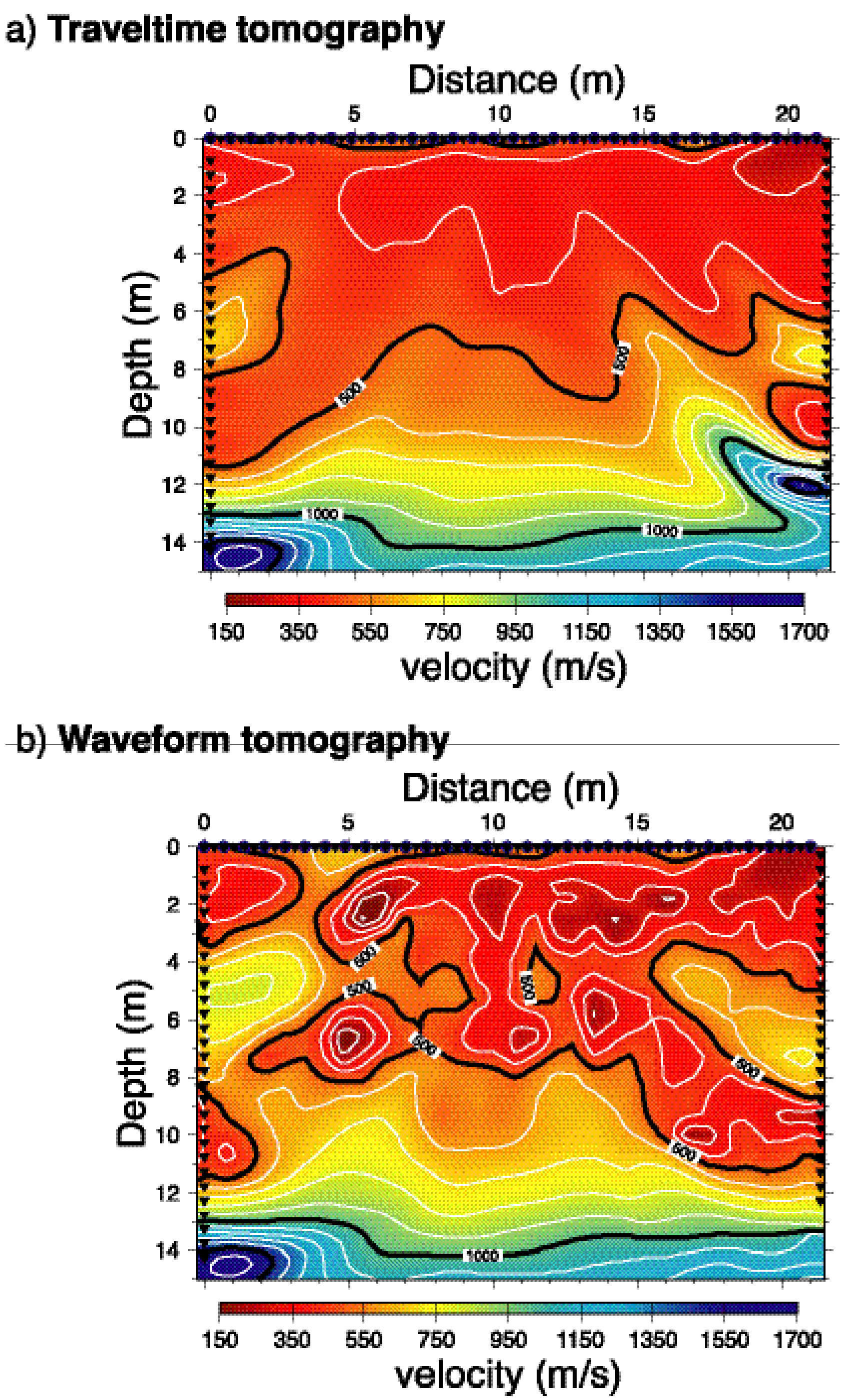


Figure 2. (a) Velocity model derived from first-arrival traveltime topography for the VSP/surface seismic experiment. A smoothed version of this model was used as input to the waveform inversion. (b) Velocity model derived from waveform inversion. The velocity varies laterally by a factor of 2-3 on a scale of 2-3 m, and changes vertically by an order of magnitude over 15 m.

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