Final 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:

As of year 5 of a 5 year project we have completed the project outlined in our original grant. The project included data acquisition, software development, and data analysis. At present the only substantive tasks ahead of us are to synthesize and publish our results. In 1998 we conducted 2D seismic reflection and refraction experiments at Hill Air Force Base Operable Unit Two (HAFB OU2), part of a Superfund site at which the dense nonaqueous phase liquid (DNAPL) tricholorethene (TCE) has contaminated a shallow aquifer (Dana et al, 1999). OU2 has been the subject of ongoing remediation efforts to remove DNAPLs that contaminate a shallow (less than 20 m) aquifer. The 2D seismic results showed that we could image a shallow paleochannel incised in a clay acuiclude that acts as a structural trap for the DNAPLs. To provide structural maps of high enough detail and general enough to be useful for the engineers engaged in site cleanup, in July-Auguest 2000 we conducted 3-D seismic reflection, tomography, and downhole seismic studies at HAFB OU2. This study had now produced subsurface images that characterize the site at a number of different scales, from the several tens of meters to the submeter scales (Levander, et al., 2003).

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

3-D Travel-Time Tomography

The analysis of the 3-D travel-time tomography experiment has 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.

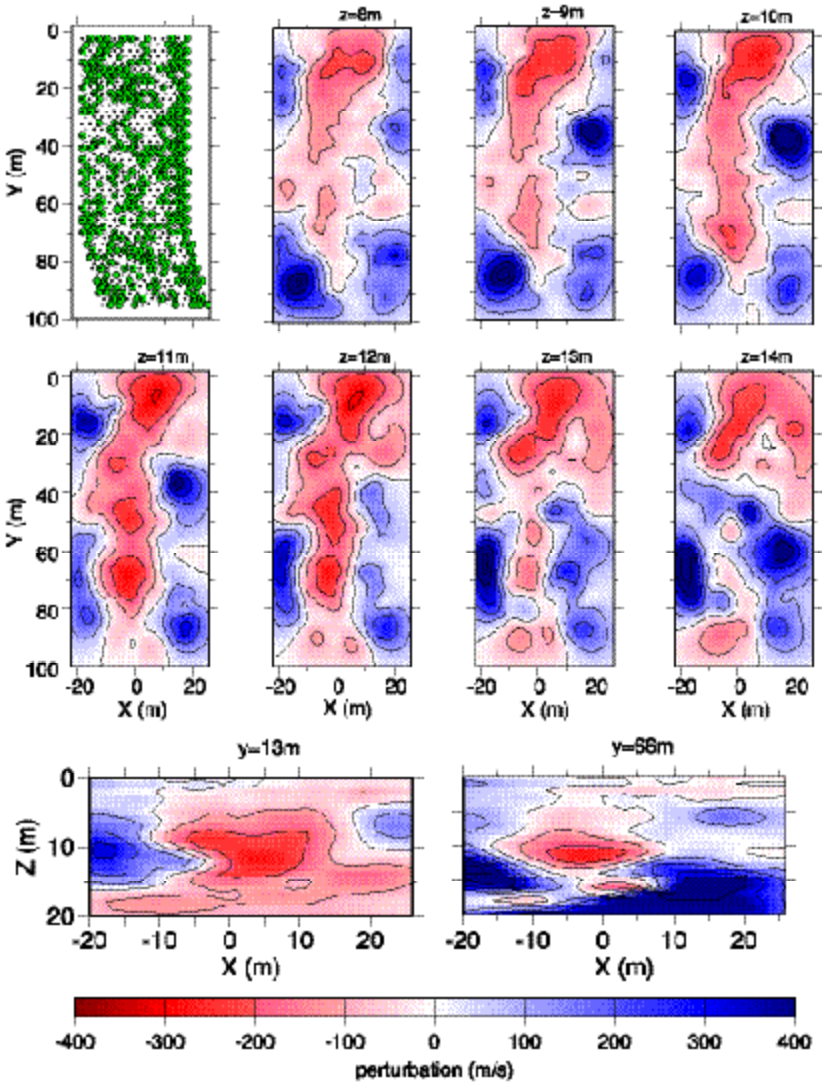

Figure 1. Horizontal (top) and vertical (below) slices through the final 3-D velocity model obtained from 3-D travel tomography. The slices are presented as perturbations with respect to the 1-D starting model. The depth (z) and north-south position (y) is indicated above each horizontal and vertical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

3-D Reflection Data

The 3D reflection data have now been processed through post-stack depth migration (Figure 2). The images correspond well to estimates of the channel made by the travel-time tomography experiment and from interpolation of the well data, as well as to the higher resolution waveform tomography compressional velocity sections (see next paragraph).

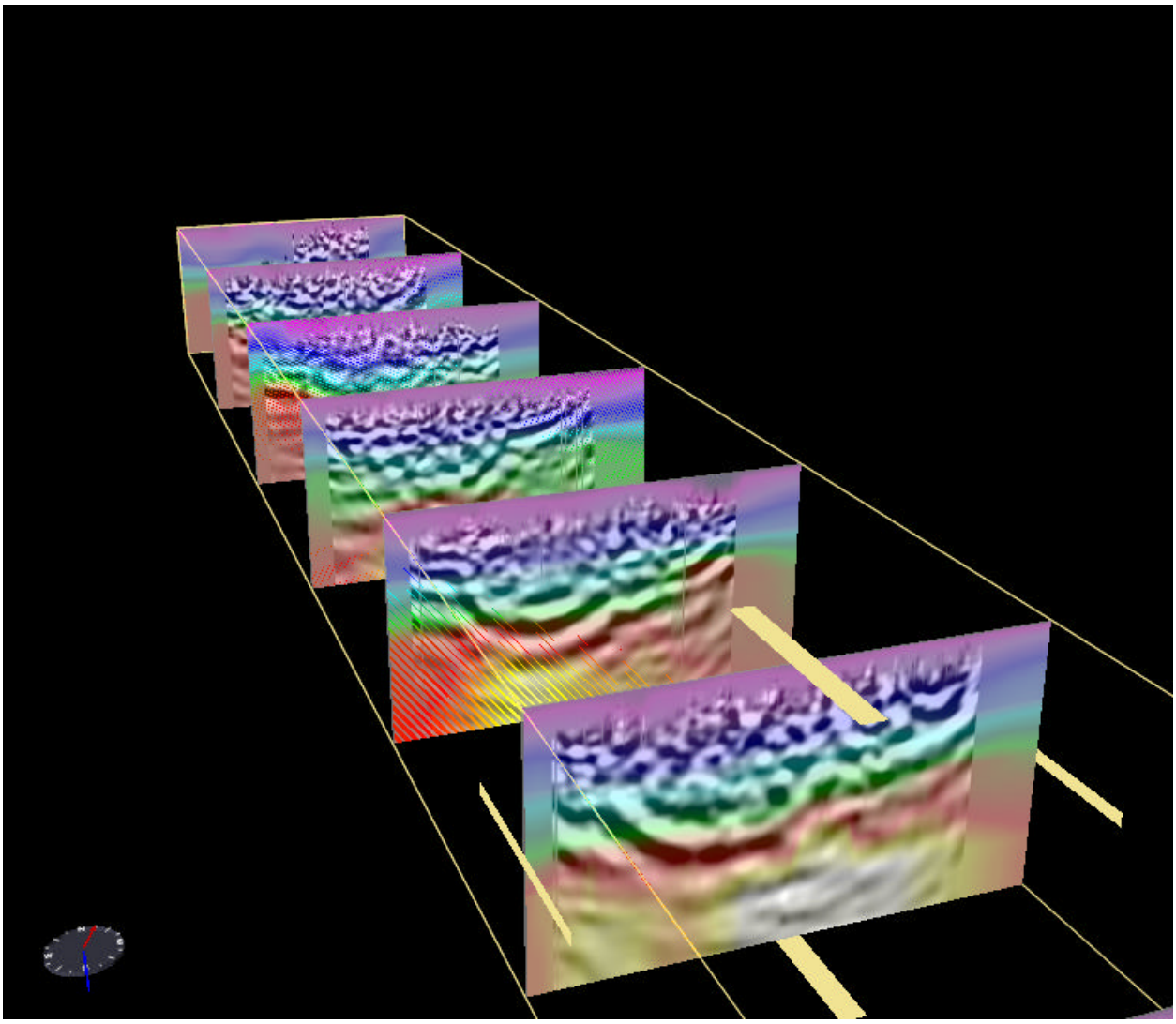

Figure 2: Every 50th post-stack depth migrated inline section from the northern 44m of the 3-D reflection dataset. Spacing between sections is 8.75m. Inline depth sections are superimposed on a smooth version of the corresponding 3-D compressional velocity model from the travel-time tomography (see Figure 1). The channel is clearly delineated in both the reflection image and velocity model. Violet is ~200 m/s. Red is ~1000 m/s.

Waveform Tomography

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 waveform tomography method of Pratt (1999) producing a considerably more heterogeneous velocity model than the traveltime tomography. Additional waveform tomography images have been made from all of the 3-D reflection inline profiles that intersect the VSP profile. Significant velocity fluctuations occur on the 2-3m scale throughout the image, and particularly at relatively shallow depths.

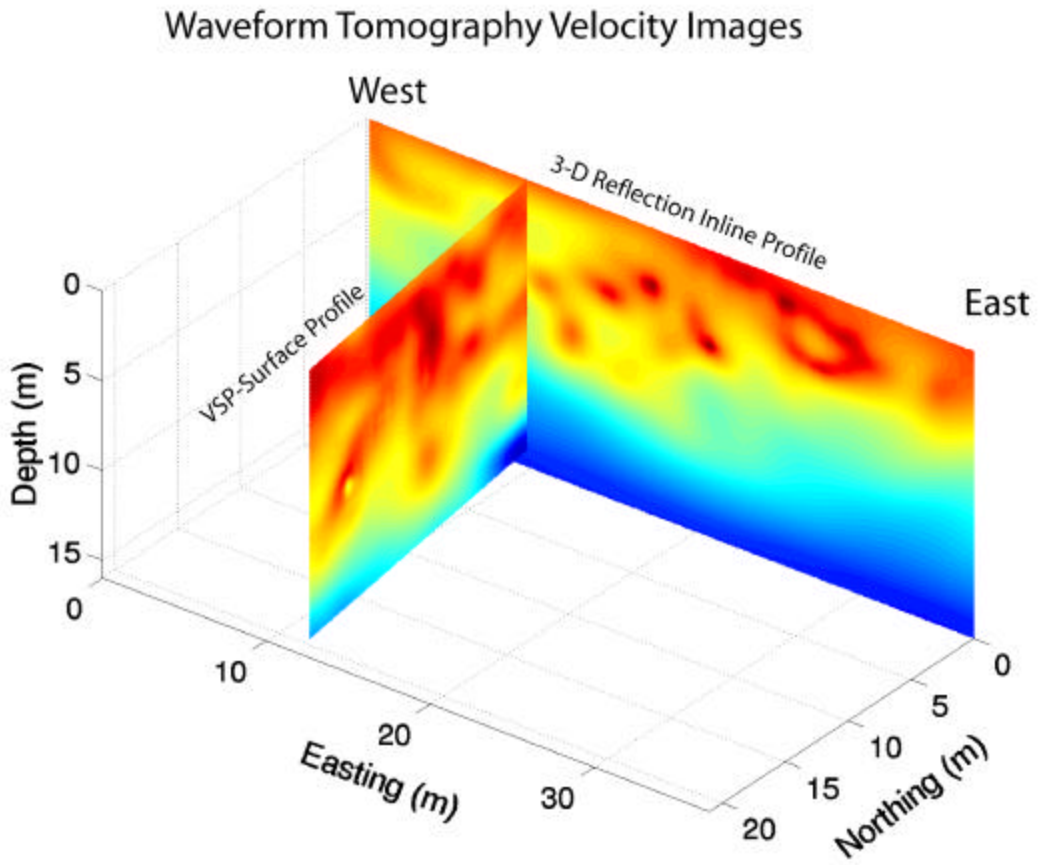

Figure 3. (a) Velocity profiles derived from first-arrival waveform tomography for the VSP/surface seismic experiment and one of the shot-receiver lines from the 3-D reflection survey. The velocities vary laterally by a factor of 2-3 on a scale of 2-3 m at any depth, and changes vertically by a factor of 7-8 in a depth of 15 m.

Planned Activities

The first task left to undertake is to write a number of papers for publication describing this research. We are working on manuscripts on the 3D travel-time tomography, the waveform tomography, the 3D reflection data, and an overview paper. A paper on the 2D experiments has been completed and will be submitted shortly.

To finish this project, and begin the work for our recently funded renewal grant, we intend to complete waveform tomography on every near-source receiver line (~45 profiles) from the 3D reflection survey. A second task is to incorporate the waveform tomography velocities into the migration velocity models for 3D prestack depth migration of the 3D reflection data.

Information Access

Center for Computational Geophysics homepage:

http://earthscience.rice.edu/department/ccg.cfm

CCG researchers' homepages can be accessed through http:// earthscience.rice.edu

http://www.trip.caam.rice.edu/txt/bios/symes/william_symes.html

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