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

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Research Objective

We are developing advanced seismic data processing, imaging, and inversion methods for high resolution seismic reflection/refraction imaging and material property estimation of the shallow subsurface. The imaging methods are being developed to map the structural and material properties of aquifers and aquitards.

Research Progress and Implications

This report summarizes work completed in the first seven months of a three year project which began in November 1997. Our research is proceeding along three lines : data acquisition, data processing, and algorithm development.

Last fall we visited a waste site at Hill Air Force Base near Ogden, Utah as a potential site for a high resolution seismic study. Unfortunately the onset of winter precluded field operations last fall. The region has been studied extensively with drilling, electromagnetic studies, as well as some previous seismic refraction investigations. The seismic target is a paleostream channel in the top of a clay layer along which trichloroethylene (TCE) solvents collect in low spots. There are a number of obstacles to overcome to use this as one of our test sites, but these are fairly common problems encountered in shallow imaging. The previous refraction studies appear to show that the near surface seismic velocity is very low (there is some ambiguity in the reports, but it looks like 300-400 m/s is the near surface velocity), and the target we are interested in is very shallow (15m), requiring a rather high frequency seismic source (200-400 Hz). On the other hand the near surface is rather poorly consolidated sands and gravels which implies high seismic attenuation. We are examining various seismic sources which might be utilized. In the meantime, we have a rather lengthy work plan to prepare to gain access to the site, and we have an OSHA safety training course to take. We also visited a DOE site at Lawrence Livermore National Lab which has also been extensively studied previously. In this case the site has been investigated with crosswell and surface seismics, which showed a very high near surface seismic attenuation. It appears to us that this may also pose some interesting challenges that would be worth investigating.

In the meantime, we are processing high resolution data we acquired prior to the beginning of this study. In 1996 we conducted a high resolution seismic survey along the rim of an open pit porphyry copper mine in Southwest New Mexico. The survey employed reflection, refraction and transmission profiles in order to image features exposed in the mine walls. The local geology consists of a sedimentary layer, the Gila conglomerate, overlying crystalline rock. The crystalline rock includes unaltered country rock and mineralogically altered rock that is the ore for the local mining operation. For this study, targets for imaging include bedding within the Gila conglomerate; the unconformity between the sedimentary layer and the crystalline basement; the contact between altered and unaltered crystalline rock; and near surface structural features.

Dynamite and hammer data were acquired, processed separately, and then combined into a total mine depth section. The combination of data from the two source types provides seismic resolution at two slightly different scales (bandwidth of 20-80 Hz for dynamite and 60-150 Hz for hammer) and

a validation of individual source results. Following initial data clean up, bandpass filters were used to remove low frequency and 60 Hz noise. Various types of deconvolution including surface consistent decon were applied to the data. Surface-consistent decon produced the best results. Data from both source types were still dominated by strong ground roll and linear noise masking the weaker reflections. The coherent noise was removed with f-k filters.

An initial velocity model was constructed using ray-based 2 D inversion of the surface to surface travel times. The model included the strongly variable velocity in the most shallow subsurface, but was unable to resolve velocity variations below the sedimentary layer. Extending the model to 2.5 D by incorporating travel times from transmission and refraction data, allowed us to adequately constrain velocities below the sedimentary layer, and construct a velocity model for depth migration. Following CMP processing, data from both source types were poststack depth migrated using the velocity model and combined into a seismic section of the total depth of the mine.

The seismic results correlate with visible expressions of the formations within the walls of the mine. Specifically, we see: 1) Sedimentary bedding within the conglomerate, 2) The contact between sedimentary sequence and gneiss, 3) The contact between mineralized and unaltered gneiss, and features such as 4) The fracture zone at the contact between mineralized and unaltered gneiss, which acts as a conduit for groundwater movement.

The feasibility of simultaneously imaging differences in lithology, contrasts due to mineralogic alteration, as well as structural faulting has implications for directing the mining operation. Locating structural features, such as those controlling groundwater flow, also has environmental applications. The consistency of the independently processed data sets provided a valuable internal check for the validity of the overall processing scheme.

In terms of algorithm development we have continued work on wide-angle migration and travel time tomography. In order to determine the three-dimensional long-wavelength velocity model needed for pre-stack depth migration, a traveltimes tomographic approach is being developed for both refracted and reflected arrivals. The forward step uses a finite difference solution of the eikonal equation, and therefore is ray-theory accurate. Traveltimes from pre and post critical arrivals are used in a combined, simultaneous reflection and refraction tomographic method, much like that developed by Zelt and Smith (1992) for two dimensions, except on a uniform grid. Tomographic inversion for refracted arrivals has already been developed and thoroughly tested (Zelt and Barton, 1998), and the forward calculation of reflection traveltimes from an arbitrary surface defined on a uniform grid has also been completed. Current work centers around including the reflected arrivals in a regularized inverse scheme, and “tying” the velocities between the layers to the interfaces.

Planned Activities

The 3-D travel-time tomography should be completed by the end of the first year of the proposal. Within the next 6 months we will conduct at least one high resolution seismic survey and possibly two, one of which will be either the Hill AFB site or LLNL, the other of which will be a control site at Rice. We already have traditional CMP data from this site. We will refine the migration velocity focusing algorithms we have developed, and apply them to the test near vertical to wide-angle seismic datasets that we collect.