Advanced High Resolution Seismic Imaging, Material Properties Estimation, and Full Wavefield Inversion for the Shallow Subsurface : Annual Report: DOE DE-FG07-97ER14827

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

RESEARCH PROGRESS AND IMPLICATIONS: In the past year we have been engaged in:

1) Processing and interpreting seismic data from the Hill Air Force Base Operable Unit 2 waste remediation site (Dana, Araya, Azaria, Zelt, Levander)

2) Designing a 3-D experiment for the Hill AFB site (Morozov, Dana, Zelt, Levander)
3) Developing algorithms for migration velocity analysis for near vertical to wide-angle seismic data (Morozov), and
4) Developing software infrastructure for seismic inversion research (Symes).

We describe the 4 areas of activity in order below.

1) Data processing:

In August 1998 we acquired three seismic profiles at the OU-2 site at Hill AFB, which we described in our previous annual report (see also http://terra.rice.edu/department/ccg). We have now examined data from all three seismic lines and the data from all three seismic sources (accelerated weight drop, 0.22 caliber rifle, and 10 gauge shotgun). The seismic data from Line 2 have now been processed through post-stack depth migration, prestack depth migration, and several versions of traveltime tomography. Line 2 is also being used as the testbed dataset for migration velocity analysis using the software developed under this contract.

Principal results to date: We clearly image the base of the acquifer in the reflection data and correlate the reflections from the bottom of the paleochannel with the available well data. The prestack depth migration produces a considerably superior image to that obtained by post-stack migration, and the preliminary tests of the depth focusing (migration) velocity analysis are the clearest images of the channel that we have been able to form. (Figure 1: Igor's figure). True amplitude Kirchhoff inversion has also produced a fairly clear image of the channel (Figure 2: Kidane's figure).

Obstacles to progress are the development of a completely consistent migration velocity model, the focal point of our software development efforts in the coming year.

Traveltime inversion/tomography of first arrivals has been performed using two different model parameterizations, a layered model (traveltime inversion), and a gradient model (traveltime tomography). It appears that the first arrivals are sensing the velocity in the upper part of the aquifer and the velocity at the top of the water table, but not the top of the clay layer forming the aquitard. This helps us identify the reflections due to the water table in the reflection image and helps us with the starting model for migration, but surprisingly has not helped improve migrations beyond the starting model. The velocity models from first arrival data have too abrupt transitions in velocity to produce coherent reflection images without depth focusing analysis.

2) 3D Survey design

In the past year we consulted with the 3D seismic design group at Western Geophysical to determine the optimal shot/receiver configuration for our 3D seismic reflection experiment. We analysed the 2-D data for coherence and stack power, determining the best source receiver offsets to emphasize in the survey design (4-12 meters), what maximum geophone and shot interval would be tolerable (0.35m), and what source-receiver geometry to employ (staggered brick/ 4-6 parallel lines).

Additionally, Zelt has determined a 3-D experiment design for travel-time tomography.

We had originally scheduled the experiment for June 1999, however the required high frequency sensors were not purchased for the new set of seismic recorders that we intended to employ by IRIS/PASSCAL until October 1999. This was too late in the year to arrange for the 18-20 field personnel (more than half of whom would be graduate students) needed to conduct the experiment. The 3D experiment has been rescheduled for July-August 2000. In the past year IRIS/PASSCAL has acquired both the necessary high frequency sensors and puchased an additional 200 sensors, increasing the number of seismic channels we will be able to field by approximately 40%. The delay of one year will likely greatly improve the quality of the survey that we conduct in 2000.

We also conducted a pilot 3D survey at Rice to determine the best operational model for the Hill AFB study using the new IRIS instruments.

3) Depth focusing algorithm development

Crucial to depth migration using near-vertical to wide-angle seismic data is development of an accurate subsurface velocity model. Depth-focusing refers to a process by which seismic data are iteratively migrated and examined for image quality and image attributes at an intermediate step of the processing before final image formation. Characteristic patterns in the pre-stack migrated data volume are be used to update the short and intermediate wavelength features of the velocity model. The velocity corrections are determined frm traveltime residuals calculated in the pre-stack data volume using a tomographic approach. This processing step can be used with any form of depth migration, and has been implemented for a number of diffraction stack and Kirchhoff integral formulations of the acoustic depth migration integrals. The software development effort has necessarily required development of depth focusing, tomography, data visualization, data coherency, and migration algorithms (Igor's flow chart figure). The current implementation for 2D migration is nearly completed and is now being used to examine the Hill AFB dataset.

4) Full wavefield inversion algorithm development

During the period of this project, we have built a software environment for inversion well adapted to exploration of the complex physics underlying near-surface seismic. This environment consists of three components: 1) a rich software substrate, the Hilbert Class Library ("HCL", development supported by other grants from NSF and DoE), defining interfaces for the common objects appearing in the mathematical statement of the inversion problem: vectors, linear and nonlinear operators, functions, and many state of the art numerical optimization and linear algebra algorithms implemented in terms of these interfaces (Gockenbach et al., 1999); 2) vector classes implementing standard seismic data structures, such as SEGY, as HCL classes; 3) the FDTD class, which encapsulates time-stepping methods in a common HCL operator framework linking seamlessly with the optimization algorithms in HCL (Gockenbach et al., 2000). FDTD also provides the gradient code needed in optimization, through an optimally efficient universal implementation of the adjoint state method, and accomdates automatic differentiation ("AD") of the core time step methods. AD performs differentiation at the level of high-level code (Fortran etc.) and thus eliminates a tedious and error-prone layer of programming from these projects.

A project in summer 1999 joined all of these elements in an implementation of 2D acoustic model driven inversion, which met all expectations. Performance of the inversion modules created in this fashion was the same as, or better than, pure Fortran implementations of the same methods. In the coming months we will integrate the 3D viscoelastic modeling code mentioned above into the FDTD environment. We will also design into the resulting inversion code the capability to adjust the parameters of multipole source and receiver models. Such source and receiver calibration is essential in fitting seismic survey data, especially that produced by land surveys where source and geophone coupling to the Earth is variable. Prior work at Rice has shown that inversion can usefully constrain the parameters of source and receiver models, thus calibrating them to the extent permitted by the data (Minkoff, 1995).

INFORMATION ACCESS:

Center for Computational Geophysics homepage:

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

CCG members homepages:

http://terra.rice.edu/department/faculty/zelt
http://terra.rice.edu/department/faculty/levander
http://www.trip.caam.rice.edu/txt/bios/symes/william_symes.html
http://terra.rice.edu/department/staff/morozov
http://terra.rice.edu/department/students/dana

Papers

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