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Title: **Pre-Stack Migration of Three-Dimensional Seismic Data**

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Pre-Stack Migration of Three-Dimensional Seismic Data

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Abstract

This is the final report of a two-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The project sought to develop and test a three-dimensional pre-stack migration code to run on the Los Alamos CM5. This work was done in collaboration with Texaco. We implemented a version of Texaco's phase-shift with interpolation algorithm on the CM5. We also tested the algorithm on the Cray T3D in collaboration with Cray participants. Processing of seismic data is extremely compute and I/O intensive. We developed methods for efficiently performing both I/O and computing as appropriate for a large three-dimensional seismic dataset. The result was improved capability to image subsurface structures in the earth. Our emphasis was on structures that are beneath salt in the US Gulf Coast, where many oil and gas reserves are known to exist but where identifying them from surface seismic data is currently difficult due to the large impedance contrast between the salt and surrounding strata.

1. Background and Research Objectives

The oil and gas industries rely on seismic data both for exploring for new reservoirs and for maximizing the productivity from existing reservoirs. The seismic data require considerable processing before they can be interpreted. Typical processing steps include wavelet shaping, noise reduction, statics correction (for land data), velocity analysis, normal move-out (NMO), stacking and migration. Of these, all but migration have become fairly well-understood and easily applied procedures. Migration of seismic data moves or migrates the signatures of diffractors from the position in which they were recorded to their correct position on a subsurface image, and thus, is crucial to correctly imaging the subsurface. Migration has become generally used, but usually with simplifying assumptions to minimize the computing necessary. Migration can be the single most important processing step for data taken in areas of complicated geologic structure. For the domestic oil and gas industry, there is increased

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interest in finding petroleum reserves beneath salt structures in the Gulf of Mexico. Imaging beneath salt presents great difficulties because of large contrasts in elastic properties between the salt and the surrounding strata. This contrast limits the amount of seismic energy that can be transmitted through the salt and results in decreased signal to noise ratio for signals returning from horizons located beneath the salt. In addition, the rapid change in material properties violates assumptions that are conventionally used to stack data. For these reasons, both pre-stack time migration, where velocities are considered to vary only with depth, and post-stack depth migration of seismic data fail in areas where seismic waves encounter salt.

Industry believes that pre-stack depth migration, which can correctly handle three-dimensional velocity variations, will allow better images of sub-salt structures to be obtained. The need to do pre-stack depth migration of seismic data has increasingly become the data processing bottle-neck. The amount of seismic data that must be migrated has expanded from Megabytes to Gigabytes to Terrabytes as a result of the change from acquisition of two-dimensional to three-dimensional data sets. To migrate a three-dimensional data set before stack consumes many months of computing alone for a single migration iteration. Several migration-interpretation steps are usually necessary to obtain a reliable result. Thus, an implementation of seismic migration that would reduce processing time by a factor of 10 or 100 is currently an urgent goal of the oil and gas industry. What appears the most likely way to achieve such an implementation is to do the computations on a massively parallel computer.

We are currently developing and testing a code for three-dimensional pre-stack migration to run on a massively parallel computer. Working with researchers from Texaco, we are implementing their phase-shift with interpolation method of doing pre-stack depth migration. Texaco is currently running this code on a cluster of workstations, but the performance they are achieving is not adequate for them to do routine pre-stack processing. They currently cannot process a whole seismic survey through their system. They thus cannot fully realize the potential benefits of the advanced processing. Our objective is to determine if pre-stack migration of three-dimensional data significantly improves the details that can be resolved in the resulting subsurface image. We have investigated several computing platforms and compared codes against other migration algorithms as part of this effort.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in theory, modeling, and high-performance computing as well as earth and environmental systems. It enhances the Laboratory's visibility in modeling petroleum reservoirs and increases LANL's ability to

respond to initiatives in that area. The benefits to both the oil and gas industry and DOE will be in the applications of the new implementation of seismic migration. Exploration targets that are located beneath salt structures will be able to be identified with greater confidence, improving the success rate of domestic oil and gas exploration. Existing reservoirs will be able to be produced more effectively by improved planning of development strategies and more effective siting of development wells. Maintaining and increasing domestic energy production are important goals both for economic as well as national security reasons.

3. Scientific Approach and Results to Date

This project focused on the parallel implementation of the Texaco phase-shift-plus-interpolation approach for performing pre-stack depth migration on three-dimensional seismic data. The algorithm requires many fast Fourier transforms (FFT) to be performed on the data. In addition, there would be significant issues about data transfer between mass storage and the parallel computer that need to be addressed. The first part of the project involved becoming familiar with the Advanced Computing Laboratory computing environment, working with Texaco to install their seismic processing package, SeisPak, on LANL machines, and scoping how to implement the Texaco code on the parallel computers. The SeisPak package is used to control the flow and pre-processing of data, and the visualization of the results. We focused on the coding portion of the project and paid little attention to I/O issues, even though we know they are extremely important when processing large data sets. The I/O issues were minimized by testing codes only on a small subset of the full 40-Gigabyte three-dimensional dataset provided to us by Texaco. The reduced dataset was still of sufficient size to allow us to address the advantages of pre-stack depth migration over other processing methods and to investigate different parallelizing strategies.

We had planned initially to implement the Texaco code on the Thinking Machines CM-5 at Los Alamos National Laboratory. However, when Thinking Machines filed for bankruptcy in the middle of our project, the CM-5 lost its viability to much of the oil industry, including Texaco. Furthermore, our coding efforts on the CM-5 led us to conclude that exploiting specialized MPP architectures requires writing machine-specific code that is useless on other MPP machines. Thus our focus changed to the Cray Research T3D and the distributed parallel-computing environment supported under Parallel Virtual Machine (PVM). Use of PVM allows simpler and more portable implementations of the Texaco code while still exploiting the parallelism of multi-node systems. The final deliverable was a working PVM implementation of the existing Texaco phase shift code. A version that runs on a cluster of

SUN and Silicon Graphics workstations was written first. The code was then ported to the PVM implementation currently operating on the Cray T3D.

In addition to working on the existing Texaco pre-stack migration code, the project investigated some novel approaches to calculating travel times and amplitudes of the forward-propagated source wavefield in complicated structures. Speeding up the source calculation is important to the continued development of more efficient pre-stack migration programs because of the additional computations required to process non-zero-offset data sets. Improving the accuracy of the wavefield calculation improves the resolution of the migrated image by providing better estimates of travel time and amplitude used to satisfy the imaging condition of the pre-stack algorithm.

We have accomplished the following tasks:

- Los Alamos investigators have become familiar with data-parallel programming on the CM-5 and have made test runs of basic programs appropriate for understanding data layouts and vector operations that would have been important for optimizing the migration code for that machine. Enough experience was gained with the CM-5 and migration algorithms to conclude that more standardized architectures and parallel strategies were most appropriate for implementing production-grade migration codes.
- A serial version of Texaco's phase-shift migration code was installed on a workstation at LANL and an initial test run was performed on the reduced Texaco dataset. SeisPak was successfully implemented and tested on LANL workstations and is currently being used as a tool for manipulating and viewing the Texaco data set. PVM was also installed on the workstation cluster. A stand-alone version of the migration code, that can be run on any machine with a Fortran compiler and does not require SeisPak to be installed, has been completed. The appropriate PVM message-passing calls installed in this code allow the program to be spawned on all processing nodes that make up the virtual machine. PVM implementations for our Sun/SIGI cluster and the Cray T3D will be deliverable when the project terminates.
- Some novel approaches to improving the efficiency of pre-stack migration algorithms were investigated. New algorithms for calculating travel times and amplitudes of the forward-propagated source wavefield were developed and two journal papers describing this work have been submitted.

Publications

Cheng, Ningya; House, Leigh; and Fehler, Michael, "Amplitude and Traveltime Calculation Using Higher-order Parabolic Equation," *Seismological Society of America Bulletin*, (submitted).

Cheng, Ningya and House, Leigh, "Minimum Travel Time Calculation in 3D by Graph Theory," *Geophysics*, (submitted).

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