New Methods for Modeling and Processing Seismic Data

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As new oil and gas reserves become more difficult to find and expensive to drill for, there is increased interest in obtaining ever better images of the earth beneath increasingly complicated structures. The demand for processing large seismic datasets to obtain high-quality images has thus become of critical importance. This proposal consists of three parts, each with different participants. and addressing a significant issue in analysis of seismic data. We propose to develop and test new approaches to each of the issues. Although each portion of the project will benefit from progress made by the other two portions, we discuss each part independently to allow a more focused assessment of each project. A budget summary is presented at the end of the proposal.

Fast 3D Modeling and Prestack Depth Migration Using Multi-Screen Wave Propagator

Participants: ARCO, Conoco, Cray Research, nCUBE, Schlumberger, Shell, Sun Microsystems, UNOCAL, Institute of Tectonics at the University of California at Santa Cruz, Earth Resources Laboratory of the Massachusetts Institute of Technology (MIT), Los Alamos National Laboratory (LANL)

Statement of the Problem and Assessment of Current Technology

3D acoustic pre-stack depth migration has been studied and developed over the past several years on a small-scale, experimental level, but owing to the formidable computational costs of existing procedures, practical application has been limited. The two most popular methods are the Kirchhoff ray algorithm and the reverse-time finite difference algorithm. These methods are prohibitively time-consuming for large-sized problems as both 3D ray-tracing and 3D finite difference are computationally intensive processes, even in the acoustic case. In regions of highly complicated structure with large variations in elastic properties, it is necessary to consider both compressional and shear modes of propagation to correctly handle and preserve amplitude during migration adding further to the computational load.

We propose to use the multi-screen (phase-screen for acoustic waves, complex-screen for elastic waves) algorithm as a backpropagator for 3D pre-stack migration in laterally inhomogeneous media. The method is a wide-angle one-way elastic wave propagator that neglects reverberations and adopts a fast dual-domain (space and wavenumber) implementation. The elastic complex-screen (ECS) method has several advantages over conventional approaches: it handles elasticity, it is computer memory efficient, it preserves amplitudes, and it is two to three orders of magnitude faster than the finite difference method.

Technical Approach and Tasks

We propose to refine the multi-screen method and define its range of applicability. The method will be tested against other modeling schemes such as 3D finite difference for modeling wave propagation. We will develop and test a procedure for using the multi-screen algorithms to conduct 3D prestack migration on synthetic and field data. The method will be compared against other modeling and migration procedures in existence or under development at our collaborating companies. We will develop and test a fast 3D forward modeling method for obtaining synthetic data for backscattered waves. We will investigate the importance to oil and gas exploration problems of incorporating elastic wave propagation effects. We will explore the use of hybrid methods to correctly handle multiples. Both the modeling and migration codes will be tested for complex media containing features relevant to petroleum exploration such as salt structures and thrust fold zones. These codes will be implemented on massively parallel computers to compare their characteristics to other methods in a state-of-the art computing environment.

Teaming and Contributions of Each Participant

The basic framework for using the multi-screen method to model elastic wave propagation in complex media was developed by Ru-Shan Wu, the UC Santa Cruz collaborator on this proposal. He developed an approach for using the methods for prestack migration and made rudimentary tests. Santa Cruz will participate in further development and testing of the procedures for modeling and migration.

LANL, ARCO, Conoco, Schlumberger, Cray and Sun will collaborate with UC Santa Cruz in refining the modeling and migration codes and in making them as machine independent as possible.

Cray and SUN will provide access to computer time on T3D and SPARC 2000, respectively, for developing and testing the algorithms; and assistance in optimizing codes for their machines.

MIT and nCUBE will assist in developing hybrid methods for modeling multiples and in optimizing the code for distributed memory machines and distributed machine networks. MIT will contribute synthetic data from 3D elastic finite difference modeling and implement a 3D finite difference migration code on the nCUBE computer to rigorously benchmark the performance and accuracy of the multi-screen method.

Shell, Sun, ARCO and UNOCAL will participate in testing and comparing the method with other existing 3D prestack migration algorithms as well as provide advice and field data for testing the method.

Plan for the Transfer or Commercialization of Results

Codes and results will be made available to all industrial partners in this project. Discussions among all participants will occur at regular intervals to discuss and evaluate progress. University and laboratory participants will publish the scientific results of this work.

Deliverables

FY 95: Develop and refine migration method for elastic/acoustic media using complex screens and test on serial machines. Emphasis will be put on using pressure data. The program will handle either acoustic or elastic models. Test method using synthetic data and comparison with other approaches.
FY 96: Port migration scheme to parallel computers and continue the tests and comparison on synthetic and possibly field data. Develop and test 3D fast forward modeling scheme using ECS (elastic complex-screen) as propagator in complex elastic media. The method will be tested and compared against 3D finite difference method. Extend method or develop hybrid scheme to include effects of reverberations.
FY 97: Test migration code on field data and compare with other methods. Define range of applicability and merits of the method. Port modeling code to parallel computers and test on real field cases.

Statics Estimation for Complex Media Using Prestack Migration

(Participants: ARCO, Cray Research, Western Geophysical, Mobil, Mitchell Energy, Shell, Union Pacific Resources, Center for Wave Phenomena (CWP) at the Colorado School of Mines (CSM), Los Alamos National Laboratory)

Statement of the Problem and Assessment of Current Technology

Irregularities in the near-surface are the major source of structural distortions and deterioration of signal quality in land seismic data. These distortions, which can greatly limit resolution and interpretability of seismic data, are attributed to trace-dependent, time-invariant shifts or “statics” associated with travel time along vertical paths near the sources and receivers. Estimation of residual statics corrections works well where the subsurface structure is layered and relatively uncomplicated, and where data contain little noise. Conventional methods involve estimation of "reference traces," which are cross-correlated with individual data traces to estimate a static time shift for each trace. The reference trace for a common-midpoint (CMP) gather is often constructed from the CMP stack of the normal-moveout (NMO) corrected data traces in the gather. This reference trace emulates the data traces, but lacks static time shifts and has reduced noise. The time lag of the largest peak in the cross correlation is used as an estimate of the time shift for each trace.

Errors in moveout corrections and additive trace noise in the raw data will cause the reference signal to be an inadequate representation of the individual traces in the CMP gather. Also, when structure is complex or there is a rapid stacking velocity variation, moveout of reflections within CMP gathers can be non-hyperbolic, thus degrading the NMO stack. Prestack depth migration properly corrects for non-hyperbolic moveout. Larner and others at CSM therefore have proposed that prestack depth migration be used to overcome the problems of rapid structural variations when estimating statics. Their procedure consists of prestack depth migration, to create a common-reflection-point (CRP) stack of the migrated data, and an inverse depth migration of the CRP stack to obtain a reference trace for each data trace. This method was tested using the 2D Marmousi synthetic data set with added random statics. Those tests demonstrated the viability of the method for data collected in structurally complex environments.

Technical Approach and Tasks

The application of the method to real data must be investigated. In particular, problems of data noise and of imperfect velocity information need to be characterized, and the relative cost to benefit of this computationally intensive method needs to be evaluated. Since the results will depend greatly on the accuracy of the subsurface velocity model used, the method requires an iterative use of migration, and statics and velocity estimation. We propose to investigate the applicability of this method to real data, recognizing that the practicality of the method will depend on developing highly efficient means of doing accurate prestack depth migration and inverse depth migration.

Because of the large amount of computing resources required to use this method, the method will be tested using 2D data. Problem design will be developed and tested in a pilot study on limited 3D data to confirm the results obtained from using 2D data and to explore the feasibility of the method in difficult terrain and where subsurface structure has 3D complexity.

Teaming and Contributions of Each Participant

The methods to be used are under development at CSM. CSM will take the lead in implementing and testing the methods on 2D data. LANL will assist in porting the depth migration and inverse depth migration codes to parallel machines and in verifying their accuracy (particularly for long offsets) Cray Research will provide a collaborator who is knowledgeable in seismic processing and optimization on Cray supercomputers and will provide access to time on one of its massively parallel machines. Industrial partners will contribute land seismic data containing known difficulties in statics estimation and will assist in interpretation of results. They will also provide advice and guidance on prestack depth migration issues.

Plan for the Transfer or Commercialization of Results

Codes and results will be made available to all industrial partners in this project. This project will be part of the CWP consortium at CSM and results will be made available to all members. University and laboratory participants plan to publish the scientific results of this work.

Deliverables

FY 95: Algorithms for 2D prestack depth migration and prestack inverse depth migration on massively parallel machines and possibly on distributed parallel machines. Demonstrations of the feasibility, and tests of the practicability and cost-effectiveness, of convergence toward an improved statics (and velocity) solution in the presence of noise on the 2D Marmousi synthetic data set. Assessment of alternative processing approaches and sequences for addressing the stated statics problem most cost-effectively.
FY 96: Similar tests on at least two field 2D data sets known to suffer from severe statics problems where the subsurface is structurally complex but nominally only in 2D. Algorithms for doing 3D prestack depth migration and prestack inverse depth migration on massively parallel machines.
FY 97: 3D problem design and pilot study on synthetic 3D data (using the SEG/EAEG 3D salt-dome model data, artificially contaminated with statics).

True Amplitude Dip Moveout

Participants: Amerada-Hess, Amoco, ARCO, Conoco, Cray Research, Mobil, Western Geophysical, Marathon, Center for Wave Phenomena (CWP) at the Colorado School of Mines (CSM), Los Alamos National Laboratory

Statement of the Problem and Assessment of Current Technology

Dip-Moveout (DMO) or Transformation-to-Zero-Offset (TZO) is a method that takes data from each fixed offset between source and receiver and transforms it to the “equivalent” data at zero offset, i.e., coincident source and receiver. This requires a propagation speed. It is well known how to do this in such a manner that the “timing” of events (reflector responses) is properly replaced in the equivalent zero offset data. However, knowledge about the effect on amplitude is incomplete. For a planar reflector in a medium of constant background velocity, it has been shown that the geometrical spreading for finite offset is equal to that for zero offset and the angular dependence of the reflection coefficient is preserved. For amplitudes to be corrected for more general cases, the effect on amplitude of reflector curvature must be analyzed.

For regions of interest, one may conduct expensive prestack migration or inversion techniques to study amplitude versus offset for earth parameter estimation. For the purposes of reflector imaging, the combination of DMO and zero-offset processing requires less CPU time than prestack migration. Knowledge of the relationship between the amplitude of the DMO processed data and the angular dependence of the reflection coefficient eliminates the need to do pre-stack migration.

All the information for imaging and parameter estimation is contained in the zero-offset migration and in the DMO processed prestack data that was used to generate that migration, making the analysis of the data faster and cheaper than by current processing techniques.

Technical Approach and Tasks

We propose to investigate amplitude effects by high-frequency asymptotic analysis of the application of a DMO formalism to Kirchhoff-approximate data for a single reflector. It is known that for a planar horizontal or dipping reflector, DMO preserves the angularly dependent reflection coefficient at specular. Furthermore, DMO transforms the finite offset geometrical spreading factor to that at zero offset. It is not known how the curvature of the reflector affects this result. Analysis of this case is our first objective.

The research will first be carried out in the 2.5D case, under the assumption of a line of data gathered over a cylindrical reflector with no variation in the out-of-plane direction, but only along the data line. Furthermore, the background propagation speed will be assumed to be constant in this first study. These results will then be extended to 3D, in which an areal survey is carried out over a general curved reflector. The 2.5D and 3D results will be extended to the case of a depth-dependent background propagation speed.

Kirchhoff data is used for these studies because DMO is a high frequency method that is not restricted to small increments in earth parameters across reflectors. Kirchhoff data exactly fits that model. “High frequency” here means that the wavelengths are small compared to other length scales of the problem; e.g., range to the reflector, radius or radii of curvature of the reflector.

Teaming and Contributions of Each Participant

The methods to be used in this project have been under preliminary development at the CSM. LANL will collaborate with CSM in development of the methods and will assist when running large computational problems at the LANL Advanced Computing Laboratory. Industry will provide guidance needed to define research objectives in a manner suitable for validation using available data. They will also provide data for testing of the methods and feedback on the results obtained.

Plan for the Transfer or Commercialization of Results

Codes and results will be made available to all industrial partners in this project. This project will be part of the CWP consortium at the CSM and results will be made available to all members. University and laboratory participants plan to publish the scientific results of this work.

Deliverables

FY 95: Theoretical results for the case of a curved reflector in 2.5D, constant background. Computer code to process a line of data, tests on synthetic data, field data.
FY 96: Theoretical results for the case of a curved reflector in 3D, constant background, 2.5D in a depth-dependent background. Computer code for the 3D constant background case, tests as above in 2.5D. Design of code for 2.5D and 3D depth-dependent background.
FY 97: Completion and testing of codes in depth-dependent background. Explore theoretical extensions to finely layered media, transversely isotropic media.

Funding Profile by Fiscal Year
FY 1995:

From DOE:	Cost Sharing by Industry:		
LANL: $400K	Shell: $40K	ARCO: $100K	Mobil: $20K
UC: Santa Cruz: $250K	Amoco: $40K**	Sun Microsystems: $75K	nCUBE: $100K
MIT: $100K	Amerada-Hess: $40K**	UNOCAL: $50K	Conoco: $90K**
CSM: $220K	Marathon: $40K**	Cray Research: $125K	Western: $60K**
	Mitchell Energy: $30K	Schlumberger: $10K	Union Pacific: $30K

Total FY 1995 DOE Request: $970K
Total Industry Support: $855K

FY1996*: From DOE
LANL: $400K UC Santa Cruz: $250K
MIT: $100K CSM: $220K

FY1997*: From DOE
LANL: $400K CSM: $220K
MIT: $100K UC Santa Cruz: $250K

* Cost sharing by industry will be similar to first year. Project will be open to additional companies.
** direct collaboration plus portion of contribution to Center for Wave Phenomena