ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

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(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

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(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

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As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

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A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

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There is nothing to report on this program for the reporting period.

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(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

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Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

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Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

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- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

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Highlight:

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

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Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

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- Experiments on stress-stimulated particle mobilization started

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can have strong impacts on porous flow behavior.

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

- Evaluation of conventional and miniature sensors for seismic data

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Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

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Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

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- Experiments on stress-stimulated particle mobilization started

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can have strong impacts on porous flow behavior.

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

- Evaluation of conventional and miniature sensors for seismic data

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Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

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Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

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- Experiments on stress-stimulated particle mobilization started

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can have strong impacts on porous flow behavior.

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

- Evaluation of conventional and miniature sensors for seismic data

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Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

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Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

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- Experiments on stress-stimulated particle mobilization started

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can have strong impacts on porous flow behavior.

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

- Evaluation of conventional and miniature sensors for seismic data

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Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

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Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

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Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

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An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

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- Experiments on stress-stimulated particle mobilization started

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can have strong impacts on porous flow behavior.

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Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

Los Alamos
Los Alamos, NM 87545
(505) 667-7811

Sandia
Albuquerque, NM 87185
(505) 844-7333

Lawrence Livermore
Livermore, CA 94551
(925) 422-5196

Lawrence Berkeley
Berkeley, CA 94720
(510) 486-5085

Argonne
Argonne, IL 60439
(202) 488-2415

Brookhaven
Upton, NY 11973
(516) 344-3819

Idaho
Idaho Falls, ID 83415
(208) 526-7004

Oak Ridge
Oak Ridge, TN 37831
(865) 574-4941

Pacific Northwest
Richland, WA 99352
(509) 372-4565

To: William F. Lawson, Associate Director
National Energy Technology Laboratory
One West Third Street
Suite 1400
Tulsa, OK 74103-3519

From: J. Albright, Los Alamos
D.J. Borns, Sandia
J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
R. Long, DOE-NETL-Tulsa
K. Sterling, DOE-NETL-Tulsa
J. Ammer, DOE-NETL-Morgantown
D. Gurney, DOE-NETL-Morgantown
H. Guthrie, DOE-NETL-Morgantown
B. Gwilliam, DOE-NETL-Morgantown
J. Rogers, DOE-NETL-Morgantown
B. Tomer, DOE-NETL-Morgantown
F. Toro, DOE-NETL-Morgantown
M. Vargas, DOE-NETL-Morgantown

Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

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(ChevronTexaco and LANL)

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Highlight:

- Evaluation of conventional and miniature sensors for seismic data

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Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

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We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

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(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

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(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

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(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

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Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

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ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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Berkeley, CA 94720
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Argonne
Argonne, IL 60439
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Upton, NY 11973
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Idaho
Idaho Falls, ID 83415
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J. Ziagos, Lawrence Livermore
N. Goldstein, Lawrence Berkeley
D. Schmalzer, Argonne
A. Goland, Brookhaven
B. Reynolds, Idaho
J. McFarlane, Oak Ridge
B. Saffell, Pacific Northwest

cy: E. Allison, DOE Fossil Energy
L. Capitanio, DOE Fossil Energy
G. Dehoratiis, DOE Fossil Energy
A. Hartstein, DOE Fossil Energy
B. Hochheiser, DOE Fossil Energy
E. Subia-Melchert, DOE Fossil Energy
N.B. Woodward, DOE Office of Science
D. Alleman, DOE-NETL-Tulsa
J. Casteel, DOE-NETL-Tulsa
N. Comstock, DOE-NETL-Tulsa
R. Lindsey, DOE-NETL-Tulsa
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K. Sterling, DOE-NETL-Tulsa
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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Drilling, Completion, and Stimulation Technology Oil and Gas Recovery Technology Diagnostic and Imaging Technology	Natural Gas Technology Upstream Environmental Technology Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

No report received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell, Whitehill Manufacturing, and ORNL)

No activity to report during this period.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Project closed out.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

This project is on hold until additional funds from DOE are received. Funds are scheduled to be in the August Financial Plan. There will not be a monthly report until the project starts again.

Laboratory Study on Borehole Stability and Sand Production in Weakly Cemented Sand

(ChevronTexaco, Shell, and LBNL)

No report received.

Development of Smart-Proppant Technology for Hydraulic FracturingTubing

(U of Tulsa and INEEL)

As reported during the last period, work continues on the development of polymeric carrier systems as well as the selection and growth of thermotolerant bacteria expressing appropriate enzymes such as beta-mannanase and alpha-galactosidase. Currently, cultures of select organisms have been grown and analysis of enzyme activity is underway. Efforts to develop and verify colorimetric enzymatic tests are also ongoing and will be verified against viscosity reductions. Utilization of colorimetric analysis will greatly reduce the time and resources required to screen or analyze the activity of developed material. Pending completion of this task, beads of material suitable for laboratory proppant-pack inclusion will be generated at the University of Tulsa. These beads will contain viable biomass capable of enzyme expression that will be used for further experimentation.

Application of High-Powered Lasers to Drilling and Completing Deep Wells

(GTI, PDVSA, Parker Geosciences, Colorado School of Mines, and ANL)

Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

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January, March, May, July, September, November	**February, April, June, August, October, December**
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Drilling, Completion, and Stimulation Technology

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

No report received.

Acoustic Telemetry (MWD) Drilling

(ABB, Electroacoustics Research Laboratory, Extreme Engineering, and SNL)

Highlights:

- Sandia National Laboratories and Extreme Engineering win an R&D 100 Award!

Extreme Engineering now offers a commercial version of the Acoustic Telemetry Technology that it has licensed from Sandia National Laboratories. As such, we jointly entered the technology in this years R&D 100 competition. This annual contest, sponsored by the Chicago-based trade magazine *R&D Magazine*, uses technical experts to help determine the best applied new technologies. One hundred winners are chosen from an international pool of contestants from universities, private corporations, and government labs. *R&D Magazine* announced that our technology "has been selected by the independent judging panel and editors of *R&D Magazine* as one of the 100 most technologically significant products introduced into the marketplace over the past year."

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No activity to report during this period.

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Studies on drilling petroleum reservoir rocks with lasers have shown that modern infrared lasers have the capability to spall (thermally fragment), melt and vaporize natural earth materials, with thermal spallation being the most efficient rock removal mechanism. Although laser irradiance as low as 1000 W/cm^2 is sufficient to spall rock, firing the beam on a single spot for too long at that intensity causes rock melting and reduces removal efficiency. Also, it is difficult to visualize an efficient way to create a six or eight inch hole by sending one large beam down hole. Alternatives are either to raster the beam to cover the 20 cm^2 hole area or, using a pattern of many small beams illuminated sequentially or in groups, creating a nearly circular work face. To test this Multiple Small Beam Method, a number of tests were performed (see publication below). The effect on rock removal efficiency of several parameters, including relaxation time between laser bursts, basic patterns of multiple beams, and beam spot overlapping amounts were determined.

The tests indicated that a combination of several small illuminated spots will create a larger hole. The heat is dissipated quickly enough to prevent melting if the spot is allowed to "rest" between illuminations. Major findings include:

1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.

ACTIVITY REPORT

July 2003

Natural Gas & Oil Technology Partnership

Bringing Department of Energy national laboratories capabilities to the petroleum industry.

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1.The tests showed that a large hole can be created without the need for moving parts in the bottomhole assembly, such as a rastering or rotating system;

2.The application of a significant amount of laser energy to a small rock sample without causing the onset of melting is very important. Avoidance of melting is essential to efficient rock spalling;

3.The concept of the transport downhole of laser energy by fiber optics or other waveguide materials is supported by the low power requirements at each of the many spots used to create a large hole in the subsurface; and

4.The power requirements are within the tested capabilities of current fiber optics to significant depths, while technology in the research phase, such as hollow core fibers, will allow the use of laser drilling to depths to which the industry is currently capable using mechanical methods.

Publication

R. A. Parker, Z. Xu, C. B. Reed, R. Graves, B. Gahan, & S. Batarseh, "Drilling Large Diameter Holes in Rocks Using Multiple Laser Beams," submitted to *International Congress on Applications of Laser & Electro-Optics*, Jacksonville, FL, October 13-16, 2003.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

A pump instrumented with a compression chamber pressure transducer has been fabricated by Harbison-Fischer for Texas Tech. It is ready for assembly and will undergo functional testing.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(ExxonMobil, Schlumberger, UT-Austin, and SNL)

There is nothing to report on this program for the reporting period.

Publication

S.E. Minkoff, C.M. Stone, S. Bryant, and M. Peszynska, "Coupled Geomechanics and Flow Simulation for Time-Lapse Seismic Modeling," *Geophysics*.

Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NM Tech, and SNL)

Research continued during this project period on the application of the 2D code and the implementation of the 3D code. In addition to the PI, project staff contributing during this period included graduate interns Dave Boutt (NMT), Dave Farrell (Clarkson), and Scott Johnson (MIT), as well as postdoctoral associate Erik Strack. Our recent work has focused on two activities: 1)the development and testing of 2D model specimens for the sanding simulations; and 2) the integration of the 3D fluid solver with the 3D Discrete Element Modeling (DEM) code.

The model generation scripts for 2D specimens were completed during the project period. These scripts provide a semi-automated means for a user to develop large DEM models with specified particle shape and size distributions. Multiple models were constructed and subjected to numerical biaxial tests to connect the microstructure and particle properties to the bulk material properties. These models will be shared with our industry partners to provide them with a suite of DEM specimens with known bulk properties. They are also being used as the basis for the sanding sensitivity study.

In the 3D code, we completed the implementation of the immersed moving boundary scheme and have partially completed its validation. Validation results include the accurate calculation of the fluid drag and torque on a sphere in low Reynolds flow (compared to an analytical solution), and the accurate calculation of the fluid drag and pressure field for a sphere in an inertial flow (compared to both empirical and other numerical results).

Project Presentations / Publications:

Cook, B.K. et al. "Discrete Element Modeling Applied to Wellbore Modeling", Sandia Workshop on DEM, Albuquerque, NM, July 24, 2003.

Boutt D.F., B.J.O.L. McPherson, B.K. Cook, and J.R. Williams, "Fluid-induced Fracture Initiation and Propagation in Geologic Systems: A Discrete Analysis", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Johnson, S., J.R. Williams, and B.K. Cook, " Application of an Ellipsoidal Approximation for Discrete Element Modeling", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Strack, O.E., and B.K. Cook, "Three-Dimensional Coupling of Particle Motion and Fluid Flow Using the Discrete Element and Lattice-Boltzmann Methods", 7th U.S. National Congress on Computational Mechanics, Albuquerque, NM, July 2003.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, Halliburton, Kerr-McGee, Shell, and SNL)

Work focused on bounding the probable range in constitutive behavior of massive deepwater GoM (Gulf of Mexico) salt bodies via determination of the mineralogic composition. This work is nearly completed. Cuttings were provided by seven industry partners, with XRD analysis costs sponsored by BP, ExxonMobil, and ChevronTexaco. Over seventy cuttings samples were provided from fifteen different fields spanning seven geographic areas across the shelf and deepwater as defined by the Minerals Management Service (MMS), including Green Canyon, Mississippi Canyon, Walker Ridge, Atwater Valley, Garden Banks, Ewing Bank, and Ship Shoal.

The funding agreements to extend the project to Phase 2 for two additional years were signed and executed by the seven companies that will participate in Phase 2. Each company will contribute direct funding for an additional two years to complement the DOE FY03 funding that was received, as well as the continued funding anticipated for FY04.

An Integrated Approach to Assessing Seismic Stimulation

(Aera Energy, ASR, BP Amoco, ChevronTexaco, ConocoPhillips, Halliburton, Marathon, OGCI, Piezo Sona-Tool, Schlumberger,Shell, UC-Berkeley, LBNL, and LANL)

Highlights:

- PI's co-chair stimulation session at SEG Development & Production Forum
- Experiments on stress-stimulated particle mobilization started

On July 20-23, the Society of Exploration Geophysicists (SEG) held its annual Development & Production Forum at Big Sky, Montana. Project PI's attended this forum and presented their research to an audience of 31 attendees from the oil and gas industry, national laboratories, and universities. The PI's also were on the Forum Organizing Committee and chaired a special technical session devoted to current research and application efforts on "Elastic Wave Stimulation of Oil Production". Speakers for six oral and one poster presentation were invited. The keynote speaker, Igor Beresnev of Iowa State University, delivered a talk voted the best of the forum. Several talks from the stimulation session will be presented again at the upcoming annual SEG conference in Dallas, in a special workshop titled "The Best of the 2003 D&P Forum".

Experiments were started to investigate the effects of dynamic stress on sub-pore-scale particle behavior during porous flow. These include both core-scale fluid flow enhancement tests on porous rocks during low-frequency stimulation, and microscopic visualization of micron-size particles in fluids under the influence of high-frequency acoustics. Initial observations indicate three major types of particle behavior that can be induced by acoustics: 1) particle conglomeration and separation; 2) bulk particle transport due to acoustic streaming; and 3) particle attachment to and detachment from solid surfaces. All three affects

can have strong impacts on porous flow behavior.

Final plans were made in July for two different field experiments in diatomite in the Central Valley of California, one at ChevronTexaco Lost Hills diatomite and Aera LLC's south Belridge field. These will be monitored in wells at varying distances with geophones and a wide band (1 hertz to 10,000 hertz) pressure transducer at the depth of stimulation. The stimulation source will be the ASR pressure pulsing device in both cases.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

Awaiting new funding. No work scheduled.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output and LANL)

Highlight:

- Evaluation of conventional and miniature sensors for seismic data

Analyses were completed of seismic line data obtained from sensors deployed at the San Ysidro experimental site. Two separate tests were conducted. In the first test, conventional and miniature sensors were co-located and deployed in a shallow trench. These sensors were used to simultaneously collect data from a 1200-ft seismic line. In the second test, miniature sensors were deployed in an adjacent microhole in a single borehole instrumentation package. Data were recorded from source locations along the same seismic line. An accelerated impact device was used as the seismic source for both tests.

Comparisons were made between the performance of the conventional and miniature sensors deployed in the trench, and between the miniature sensors deployed first in the trench and then in the microhole at a depth of 320 ft. The miniature sensors used included geophones, piezoelectric transducers, a hydrophone, and MEMS devices. With one exception, these sensors were pre-commercial prototypes supplied by commercial companies. The conventional sensors included geophones and a research-grade piezoelectric transducer commonly used in seismic applications. The performance of the transducers was measured on the basis of signal-to-noise over the frequency range of the detected seismic signals.

Analyses showed an expected, but nonetheless striking, attenuation of the surface wave in the signal reaching the microhole transducers as well as a pronounced shift in the detected seismic wave frequencies above 20 Hz to greater than 100 Hz. The overall signal-to-noise response of the best performing sensors did not differ between trench and microhole. Thus the use of microholes allowed acquisition of high frequency seismic waves having a good signal-to-noise ratio that was not possible with surface deployed sensors. Three of the miniature sensors had performances nearly identical to the conventional-sized transducers irrespective of whether they were deployed in the trench or in the microhole. Consequently, these tests have shown that sensors of appropriate size for microhole use and exhibiting performance comparable to full-size conventional sensors exist in the commercial sector.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, ConocoPhillips, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

Carry-over funding for this project is currently being utilized for developing two reports documenting the mathematical theory and numerical algorithm of the full waveform elastic inversion approach. Applications of the inversion methodology to simple synthetic seismic datasets are included in this documentation. Evaluation of the three-dimensional inversion procedure with field-recorded seismic data awaits the identification of a suitable industrial seismic reflection dataset. Finally, an adaptation of the full waveform inversion approach to the seismic amplitude vs. offset (AVO) problem is being developed for a future NGOTP proposal submission.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Fugro Geoservices, GeoCenter, Geophysical Development, GX Technology, Marathon, Mitchell Energy, Paradigm Geophysical, PGS, Phillips, Shell, Unocal, Veritas DGC, WesternGeco, SEG, Stanford University, University of Houston, LANL, and LLNL)

Highlight:

- Synthetic elastic data computations continuing in SEG/EAGE salt model

Synthetic elastic seismic data have been computed for more than 90 shots in Phase II of the 3D calculations in the SEG/EAEG salt structure. Phase II calculations require nearly 700 cpu-hours per shot, and produce nearly 1 GB of synthetic trace data and wavefront data per shot. The wavefront snapshots are produced every 100 time steps and are extremely helpful in interpreting the various arrivals that are seen in the trace data. In addition to simulated marine streamers and Ocean-bottom-cables (OBC), the Phase II simulations include 13 vertical wells, each of which has 291 4-C VSP receivers. Synthetic trace data for selected shots will be made available electronically. Portions of the Phase II data are being made available for use by all individuals planning to participate in the Fall, 2003 SEG workshop.

Rapid Imaging of Interwell Fluid Saturations Using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, ConocoPhillips, ExxonMobil, JNOC, Landmark, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

We have finished testing a new method for utilizing time-lapse pressure observations to infer reservoir permeability. The preliminary results of synthetic testing are very encouraging. Tests indicate that we are able to recover large-scale permeability variations even in the presence of significant errors in the estimates. The technique is very efficient, providing permeability estimates in a matter of minutes.

We have also tested the method using actual time-lapse EM and seismic cross-well measurements from the Lost Hills oil field. The results have been submitted to the *Geophysics* journal. Discussions are underway with our industry partners to apply the technique to 3D time-lapse data.

Offshore Oil Field Characterization with EM Methods

(Scripps, Texas A&M, and SNL)

SNL's efforts toward the development of improved electromagnetic (EM) methods for offshore oilfield characterization has attracted the attention of the Gas Technology Institute. The Institute recently participated in the creation of

the Research Partnership to Secure Energy for America (RPSEA), the goals of which are to pursue research in unconventional natural gas resource development and production from ultra-deep reservoirs. Responding to a call for proposals earlier this year, the SNL/Scripps research team made a successful bid, leveraging this NGOTP-funded oilfield characterization project, to investigate EM methods for characterization of ultra-deepwater natural gas reservoirs. Along with NGOTP and industrial support, this accomplishment represents a significant step toward the goal of creating a long-term SNL/Scripps research group whose expertise encompasses most technologies relevant to sub-seafloor EM imaging, including instrumentation, algorithm development, integrated interpretation and field deployment.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, ConocoPhillips, ExxonMobil, FairfieldIndustries, GX Technology, Petroleum GeoServices, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Highlight:

- Migration imaging

We conducted depth-migration imaging for a cross-well seismic dataset that had been provided by one of our industrial partners using different velocity models obtained from well logs and from tomography. We discussed the preliminary imaging results with the industrial partner, and compared their results using the VSP-CDP mapping approach. The comparison showed that the migration imaging provides better images for some regions of interest compared with the VSP-CDP mapping. The industrial partner is very interested in such applications that also have great potential for future monitoring of CO_2 sequestration.

We conducted further studies of the recently proposed new migration imaging condition to obtain migration images having clear physical meaning, and great potential to provide valuable information for reliable reservoir characterization. We investigated the images for different ranges of reflection angles using different synthetic datasets. This study will help us better understand what ranges of reflection angles are necessary for different depths to produce highest-quality and most-reliable images with the new migration imaging condition.

Testing and Validation of High-Resolution Fluid Imaging in Real Time

(DeepLook, KMS Technologies, KJT Enterprises, U of Wisconsin, LBNL, and SNL)

Although this project suffered a funding cutback, it is not considered to be closed out.

Numerous computational simulations of seismic and electromagnetic responses generated by a prototype single-well geophysical data acquisition tool deployed within a suite of Gulf Coast sedimentary earth models have been completed. These responses exhibit a broad range of characteristics that depend strongly upon the orientation and proximity of the recording tool with respect to near-borehole reflecting and/or scattering boundaries. Knowledge developed via these computational modeling experiments has been used to formulate a set of general recommendations for subsequent tool design improvements. Quantitative calculations of the sensitivity of the acquisition tool geometry to small perturbations in earth model properties (i.e., electrical conductivity, seismic wavespeeds, elastic moduli, mass density) are currently in the formative stages. Finally, several previously-distributed technical memoranda describing the methodology and results of the simulations are being assembled into a comprehensive project report.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

No report received.

Anisotropic Properties of Compacted Clay-Rich Rocks

(BP Amoco, ChevronTexaco, ConocoPhillips, and LBNL)

No report received.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, ConocoPhillips, Kerr-McGee, Shell, TomoSeis, and LBNL)

Highlights:

- 2.5D P-wave forward modeling in VTI media.
- Split-step complex Pade migration

The 2D P-wave acoustic wave equation in vertical transverse isotropic (VTI) media cannot simulate the wave propagated in real 3D earth. However, 3D wave equation forward modeling is too expensive for velocity models in which the velocity is the function of x and z (2.5D situation). For the 2.5D model, we have developed a finite difference method to solve the 2.5D VTI P-wave wave equation. We take the Fourier transform in the y-direction and obtain the 2D wave equation which is a function of wave number in the y-direction. A higher-order finite-difference scheme is employed to solve this 2D wave equation. We chose the wavenumber increment to reduce the "wraparound" effect introduced by the Fourier transform. Compared with the real 3D forward modeling results, the maximum relative error is less than 5%. Work has now begun to extend this method to 2.5D tilted TI media.

We have developed a split-step complex Pade migration method for isotropic media. Our new method can improve stability and accurately treat the evanescent wave. Applying this method to the SEG/EAGE salt model shows that higher quality images can be obtained. This method can be used in:

1)Fourier finite-difference migration;
2)VTI one-way wave equation migration; and
3)3D migration.

Joint Geophysical Imaging

(ChevronTexaco, Core Laboratories, Electromagnetic Instruments, ExxonMobil, and SNL)

We are still testing a 3D EM inversion scheme for mapping oil and gas saturation and permeability properties. The code includes a mask array to invert only over the reservoir volume whose boundaries are seismically constrained. The inversion scheme can treat highly complex 3D models, including peripheral structures such as salt domes, folded bedding and pinch out zones. The 3D code can handle both on shore and offshore exploration environments. Nevertheless, this flexibility comes at the expense of significant computational demands, where the scheme requires massively parallel computing resources and special care is needed in constructing accurate meshes for the computations. Our partner (Hoversten of LBL) has finished work on an AVO seismic inversion code which will be linked to the 3D EM inversion program in the coming two months. Because of the cumbersome nature of the 3D EM code, we are now implementing a much faster 2D EM inversion code, and plan to link this code to the AVO program as well; the 2D code should be completed in the next few weeks. This linkage will allow for much more rapid testing of the joint inversion program. To achieve a linkage between the AVO (reflectivity maps) and the EM (conductivity) maps, several petro-physical models of reservoirs will be provided to test the joint inversion codes. Finally, we have concluded

two licenses for the EM inversion codes (3D and 2D) with two major oil companies this month for offshore applications.

Partnership Office

The Congressional and Senate version of the Interior Appropriations Bills have moved through their initial versions of their respective committees. At this stage, the Partnership funding appears to near FY03 funding. The partnership will work with DOE technical managers to develop a program for FY04, which includes new starts in directed and focused technology areas and the continuation of high performing projects with significant industry backing.