# ACTIVITY REPORT

## July 2002

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<br>Oil and Gas Recovery Technology<br>Diagnostic and Imaging Technology | Upstream Environmental Technology<br>Downstream Environmental Technology |

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# Drilling, Completion, and Stimulation Technology

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

(Halliburton and INEEL)

The Tube Wave Suppressor (TWS), built for pore pressure prediction, was completed and is awaiting field tests. The Regenerative Combustion Source (RCS) was re-configured to operate on high voltage DC power supplies so that more future field test opportunities could be utilized. It requires bench set up and final re-assembly, and is awaiting a second field test.

The Capacitive Discharge Downhole Source (CDDS) high voltage power supply was damaged in shipping from a previous field test and was repaired. However, the initial repair of the damaged components failed and consequently, a simple redesign is being considered. The second repair/redesign was not started during this reporting period due to parts availability and schedule problems with other projects. Repair is anticipated during the next reporting period. The OYO seismic data acquisition system checkout of the first 24 channels is complete and ready for a second round of field testing. It is anticipated that field-testing of the CDDS, the RCS, the TWS, and the OYO data acquisition system will start in the next reporting period.

## Acoustic Telemetry (MWD)

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

### Highlights:

- Commercial interest in the acoustic telemetry tool is high.
- The RF surface receiver was completed by Extreme Engineering and deployed by Baker Oil Tools and SNL.

Extreme Engineering completed and delivered the radio frequency (RF) surface receiver, which allows researchers to monitor acoustic telemetry signals in rotating pipe. The system worked flawlessly in two separate tests by SNL Geothermal Research Department and Baker Oil Tools. In particular, the Baker Oil Tool tests used both an acoustic telemetry module downhole and the RF receiver uphole to test the effects of pipe rotation on mud viscosity and telemetry range.

Both telemetry tools were also deployed at the Rocky Mountain Oilfield Test Center in Wyoming. These tests were supported through a contract with Schlumberger. A report of the test results is complete.

## Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

### Highlights:

- The CRADA with GPRI ends.
- ChevronTexaco agrees to test project samples.

The Collaborative and Research Agreement (CRADA) with Global Petroleum Research Institute (GPRI) ended. GPRI arranged the close-out meeting in Houston, TX. Representatives of GPRI, Exxon-Mobil, Shell, ChevronTexaco, DOE, and ANL attended. Project researchers presented the project accomplishments. The committee agreed that the project established a good scientific basis for the novel sealants for downhole applications. One issue regarding measurement of compression strength of samples in downhole environment was raised. Because ANL does not have a curing chamber, American Petroleum Institute (API) recommended tests could not be conducted. ChevronTexaco agreed to test the samples for this project. Subsequently, DOE also funded Cementing Solutions, Inc. to assist ANL in these tests.

Independently, project researchers modified the consistometer into a curing chamber to obtain some preliminary data on the strength of the sealants cured at various temperatures and pressures. This was done by removing the mixing paddle from the slurry cup assembly and retaining the axial rod to seal the slurry cup. Slurry is poured in 10 or 60 cc syringes and these syringes are placed around the central rod. The cup is then filled with water and is then sealed. The assembly is immersed in mineral water in the consistometer and desired temperature and pressure are maintained for a given curing time. After the pre-

scribed period, samples are taken out and their strength is measured under compressive mode using an Instron machine. The only drawback of this method is that the samples do not conform to ASTM standards because of their small size. However, some useful data were obtained and inferences about curing of the sealants were drawn.

Both shallow well and deep well formulations were also tested in this arrangement. Initially, as recommended by API standards, slurry was mixed in the blender for 35 seconds and then was placed in the curing chamber. It was cured for 24 hours and then its compression strength was tested. The shallow well composition set when cured at 80 °F and 700 psi but the deep well formulation did not set even when cured at 250 °F and 13285 psi. This indicated that the deep well formulation does not dissolve the binder in the slurry during blending and needs much more time of mixing. This is because the binder components were slowed down to allow 3 - 5 hrs of pumping time. As a result, the dissolution was too slow. Researchers mixed the deep well composition in the consistometer at 250 °F and 13285 psi for 2 ½ hrs to reach 70 Bc, then put it in molds and cured it at the corresponding static temperature of 300 °F and the downhole pressure of 13285 psi. The slurry now set into hard cement.

The compression strength of the shallow well composition in this test was 1,367 psi, but the same for the deep well composition was 759 psi. The low values appear to be due to the fracture of the specimens on the surface, due to differential setting of these materials underwater. They set hard in the bulk of the material but are softer on the surface where they have contact with water. This is not necessarily a drawback in the use of the sealant because in an actual well, a large amount of slurry is pumped and the ratio of volume to surface area is very small. The ratio is large in project tests, and thus, the effect of the surface is exaggerated.

Project researchers are now waiting for the results of more standard tests that will be conducted at ChevronTexaco and Cementing Solutions, Inc. These tests should provide more reliable numbers.

## Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring

(DeepLook, Phillips, and LANL)

### Highlight:

- Improvements in the mud cleaning system enhance performance.

**Mud Cleaning System**

Upgrades to the microdrilling mud system were completed and the system was moved to the San Ysidro test site for evaluation. The improvements consisted of installing a higher capacity pump to increase the velocity through the hydrocyclone mud cleaners, and building a polymer mixing/dispensing tank to facilitate the use of a low molecular weight flocculating polymer. Preliminary results of the evaluation of the upgraded mud system and use of the polymer indicate significant improvement in mud cleaning performance.

**San Ysidro Site**

A drilling operation was initiated through one of two 2-1/2-in steel conductor pipes that was previously run to 84 ft and cemented back to the surface using an auger drill rig. The coiled-tubing microdrill rig was rigged up to drill a 2-3/8-in hole. The microwell was drilled to 437 ft before operations were suspended due to an equipment failure. A low flow, 1-11/16-in OD positive displacement drilling motor and four-blade polycrystaline diamond composite (PDC) bit were evaluated on the first drilling assembly. The rate of penetration did not appear to improve, but upon removing the drilling assembly from the hole, it was noted that two of the seven PDC compacts on the bit were missing, which resulted in the remaining five cutters becoming damaged. The bit was returned to the vendor for repair or replacement and the low flow motor will be rerun when drilling operations resume.

## Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

### Highlights:

- A model of damaged-zone clean-up was incorporated into the current model of post-perforation fluid flow, which includes the influence of inertial and transient terms at early times.

Two additional cores of Berea sandstone were perforated: a gas-saturated core at 750 psi underbalance and an oil-saturated core at 1500 psi underbalance. Flow tests are under way in these cores and in a previously perforated core (750 psi oil-saturated at 750 psi underbalance). Computed tomography (CT) scans acquired during the injection of an x-ray absorbing fluid into these cores will provide detailed estimates post-perforation permeability variability.

Recent enhancements to the computational model enable researchers to simulate the transient pressure surge that immediately follows perforation. This pressure surge is thought to result in clean up of the damaged zone immediately adjacent to the perforation. Results from recently conducted experiments will provide additional tests of the enhanced model of post-perforation clean up and fines migration, and the resulting alteration of the permeability field.

## Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

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

### Highlight:

- Tensile testing of rope specimens continue.

Tensile testing of rope specimens with integrated optical fibers continued this reporting period. The ability of the fiber strain sensor to directly measure the applied strain in the rope is at issue in this testing phase.

Tests done in the previous reporting period on fibers integrated in twisted strand ropes showed that the measured strain was in good agreement with applied strain. Tests in this period were done on fibers integrated in braided strand rope. A 50-cm-long segment of the integrated rope was strained in a tensile test machine while the strain was measured with the optical time-domain reflectometer. Measured strain was then compared to the applied strain values. The agreement between measured strain and applied strain is good, although the rope exhibited some creep which the fiber strain sensor did not reproduce. Tensile tests with long gauge lengths of both twisted strand and braided strand ropes will begin in the next reporting period.

## Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

### Highlights:

- The assistance and expertise of SNL personnel was enlisted.
- SNL-owned optical fiber monitoring equipment was located and requested.

There is an increasing need for a high-data-rate, real-time data link between downhole instrument packages and the surface. No current system adequately addresses this need, either because of low data rates (mud-pulse telemetry), interruptions to drilling (logging cable), or the need to substantially change the drilling process (various types of pre-wired pipe or composition coiled tubing with wiring built in). In separate work, SNL and GTI are developing a system for using unarmored, “bare,” optical fiber as a disposable telemetry link. The advantage of this approach is that the bare optical fiber is so small and lightweight that the entire telemetry link can be placed directly into the drill string and deployed as needed during, and without interfering with, the drilling process. The megabit, or higher, data rate that fiber optics are noted for can be achieved. This system was developed and tested for use in conventional drill pipe. Coiled tubing offers the opportunity to combine two existing technologies: 1) cable injection and 2) disposable optical fiber telemetry, to provide a new level of telemetry to the industry. CTES is an industry leader in cable injection technology for coiled tubing.

The purpose of the proposed work is to determine the applicability of the disposable fiber optic telemetry technology developed for conventional drill pipe to coiled tubing. There are two main technical issues: 1) injectability of the fiber using some modified form of current cable injectors, and 2) survivability

of the fiber under the fluid flow conditions prevalent in coiled tubing.

SNL received 2,430 m of optical fiber and is planning a yard test with a target date of mid to late September 2002. The yard test will include injection of about 2,400 m of 400-mm-diameter bare optical fiber with a coating of approximately 730 mm. Connectors, which were ordered, will be installed on the fiber and a test will be completed to verify the integrity of the fiber. If the fiber is successfully injected, the injection will be followed by an 8-hour pump test with continuous monitoring of the fiber integrity.

Since the injection of the 2,430 m length of optical fiber is an all-or-nothing test, the feasibility of an initial test consisting of injection and integrity verification of 1,000+/- m of optical fiber is being evaluated. If this initial test is feasible, a 4-hour pump test will be completed with continuous monitoring for fiber integrity after injection is successfully completed. If this test is successful, the longer length of fiber and the 8-hour pumping will be complete.

After the pump tests, researchers will attempt to extract the fiber while maintaining fiber integrity. The extraction is an exercise that CTES will perform since there may be cases during commercial application where it is desirable to remove the optical fiber after all necessary data is collected and analyzed.

The assistance and expertise of personnel from Departments 6117 and 6211 was enlisted and SNL-owned optical fiber monitoring equipment was located and requested.

## Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

### Highlight:

- High-speed linear slide, stepper motor, and computer interfaces received.

Discussions with University of Tulsa regarding shipment of the data acquisition system to INEEL continue. The design and fabrication of laboratory inspection equipment also continues.

A preliminary design of the coiled tubing inspection head was completed. Components and materials were ordered to fabricate the coiled tubing inspection head. Details and a fabrication drawing of a commercial eddy-current inspection head were obtained to use as guidance. Components to fabricate the laboratory inspection apparatus were ordered and received. In addition, a high-speed linear slide, stepper motor, and computer interfaces were received. Lengths of 10-ft coiled tubing samples were also received from a manufacturer. Simulated defects will be placed in these tubes and will be used as the basis of the signal analysis tasks.

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

(ChevronTexaco, Shell International, and LBNL)

Previous results on the bi-axially loaded, weakly cemented sand samples pierced by a single borehole showed that samples tended to fail in an undesirable splitting mode. To resolve this problem, project researchers modified the design for the experimental setup to include the application of a small confining stress along the third axis of the sample. This prevents the splitting, and observation of the borehole failure through a small window built in the loading platen. Also, a controlled flow of air can be sent through the borehole to apply the hydrodynamic force that induces a borehole failure of thin fracture-like breakout geometry. The short-time goal using this new setup is to investigate the effect of the multi-axial stress state on the sand-producing, fracture-like borehole failure. The experiment will be conducted for a range of sandstone porosities and intergranular cementations, using sodium silicate cemented synthetic sandstone samples. Currently, the components of this polyaxial loading-frame are being fabricated, and other components of the loading system, including an additional PC-controllable high-precision syringe pump, are being acquired from manufacturers.

Researchers also designed a laboratory tool for measuring the dynamic elastic properties of weakly cemented sand in the cross-hole to borehole logging frequency range (1 kHz to 10 kHz), under confining pressures up to 1,500 psi (~ 10 MPa). Using this setup, researchers can determine the elastic properties of small core samples. Unlike well-consolidated, competent sandstones, weakly cemented sand has very large compliance and small strength, which makes the determination of the elastic properties difficult without being affected by the permanent deformation within the sample due to the intergranular slip and bond failure. Because the small-displacement dynamic measurement is free of these inelastic deformations, researchers can extract "pure" elastic parameters that help characterize the mechanical properties of the samples more clearly. The fabrication of this experimental device is scheduled in late August.

# Oil and Gas Recovery Technology

## Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Experimental work at the INEEL is complete and the final report is in preparation.

## Fluid Identification Acoustic Logging Tool

(BP Amoco, CGG, ChevronTexaco, Conoco, Landmark Graphics, Schlumberger, Shell, Smedvig Unocal, Ward Petroleum, Western Atlas, and LANL)

### Highlight:

- Acoustic characteristics of liquid with dissolved gas and very small bubbles were studied using the Swept Frequency Acoustic Interferometry technique.

All of the previous measurements and studies were made on a multiphase system with large bubbles and gas content. This situation is more characteristic of ambient pressure conditions and not for deep well situations. Under high pressure, as encountered at high depths, the gas content is in a dissolved form. Therefore, it is important to study how a liquid behaves as far as the Swept Frequency Acoustic Interferometry (SFAI) technique is concerned with dissolved gas. Initial studies were with water and sodas (commercial soft drinks). Researchers found that the SFAI measurements provide data that is very clean and easy to analyze. The dissolved gas content affects the sound speed and also the frequency dependence of sound absorption. The presence of small bubbles (0.1 mm or less in diameter) also allows good quality SFAI measurements. Researchers plan to make quantitative and systematic measurements to come up with empirical relationships to determine dissolved gas content. These measurements will also need to be repeated in oil.

## Measuring Sucker Rod Pump Parameters Downhole

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

### Highlight:

- The conceptual design for adding downhole measurement of compression chamber pressure to the test well at Texas Tech is complete.

Project researchers completed proof testing on the downhole pressure transducer used to measure compression chamber pressure on sucker-rod pumps. Researchers are now designing a method of attaching the transducer to the sucker rod pump.

The conceptual design for adding downhole measurement of compression chamber pressure to the test well at Texas Tech is complete.

## Formation Logging Tools for Microboreholes (DeepLook and LANL)

No work was scheduled for this reporting period.

## Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling (Mobil, Schlumberger, UT-Austin, and SNL)

No report received.

## Semiautomatic System for Waterflood Surveillance (ChevronTexaco and LBNL)

### Highlight:

- Meeting held with ChevronTexaco.

This DOE/ORTP project is now closed; however, ChevronTexaco continues to support it with funding.

**Water injection analysis and control**

Since February 2002, one-minute measurements of water injection rates and pressures in ten Lost Hills Section 32 wells are being transferred to LBNL once a day via an automatic FTP connection. The data is then analyzed by a process-based control software (see SPE 71751 "Control of Water Injection into a Layered Formation," SPEJ, 6 3 253-261, September 2001), for which a U.S. patent is pending. The pressure set point is calculated for each of the wells and sent back to the field operator in automatic mode.

Analysis of the field data suggests the possible importance of short-time storage effects on instantaneous injection pressures and rates. Project investigation of this phenomenon was presented at a meeting with ChevronTexaco in July. The meeting was held in Bakersfield, and the conclusions and recommendations were discussed with the field personnel. Work on incorporating the latest conclusions derived from the field data will be incorporated in the new version of control software. A joint paper with ChevronTexaco, SPE 77646 "Lost Hills Field Trial - Incorporating New Technology for Reservoir Management" will be presented at the Society of Petroleum Engineers (SPE) Annual Technical Conference and Exhibition held in San Antonio, TX, September 29–October 2, 2002.

**Analysis of satellite images and rock damage assessment**

Analysis of airborne and satellite InSAR (synthetic aperture radar interferograms) images continues to show the dynamic nature of subsidence in Lost Hills. More importantly, it now appears that the system of major subsurface faults expresses itself at the surface. If this is true, the faults divide the field into flow compartments which need to be controlled separately. In addition, analysis of production and injection data has provided new strong evidence of the conceptual model of soft rock damage presented recently in paper SPE 75230 "Oil Deposits in Diatomites: A New Challenge for Subterranean Mechanics."

## Mechanisms of Oil Recovery and Validation of Corefloods

(ChevronTexaco, Phillips, and LBNL)

### Highlight:

- Researchers developing a micro-mechanical discrete element method code to implement a 3D depositional model.

**Depositional models and generation of digital images of the rock**

Researchers are developing a micro-mechanical discrete element method (DEM) code to implement a 3D depositional model. The code will generate 3D models of real rocks by simulating sedimentation, compaction, cementation, and clay deposition. Micro-mechanical properties of natural sedimentary formations previously modeled in 2D will now be studied in 3D. The proposed approach provides means to study mechanical and flow properties of unconsolidated sandstones at *in-situ* conditions, which is impossible otherwise. The existing prototype of the DEM code demonstrates the high efficiency of the algorithms. For example, generating and compacting a rock sample consisting of 10,000 grains takes a couple of minutes on a personal computer.

The advantage of generating computer models of natural rocks is immense for flow properties modeling. The digitized image of a model rock can be obtained with arbitrarily high resolution. Therefore, the sensitivity of the pore network extraction algorithms can be thoroughly investigated and the most important features of microscopic images can be found. Knowing these features is essential in the development of adequate procedures for processing images of real cores obtained using micro-tomography or the Advanced (X-Ray) Light Source. Varying statistical parameters, like grain size distribution, and models of different types of rocks typical for oil reservoirs can be obtained.

**Statistical analysis of thin sections**

Statistical analysis of thin sections is an inexpensive and powerful tool used to classify the different types of rocks by their statistical properties. The ability to adequately evaluate such properties is important for sensible generation of model rocks.

Algorithms of reproduction of real rock thin section images by fitting the two-point correlation function using a simulated annealing method showed that such algorithms are computationally intensive even after careful optimization of the algorithms. At the same time, the generated image with very accurate fitting of the correlation function does not adequately reproduce the pore space connectivity and the grainy structure of the solid skeleton. This conclusion will be verified by the reconstruction of 3D rock samples from several thin section images.

**Pore network generation**

A pore network extraction code being developed at the University of California, San Francisco, was inspected for possible utilization. Comprehensive testing of the available version of the code was performed. The current approach for the medial axis extraction is based on the preservation of topological rock invariants and, therefore, does not reflect the flow properties of the rock. However, important information about the coordination numbers distribution and the connectivity of the pore space can already be extracted. The work on possible combination of this code and the code being developed by the project will continue.

## Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger, Shell, MIT, NMT, and SNL)

Work continues on the refinement and application of the 2D code, and the development of a non-spherical discrete element for the 3D code. In addition to the principal investigator, project staff contributing during this period include graduate interns Dave Boutt, of New Mexico Institute of Mining and Technology (NMT), and Scott Johnson, of Massachusetts Institute of Technology (MIT).

Simulations of cavity formations in unconsolidated sands are being developed. During the testing of small-scale models, project researchers realized that the realism of the simulations was limited by elementary boundary conditions and forcing schemes. To address this deficiency, a new boundary condition that allows for specified fluid pressures at in-flow and out-flow boundaries was implemented. In 3D, researchers continue to investigate alternate, more realistic particle representations to the commonly used spherical discrete-element. A recently published pseudo-ellipsoidal representation was implemented, which shows great promise as a computationally compact and physically realistic representation for natural particles like sands. Project researchers are in the process of refining the previously proposed contact detection algorithm for this representation, with preliminary numerical results suggesting a potential for a several-fold speedup in computational efficiency.

Finally, the collaboration with NMT and MIT continues to mature with the joint submission (along with the University of Oklahoma and several industry participants) of a $1 million proposal to NPTO to apply the models being developed under this program to simulate proppant transport. The project is still awaiting the formalization of the licensing agreement by the SNL legal department, which will allow NMT to begin beta-testing the codes.

**Project Publications:**

Cook, B.K., D.R. Noble, and J.R. Williams. "A Coupled DEM-LB Model for the Simulation of Particle-Fluid Systems". Accepted for publication in the *Proceedings of the 3rd International Conference on Discrete Elements Methods*, Ed. Cook and Jensen. ASCE.

Cook, B.K., M.Y. Lee, A.A. DiGiovanni, D. R. Bronowski, E.D. Perkins, and J.R. Williams. "Discrete Element Modeling Applied to Laboratory Simulation of Near-Wellbore Mechanics." Accepted for publication in the *International Journal of Geomechanics.*

Lee, M.Y., B. K. Cook, A.A. DiGiovanni, E.D. Perkins, and J.R. Williams, "Simulation of Borehole Failure Phenomena Using Discrete Element Modeling," *Eos Trans. AGU*, 82(47), T51A-0846, 2001.

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

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

### Highlight:

- A subroutine was written to facilitate application of initial non-lithostatic states of stress within JAS3D and re-calculation of state variables for the SNL cap plasticity model.

Work progressed in the following areas:

- A subroutine was written to facilitate application of initial non-lithostatic states of stress within JAS3D and re-calculation of state variables for the SNL cap plasticity model.
- A series of reservoir-scale finite element analyses were completed for the idealized pancake and pillar geometry models. The analyses include (1) non-lithostatic initial states of stress (including alternative methods for incorporating this), and (2) transient salt creep. Additional analyses are underway that consider the effect of a stiff, and possibly creeping, basement layer, and meshing of a new model based on another idealized geometry was initiated.
- Year 2 funding from seven of the nine industry participants cleared DOE/SNL.

## An Integrated Approach to Assessing Seismic Stimulation

(Aera LLC, BP, ChevronTexaco, Conoco, Marathon, Phillips, Shell, ASR, Halliburton, OGCI, Piezo-Sona Tool, Schlumberger, UC Berkeley, LANL, LBNL)

### Highlight:

- Laboratory apparatus being upgraded.

Project researchers continue to monitor a field-scale stimulation experiment at the Lost Hills oil field, in Kern County, CA. As a follow-up to the work in April, researchers selected a second well at the Aera LLC site, a diatomite reservoir approximately 800 ft away from the stimulation well. The first test well, which was 43 ft away from the stimulation well, had shown that the stimulation source, a pressure pulse in the well, created energy in the 200 to 300 Hz range. The second experiment investigated how far the energy traveled, and monitored the pressure in both wells using a hydrophone, as well as by means of a three-component geophone. Researchers are waiting for the source to be deployed after maintenance.

In the modeling and theoretical studies, a boundary-value problem involving a periodic fluid pressure pulse imposed on a constant pressure gradient was solved analytically. This problem is based on a telegraph equation and a wave equation whose dependent variables are two different linear combinations of fluid pressure and total dilatational stress. These combinations were derived previously from coupled momentum balance equations for an elastic porous medium permeated by one compressible fluid. The solutions were modeled numerically with elastic and hydraulic data for unconsolidated sand and stimulation characteristics corresponding to recent laboratory experiments. The stimulation frequency required to obtain maximum fluid flow was determined theoretically for the first time. For a semi-consolidated material with a Young's modulus of 100,000 and a Poisson's ratio of 0.35, the stimulation frequency was in the 200- to 300- Hz-range for maximum effects on the pore throats.

In the LANL core stimulation experiments the following efforts were carried out:

- A linear strain measurement system was implemented.
- A pore pressure pulsation was system designed.
- Burbank field cores are being prepared for 2-phase flow tests.
- Fontainebleau sandstone cores are being prepared for single-phase tests.

Laboratory apparatus are being upgraded. These include a linear strain measurement system using LVDT sensors and an in-line fluid piston device for creating pore pressure pulsations in the core samples instead of mechanical stress oscillations. This will allow direct comparison of laboratory results with recent theoretical developments at University of California-Berkeley (UCB).

Samples of two different rocks are being cored to fit into the LANL flow stimulation apparatus. These are 1) formation samples from the Burbank sandstone in Osage County, OK, and 2) Fontainebleau sandstone of varying permeability with minimal *in-situ* clay content. Burbank samples will be used to investigate 2-phase flow enhancement that might be caused by altered wettability mechanisms and will also provide data that can be compared with field seismic measurements to be performed by LBNL during planned stimulation tests at Osage County. Fontainebleau samples will be used to study single-phase permeability enhancement caused by disruption of fluid boundary films, as well as for comparison with the mass and momentum balance theoretical work at UCB.

# Diagnostic and Imaging Technology

## Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output, Philips, and LANL)

### Highlight:

- New version of MEMS accelerometer tested.

Input/Output Corporation provided the project with a new analog version of their micro-electro mechanical systems (MEMS) accelerometer. The accelerometer was packaged in a 1-in-diameter housing for microhole use. The microhole package was subsequently deployed in a microhole at the San Ysidro microhole test site. Seismic line data were taken using a Bison accelerated weight drop and subsequently compared with geophone, prototype piezoelectric, and earlier MEMS sensor data. These data are in the process of being analyzed; however, a substantial improvement in the performance of the MEMS sensor could be seen. Comparable performance was noted for the advanced piezoelectric and analogue MEMS sensor.

## Improved Prestack Kirchhoff Migration for Complex Structures

(Conoco, Cray/SGI, Golden Geophysical, Kerr-McGee, Shell, and LANL)

No work scheduled this reporting period. The final meeting of project collaborators is scheduled for August 20 in Houston, TX.

## Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

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

### Highlights:

- Documentation describing both the serial and parallel versions of the 3D finite-difference elastic wave propagation algorithms continues.
- Researchers preparing two presentations for the upcoming Annual Meeting of the Society of Exploration Geophysicists.

During the past two months, significant efforts were devoted to developing documentation describing both the serial and parallel versions of the 3D finite-difference elastic wave propagation algorithms. This documentation is designed to provide 1) the fundamental mathematical theory underpinning the algorithms, 2) algorithmic implementation of the theory via explicit, time-domain, finite-difference operators, and 3) guidance on proper selection of parameter information for program execution. Documentation will be codified as SNL technical reports (SAND reports) and subsequently distributed to the project industrial collaborators.

Additionally, work is progressing on preparing two presentations for the upcoming Annual Meeting of the Society of Exploration Geophysicists (SEG). One presentation will describe the development of a novel finite integro-difference algorithm for simulating wave propagation within an anacoustic (i.e., attenuative and dispersive) fluid. The other presentation involves computing several elastic modeling examples for the SEG post convention workshop, “Advances and Limitations in “Numerical Modeling of Wave Propagation in Challenging Structures”.

## High-Speed 3D Hybrid Elastic Seismic Modeling

(Burlington Resources, GX Technology, and LBNL)

### Highlight:

- Project in close-out phase.

There was no activity on this project during the reporting period. This project is in its close-out phase.

## 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-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Unocal, Veritas DGC, Western Geophysical, Stanford, U of Houston, LANL, and LLNL)

### Highlights:

- Test modeling was done with a preliminary version of a new 3D salt model.
- New method for wave-equation migration improves accuracy of velocity analysis.

Test modeling was done with a preliminary version of a new 3D salt model. While release of the full 3D model to the project is still being discussed, some initial acoustic and elastic model calculations were done to estimate the computing resources that would be needed to accommodate operation of the full model. About 1,000 Gflop-hours for acoustic forward calculations and 200,000 Gflop-hours for elastic calculations will be needed to calculate traces from a single shot in the full model.

In the Wave-Equation Migration Velocity Analysis (WEMVA) effort, a new formulation of the downward-continuation migration was derived that relaxes some of the limitations of the small-scattering approximation. Thus, the new method will have higher accuracy in working with velocity structures that have large velocity perturbations. This can be a particularly important new development for obtaining accurate velocity structures in areas with salt bodies.

The project continues to support research by graduate students working for both Master's and Doctoral degrees. Project results were presented to participants of university-industry consortia, and were discussed in a presentation to the annual meeting of the Incorporated Research Institutions for Seismology (IRIS) Consortium.

K.J.Marfurt, D. Wilson, R. Aster, and D. Okaya presented “Shared Seismic Models for Calibration of Receiver Function Imaging Algorithms”, presented June 14, 2002 at the Annual Meeting of the IRIS Consortium, Hawaii.

## Rapid Imaging of Interwell Fluid Saturations using Seismic and Multiphase Production Data

BP Amoco, ChevronTexaco, Exxon-Mobil, JNOC, Landmark, Phillips, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

### Highlight:

- Researchers met with industry participant to discuss progress.

Researchers are now testing a prototype joint inversion code of production data (water-cut) and seismic time-lapse measurements. An initial five-spot configuration and a reference permeability field were used in the testing.

A suite of time-lapse values are combined with water-cut observations from four wells and used to invert for reservoir permeability variations. Researchers found that large-scale permeability variations are recoverable in the interwell region. The complete inversion of both water-cut and seismic observations required 18 reservoir simulations in order to converge. The time required for the entire inversion was less than one hour on a standard workstation.

Project researchers are setting up a synthetic case that is similar to the Gulf Coast dataset. As in the five-spot test, the reservoir model is a single-layer, 2D case. After these tests, researchers will consider more comprehensive 3D tests.

Project researchers met with an industry participant to discuss progress. Researchers will meet with the other participants at the upcoming Society of Petroleum Engineers meeting.

## Offshore Oil Field Characterization with EM Methods

(SNL)

No report received.

## Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, Conoco, Exxon-Mobil, Fairfield Industries, GX Technology, Petroleum GeoServices, Phillips, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

### Highlight:

- Studies continue on limited-aperture wave-equation migration.

Researchers continue to investigate limited-aperture wave-equation migration by applying the wavepath migration scheme to determine migration apertures. The method to determine the boundaries of apertures was improved. Researchers applied the limited-aperture wave-equation migration to a field dataset provided by a U.S. oil company.

Project researchers also investigated different imaging conditions in wave-equation migration to obtain higher-resolution images than those obtained using the conventional imaging condition. Synthetic and real datasets were migrated using new imaging conditions to obtain higher-resolution images.

## Testing and Validation of High-Resolution Fluid Imaging In Real Time

(LBNL and SNL)

Modeling of the electromagnetic (EM) and seismic responses of single-well configurations continued at Shell and SNL. The results indicate that high frequency signals are required to image the targets of interest within 50 m of a well in both EM and seismic applications. Noise tests were designed by KMS, Shell, and LBNL to test the signal-to-noise (S/N) ratio of currently available electronics to determine if the noise floors are such that reasonable S/N ratios can be obtained. Researchers will use the LBNL single-well seismic system with its 24-bit digitizer and fiber-optic transmission line to test the ability of the EM systems to collect low noise data at the required frequencies in open and/or fiberglass-cased wells. The tests will be carried out in August at the LBNL shallow borehole (250 ft) facility.

## Autonomous Monitoring of Production

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

No report received.

## Anisotropic Properties of Compacting Clay-Rich Rocks

(BPAmoco, ChevronTexaco, Conoco, LBNL)

Ultrasonic tests on compacted clay samples continued on shallow marine core (110 ft) provided by one of the industry participants. These tests were conducted in a uniaxial strain consolidation vessel with axial stresses up to 2.4 MPa and drained (atmospheric) pore pressures. These tests demonstrated that it is possible to propagate clearly discernible P-waves with frequencies as high as 2 MHz through thin, compacted clay disks (0.5–1 cm-thick). The P-wave velocities are in the 1300–2200 m/s range. The attenuation at these frequencies is large ($Q_P < 30$). S-wave transmission tests on the compacted clay samples produced velocities that are lower than 400 m/s. At 1–2 MHz, this low S-wave velocity produces short wavelengths ( $\lambda$ S < 1 mm) that translate into long propagation distances in terms of wavelength. By reducing the S-wave frequency to 250 kHz and using a larger diameter transducer (to generate near-planar waves), researchers were able to clearly identify transmitted S-waves across the compacted clay sample.

Using the results of the ultrasonic tests on the compacted clay samples, project researchers started work on the design of a consolidation vessel for measuring the vertical transversely isotropic (VTI) elastic constants of compacting clay-rich rocks. Researchers are working with several manufacturers to build a

1 MHz P-wave piezocomposite phased array that will be epoxy potted into one of the loading pistons.

Project researchers are in the process of testing the transducer design with anisotropic, viscoelastic finite difference time domain modeling.

### Realistic Velocity Anisotropic Estimation in Complex 3D Environments

(BP Amoco, ChevronTexaco, Conoco, Kerr McGee, Phillips, Shell, TomoSeis, LBNL)

Project researchers developed a method for calculating traveltimes in tilted transversely isotropic (TTI) media. This algorithm provides a method for the efficient computation of first-arrival traveltimes. A modification of the finite difference (FD) method proposed by Zhang et al (2002) was used to solve the eikonal equation for TTI media. In Zhang's approach, the FD equation is first transformed to the celerity domain. An FD scheme is used to solve equations of motion for each cell. The diffraction and head wave travel times are calculated at the same time and the smallest one is kept as the first arrival.

In complex velocity models, rays can change their propagation directions sharply and/or more than once. In order to account for these possibilities, project researchers employ a global scheme to compute the first-arrival times.

Examples demonstrated the robustness and accuracy of the project algorithm. One example showed that traveltimes in vertical transversely isotropic (VTI) and TTI media are different. This means that if VTI is assumed when the medium is actually TTI, travel time errors will occur, leading to errors in migration and inversion. For reasonable values of tilt and anisotropy, the errors can be more than a wavelength per 1000 m of path length.

# Partnership Office

There will be a call for innovative pre-proposals in the three Upstream (Exploration and Production) Technology Areas in FY2003. Both programmatically within DOE/FE and in the House appropriations language, there is a greater emphasis in upstream activities related to Natural Gas. This emphasis was reflected in the newFY02 Gas Issues Forum. There is need to align the traditional oil-related areas to the different needs of gas production. However, funding is still highly uncertain. As a base or worse case, the oil funding will be 50% ($3M) of the FY2002 funding ($6M). Therefore, the overall oil and gas funding could be 30% less in FY2003 ($6M) than in FY2002 ($8.5M).

**DOE Proposed Changes for FY2003 Partnership**

- All projects should be written for no more than a three-year duration. Successful proposals will receive a full-term funding commitment. After FY2003 the decision to pass from sophomore to third year funding status is a DOE decision based on the performance: meeting deliverables, meeting milestones, and project spending.
- The guideline for size of proposals is up to $350K/annum/laboratory. However, if it can be justified, DOE will consider a larger, more costly, project that could make a substantial improvement in oil/gas discovery and recovery.
- Sophomore projects will be only presented as a concurrent poster-session at the Proposal Review Meeting.
- DOE is committed to funding second-year projects.

There are new requirements for the content of Preproposals and Proposals:

**Preproposal: Need New Called-Out Sections**

- Benefits to industry,
- Why government should perform this R&D,
- On a separate page, list budget for three years and projected milestones and deliverables for each year.)

**Proposal: Need New Called-Out Sections**

- Comparison to baseline or other developing technology that address the problem stated,
- Benefits to Industry,
- Why government should perform this R&D
- Statement of Critical Decision Points
- Detailed three-year budget by task, milestone and deliverables (labor, supplies, equipment detail).