ACTIVITY REPORT

September 2001

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**
Oil and Gas Recovery Technology	Upstream Environmental Technology
Drilling, Completion, and Stimulation Technology	Downstream Environmental Technology
Diagnostic and Imaging Technology	Ultra-Clean Fuels Technology

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

Oil and Gas Recovery Technology

Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Highlight:

- Core from five wells selected for laboratory testing.

It has been shown that by injecting diluted reservoir brine in laboratory cores, waterflood oil recovery can be significantly increased under certain circumstances compared to waterfloods using reservoir brine. Twenty-eight different corefloods were performed during this past two-month period to investigate the effect of permeability, injection water salinity, and initial water saturation on oil recovery.

The coreflood ensemble included Berea sandstone cores of varying permeability, Minnelusa crude oil, and synthetic Minnelusa reservoir brine and dilutions. All corefloods were completed at 75°C (167°F) and flooded at 3 ft/day.

Results indicate that as permeability decreases, the effect of dilute brine flooding is diminished. We saw less of an increase in oil recovery from dilute brine corefloods with lower permeability cores (100 md) than we did from higher permeability cores (above 500 md). We also noted that, at least with the higher permeability cores, oil recovery was influenced by initial water saturation—higher oil recovery was observed in cores with higher initial water saturations.

Core permeability ranged from 60 md to 1000 md. Initial water saturations ranged from 16% to 24%. Diluted water was always a 100-fold dilution of the reservoir brine.

Fluid Identification Acoustic Logging Tool

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

Highlight:

- Design for electronics package completed.

LANL started building the electronics package. The design is complete. The electronics package is all digital and designed to be operated by a small computer, which gives a lot of flexibility and adaptability for testing purposes. The original analog design was quite inflexible and had to be adapted for each situation. Once the package is complete, we will first retest everything with the flow-loop at LANL, and then test it elsewhere.

High-Resolution Reservoir Characterization Using Seismic, Well, and Dynamic Data

(BP Amoco, Chevron, Exxon, Oxy, Phillips, RC2, Texaco, Western Geophysical, Texas A&M, and LBNL)

Report not received.

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, Yates Petroleum, UT-Austin, Texas Tech University, and SNL)

Report not received.

Formation Logging Tools for Microboreholes (DeepLook, Texaco, and LANL)

An agreement was initiated for access to engineering drawings of a 4-level gamma logging tool developed for National Science Foundation's ocean drilling program. The idea is not to replicate work already completed with federal funds, but rather to proceed immediately to a miniaturized equivalent.

A survey report on porosity tools for use in microholes was critically reviewed and modified.

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

Highlight:

- Meeting held with industry participants.

During the current reporting period, SNL focused efforts on benchmarking the coupled IPARS/JAS3D simulator against results obtained from another coupled flow/geomechanics simulator, ACRES (Arco's Comprehensive Reservoir Simulator), which was developed in-house at Arco. ACRES performs compositional and black-oil reservoir flow calculations that are fully coupled with poroelastic and poroplastic reservoir deformations. We selected a problem having both an injecting well and a producing well in the simulation. With the use of no-flow and symmetry boundary conditions, this model simulates a 5-spot pattern. The problem has ten layers with uniform, elastic geomechanical properties in each layer. The orthotropic permeability varies from layer to layer and remains constant throughout the calculation. The porosity is constant in each layer initially, but varies with total volume strain. A comparison of the results from IPARS/JAS3D and ACRES shows excellent agreement for both the flow solution and the geomechanical solution. Displacement histories of the surface nodes above the injector and producer show agreement within a few percent for the entire 25 year calculation. A series of calculations was run looking at the effects of varying the frequency of communication between IPARS and JAS3D. For the example problem considered here, the solution was not very sensitive to the frequency of updating the flow properties (porosity).

A meeting was held at Rice University in Houston, TX, August 1 with representatives from our industry participants to keep them informed of our progress and to allow them to make comments about the direction of the research. We have incorporated changes to the coupled code based on comments made at the meeting.

Semiautomatic System for Waterflood Surveillance (Chevron, Case Services, and LBNL)

Analysis of Satellite Images and Rock Damage Assessment

A well-attended one-day conference was held in Bakersfield, CA, with Chevron. Also, six Aera Energy engineers visited LBNL to get acquainted with our work and to present their views. The recent results regarding subsidence caused by waterfloods in the diatomite oil fields were discussed. The advantages of using the space-borne methods of estimating the rate of subsidence have been confirmed. Processed InSAR images regularly obtained from the satellites are now used as the main tool for the subsidence estimates by both companies.

Further analysis of the InSAR images along with variations of fluid injection/withdrawal rates reveals an intrinsic connection existing between the subsidence, the rate of well failure and the propagation of rock damage. Waterflood in extremely low-permeability and, at the same time, soft rocks, such as diatomites, still remains a very difficult problem and its adequate picture cannot be

obtained solely from the analysis of subsidence. The theory of rock damage propagation is now under development in co-operation with Prof. G. I. Barenblatt, of the National Academy of Engineering section of Petroleum, Mining & Geological Engineering.

Analysis and Control

Weekly or biweekly teleconferences with Chevron and Case Services continue. A semi-automatic system of injection rate-pressure data acquisition and analysis is almost complete. On-line data transfer from Lost Hills Field operations to an LBNL computer is going to start as the installation and tuning-up of the wellhead controllers is complete.

Publications

More information can be found in the following recent papers:

Patzek, T.W., and D.B. Silin. "Control of fluid injection into a low-permeability rock. 1. Hydrofracture growth," *Transport in Porous Media,* 43 537–555, May 2001.

Silin, D.B., Patzek, T.W. "Control of fluid injection into a low-permeability rock. 2. Optimal control," *Transport in Porous Media*, 43 557–580, May 2001.

Silin D.B., and Patzek, T.W. "Control of water injection into a layered formation," SPE 71751, *Society of Petroleum Engineers Journal*, September 2001.

Patzek, T. W. Silin, D. B., and Fielding E. "Use of satellite radar images in surveillance and control of a two giant oil fields in California," SPE 71610, Presented at the Society of Petroleum Engineers Annual Technical Conference and Exhibition, New Orleans, LA, September 30–October 2, 2001.

Patzek, T. W., Silin, D. B., and Barenblatt, G. I. "Impact of rock micro- and macrostructure on the behavior of two-phase flow," Invited Paper, Presented at the 22nd Annual International Energy Agency Workshop and Symposium, Vienna, Austria, September 10–12, 2001.

Mechanisms of Oil Recovery and Validation of Corefloods (Chevron, Phillips, and LBNL)

Pore Network Flow Modeling

The MatLab version of primary drainage/secondary imbibition network simulator is being converted into ANSI C++ code. The new code is object-oriented and makes the future extensions of the pore-level physics easy. The drainage part was transferred to Phillips Petroleum. It it was tested successfully. Upon completion, the code will be available to all interested parties.

Depositional Model

Strain-stress curves calculated using 2D PFC code have been analyzed. The depositional model can now mimic various types of rocks with a wide range of mechanical properties. Development of 3D computations started.

Rock Imaging

Three 1.5-in.×6-in. sandstone coreplugs with gas permeability between 1400 and 3000 md were selected from a batch of 20 samples. For homogeneity control, the coreplugs were computer tomography scanned dry and fully water saturated using 3 mm slice thickness and 133 kV settings. The length of the plugs allows cutting 3–4-in. plugs for relative permeability and capillary pressure measurements and small samples for micro-imaging and for thin sections.

Publications

More information can be found in the following recent papers:

Patzek, T.W., Silin, D.B. "Shape factor and hydraulic conductance in noncircular capillaries: I. One-phase creeping flow," *Journal of Colloid and Interface Sciences*, 236, 295–304, April 2001.

Patzek, T.W., Kristensen, J.G. "Shape factor and hydraulic conductance in noncircular capillaries: II. Two-phase creeping flow," *Journal of Colloid and Interface Sciences*, 236, 305–317, April 2001.

Patzek, T.W. "Verification of a complete pore network model of drainage and imbibition," SPE 71310, *Society of Petroleum Engineers Journal*, 62, 144–156, June 2001.

Direct Simulation of Near-Wellbore Mechanics (Chevron, Halliburton, Shell, MIT, and SNL)

Highlights:

- Model results compared.
- SandFlow2D refined.

Significant progress was made during the past six months validating the numerical formulation, and prototyping the computer codes. A detailed comparison of model results to the analytical solution of Couette flow demonstrated second-order convergence for the coupled lattice-Boltzmann/DEM numerical scheme. The 2D code (SandFlow2D) was refined and now supports interactive model setup and visualization for both Darcy and lattice-Boltzmann fluid flow and particle transport simulations. SandFlow2D will be released in October to industry for beta testing. Current work is focused on the final implementation of a parallel version of the 2D code and the prototyping of the 3D code.

Industry support for this project remains strong, with $60,000 in direct funding received year-to-date in CRADA funds. A project briefing and model short course has been organized for October 8–9 in Houston, TX, to solicit feedback on application problems and future model enhancements. Input from industry participants will guide SNL in its selection and development of validation simulations.

Publications

Cook et al. "Discrete Element Modeling Applied to Laboratory Simulation of Near-Wellbore Mechanics," submitted to the *International Journal of Geomechanics* in September 2001.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs (BHP, BP Amoco, Chevron, Conoco, ExxonMobil, Halliburton, Kerr-McGee, Phillips, Shell, and SNL)

Highlights:

- Project kick-off meeting held.
- Work agreements signed.
- Work commences with receipt of funding.

The deepwater Gulf of Mexico (GoM) is the most active deepwater region in the world and currently provides some of the greatest challenges in scope and opportunity for the industry. Undiscovered recoverable resources of at least 13 billion BOE are estimated, and the region is known to harbor exceptional reservoirs such as Crazy Horse. The complex salt tectonics and extreme water and reservoir depths necessitate high development costs, in addition to requiring innovating technology to bring these fields on stream. Integral to the successful economic development of these fields (where the cost of a single well is tens of millions of dollars) is a well lifetime of 10–20 years. This project focuses on identifying, quantifying, and mitigating potential well integrity issues associated with sub-salt and near-salt deepwater GoM reservoirs.

This project was initiated May, 2001. The kickoff meeting, which was held in Houston, TX, May 24, was attended by 13 representatives of the participating companies. Work agreements with the nine industry participants were signed over the summer months, and by the end of September, the Year One funding under each of those agreements was in place at SNL. Work is under way in two areas. Geomechanical nonlinear finite element simulations are

being conducted at the reservoir scale using idealized geometries representative of the deepwater GoM. These include both near-salt and sub-salt configurations. Geomechanical nonlinear finite element simulations are also being performed for various casing designs. These efforts focus on assessing the influence of salt deformation on resource recovery at both the reservoir and wellbore scales.

Drilling, Completion, and Stimulation Technology

Real-Time Coiled Tubing Inspection System

(Quality Tubing and INEEL)

No work was accomplished and no hours were expended on the project. Only milestone left is to complete a final report on the project, which will be completed by November.

Perforation Dynamics in Geological Media

(Columbia Gas Transmission, Halliburton, National Fuel & Gas Supply, Panenergy, and LLNL)

Report not received.

Drill Cuttings Injection Field Experiment

(BP Amoco, Chevron, Exxon, Gas Research Institute (GRI), Halliburton Energy Services, Hughes Christensen, MSD, Pinnacle Technologies, Schlumberger, Shell, and SNL)

Project is in close-out phase; reporting and technology transfer are under way.

In-Well Imaging and Heating: Multiple-Use Well Design

(Aera Energy LLC, Chevron, SteamTech Environmental Services, and LLNL)

Report not received.

3D Analysis for Induction Logging in Horizontal Wells

(BP Amoco, Chevron, Conoco, Electromagnetic Instruments, Exxon, Halliburton, Mobil, Phillips, Schlumberger-Doll, Shell, Texaco, Unocal, Western Atlas, and SNL)

Highlights:

- Algorithm implemented in stored matrix version of the SGFD code.
- Testing is under way.

Work on the low-induction number (LIN) preconditioner is proceeding. The algorithm is now implemented in stored matrix version of the SGFD code, and testing is underway. This marks a major milestone in the code development for analyzing induction logs recorded in horizontal wells. If the LIN performs for anisotropic media as well as it does for isotropic media (results to appear in an upcoming *Geophysics* paper), then we can expect an order of magnitude reduction in the computer time needed to simulate each logging point.

Work is also beginning on constructing a GUI for the 1D induction and direct current anisotropy codes. The GUI will allow easy building of 1D models with deviated wells for an array of different tool configurations, and the display of the synthetic logs post computation.

Other accomplishments include:

- modification to the prototype 1D inversion scheme developed earlier this year to make it more robust and quicker
- completion of final changes to four manuscripts for publication in *Geophysics* (2) and *Petrophysics* (2).

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

(Chevron, INEEL, and LBNL)

Highlights:

- Feasibility report completed.
- Savoy Field Research Facility selected for prototype testing.
- Prototype constructed.

INEEL continues design and construction of two seismic sources for Pore Pressure Prediction (a.k.a. Ahead of Drill String Seismic Source). The two sources are, the Plasma Spark (now known as Capacitor Discharge Seismic Source (CDSS) and the Regenerative Combustion Seismic Source (RCSS).

The construction of the prototype CDSS device is nearing completion, and parts and material for its assembly have been partially received. Some assembly should occur by October 10.

The RCSS is comprised of components previously tested in the Arkansas experiments, and is therefore already complete.

Chevron visited the Seneca test site and has initiated coordination efforts to facilitate tests there. Initial preparations were accomplished to accommodate testing of the two devices (and an Orbital Vibrator may be concurrently tested) at Seneca Lake Naval Test Facility in New York state. Efforts include site preview and preparation of shipping arrangements, as well as some scoping plans for test methods.

A bench-scale test apparatus for ascertaining the effects of pressure on the CDSS was constructed and test apparatus collected. Following the review of operational and safety issues, bench-testing can commence. An independent hazard review to perform the test was finalized.

Acoustic Telemetry (MWD)

(ABB, Passband Downhole Communications, Electroacoustics Research Laboratory, and SNL)

Highlights:

- Prototype tools successfully field tested.
- Drilling test scheduled.

SNL and Extreme Engineering successfully deployed the prototype acoustic telemetry tools in the 3000-ft well at the PITS training facility in Alberta Canada. We operated both tools satisfactorily and without malfunction. Downhole data were collected from on-board accelerometers, as well as voltage, pressure, and temperature sensors. Data were stored in memory and also successfully shipped to the surface via the acoustic carrier wave at transmission rates of both 3 and 33 baud. Moreover, we subjected the tools both to rotation off bottom and to static drill-string loads. In addition, we used the surface demodulation code, Babel, for real-time interpretation of the acoustic-telemetry messages. Given the success of this test, we have scheduled the first drilling test for late October in a commercial shallow-gas drilling project.

Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

Highlights:

- New consistometer received and being used
- Compositions developed providing pumping times between 3 and 5.5 hours in the temperature range of 80–300 degrees F
- Class C fly ash selected as best additive for oil field applications due to its consistancy and sealant strength increases (typically × 3)

ANL received a new consistometer. We used it to test the original formulation of the ceramic borehole sealant for both Class C and F ashes as fillers, and identified a composition that meets the time and thickness requirements of the API standards. We have been able to develop compositions for wells with the downhole temperatures between 80–300°F and in the pressure range of 700–16650 psi. Our next task will be to get this formulation tested at Chevron under the cooperative research and assistance agreement, and get the sealant validated for use.

Previous testing at Chevron established that Ceramicrete formulation is valid for applications in wells with varying depths, but there existed considerable scatter in data. It appears that this scatter arose because of the Class F fly ash that was used in the composition. Substituting this ash with Class C ash has resulted in a borehole cement composition that provides pumping times between 3–5.5 hours in the temperature range of 80–300° F and in the pressure range of 700–16650 psi. ANL completed a series of tests on thickening time using the newly acquired consistometer. This data indicates that the borehole sealant developed in this project should be applicable to most of the wells.

Because of the success with Class C ash, we will study its characteristics to provide full prescription of the components for field-scale uses.

In addition to the consistometer, ANL purchased a permeameter, which is being set up for operation and will be used to study the permeability of the borehole sealants. In addition, Exxon sent us core samples of three different rocks to study the bond strength between the newly developed borehole sealant and the rock surfaces. The samples are being cut in proper shapes and test samples are being prepared.

Following the successful small field demonstration described in the last report, we are planning a full-scale demonstration of Ceramicrete as a casing cement. We plan to use this recently developed borehole sealant to tag-cement the bottom 80 ft of the 500-ft-long 12-3/4-in. intermediate casing string in a deep exploratory geothermal well being drilled in the Lightning Dock Known Geothermal Resource Area in southern New Mexico. Twenty-seven cubic feet of this hydrophobic slurry will be poured down the inside of the intermediate casing string, and then, using pressure, completely displaced out of the casing and up the annulus between the centralized casing and the rock. This first deep field test will be completed at AmeriCulture's geothermal facility in the Animas Valley, in the far southwestern corner of New Mexico. The binder materials needed for this demonstration are being procured, while 1800 lb of Class C fly ash (for the 50:50 slurry mixture of binder and fly ash) was delivered to the site. This demonstration, being spearheaded by LANL, is planned for late October, and the results will be reported at the NGOTP meeting in Houston in mid November.

Finally, we have submitted the preproposal for the Cards-on-Table evaluation of the project and are planning the presentation in the DOE partnership committee meeting in November.

Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring (DeepLook, Phillips, Texaco, and LANL)

Highlights:

- New depth record of 215 m reached.
- Recovered fish from temporary abandoned well.

A second well was drilled at the San Ysidro (New Mexico) upper site to a depth of 706-ft with a 2-3/8-in.-bit and motor run on 1-in. coiled tubing when incessant mud pump failures precluded drilling any deeper. The bore showed signs of becoming unstable and an attempt to cement-in a plastic casing was made. A hole failure occurred while preparing to cement-in the casing at 700-ft and the casing was pulled to 430-ft where an attempt to cement-in the casing was carried out. The result was a premature set, the inside of the casing fully cemented, and an uncemented annulus. The hole will be abandoned by cementing-up the annulus using a mining rotary rig and a wash over string.

A reentry of the first hole at the upper site was made with the mining rotary rig. The hole was cleaned out to the top of the lost tools and a fishing assembly was used to recover the microdrilling assembly fish. The hole was deepened using the mining rotary drilling assembly and preparations are being made to case the hole at 390 ft.

A rough-draft white paper of the road map to drill a 5000-ft deep is 1/3 completed.

Effects of Well Conditions on Post-Perforation Permeability (Halliburton, Penn State, and LLNL)

Report not received.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

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

Highlight:

- Bench-scale tests under way.

The project goal is to develop and demonstrate a reliable and robust method for monitoring strain in braided and twisted strand Synthetic Fiber Mooring Ropes (SFMR), with the ultimate objective of deploying a strain monitoring system on SFMR anchoring deep-water platforms in the Gulf of Mexico.

ORNL began an evaluation of the available multi-mode polymeric optical fibers to determine their suitability for use in the strain measurement system. Two candidate fibers were identified, and test spools of each fiber were obtained. Bench-scale measurements of their transmission characteristics at design strain values are under way.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

Highlights:

- Contract placed with industry participant.
- Design of prototype fiber injector prepared.

The need for high-data-rate, real-time, data link between downhole instrument packages and the surface continues to increase. No current system adequately addresses this need, either because of low data rates (mud-pulse telemetry), interruptions to drilling (logging cable), or need to substantially change the drilling process (various types of prewired pipe or composition coiled tubing with wiring built in). SNL and GTI have been developing a system for using unarmored, "bare," optical fiber as a disposable telemetry link. This approach is advantageous because 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 the drilling process without interfering with drilling, while providing the megabit or higher data rates. This system has been developed and tested for use in conventional drill pipe. Coiled tubing offers the opportunity to combine two existing technologies, cable injection and 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 to coiled tubing of the disposable fiber optic telemetry technology developed for conventional drill pipe. There are two main technical issues:

- injectability of the fiber using some modified form of current cable injectors
- survivability of the fiber under the mud flow conditions prevalent in coiled tubing.

A contract was placed with the industry participant, CTES, for their portion of the design, construction and testing of the fiber injection apparatus.

A design was prepared and reviewed for the prototype fiber injector.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output, Texaco, and LANL)

An interface between the MEMS array output and standard seismic data acquisition was completed. Field testing and evaluation of the array will begin on completion of the San Ysidro microhole.

Development of Single-Well Seismic Imaging Technology

(BP Amoco, Chevron, Conoco, Exxon, OYO Geospace, P/GSI, Phillips, Schlumberger, Shell, Texaco, TomoSeis, Unocal, Western Atlas, Stanford, LBNL, SNL, and INEEL)

The Salt Imaging Consortia (SIC) meeting was held in Houston, TX, in late September where it was decided to move forward with another test at a salt dome. Site criteria were identified, and SIC members voted to continue the effort. Results from the tube wave suppression (TWS) tests were presented, which showed up to 60 db of attenuation with the high-frequency sources (piezoelectric, up to 2000 hertz) and 24 db of attenuation with the AC orbital vibrator (up to 500 hertz). The INEEL tube wave attenuator was tested at a 2000 ft depth at Chevron's Lost Hills site. The attenuator was located between the LBNL/Conoco piezoelectric source and a 24-level hydrophone string. Deeper tests are scheduled for this fall. SNL modeling showed that including attenuation and viscoelasticity more realistic models of the Bayou Choctaw data could be obtained. Future work will focus on source as well as receiver common offsets.

Large Downhole Seismic Sensor Array

(Chevron, Conoco, Exxon, OYO Geospace, Shell, Texaco, U of Arkansas, and INEEL)

Project complete. Waiting on Legal to release final report.

Improved Prestack Kirchhoff Migration for Complex Structures

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

LANL continues testing the migration algorithm on 2D models. We are beginning to investigate the issue of migration quality being influenced by model velocity. The reason for this is that we have found that using multiple valued traveltime tables does not substantially improve the image quality when we use field data, but use of such tables does improve image quality with synthetic data. We are arranging to work with one of our participants to investigate an improved velocity model for a field data set so we can investigate the impact on image quality.

Testing Advanced Computational Tools for 3D Seismic Analysis Using the SEG/EAGE Model Dataset

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco, Edison Chouest Offshore, Exxon, GECO-Prakla, Golden Geophysical, Kerr-McGee, Marathon, Mitchell Energy, Mobil, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco, Union Pacific Resources, Unocal, Western Geophysical, Houston Advanced Research Center/Rice, Stanford, UC-Davis, U of Houston, LANL, LLNL, and ORNL)

Highlight:

- Processing of the marine streamer data physical model continued.

Three-dimensional imaging of the marine data collected from the physical model continued using a 3D prestack implementation of the split step method. This is a shot-record migration, which is relatively inefficient with this relatively sparse 32-receiver shot gathers of this data set. Migration of a single line takes about 3,600 cpu-hours (SGI/Origin 2000). Two lines have been migrated so far into a common 3D image volume. A more efficient common-azimuth imaging method will be used to migrate more of the marine survey data.

Publications

Roberts, P., L. House, L.-J. Huang, R. Wiley, and K.K. Sekharan. "3D imaging of seismic data from a physical model of a salt structure," *Experimental Abstracts of the Society of Exploration Geophysicists*, 71st Annual Meeting, p 1119–1122, 2001.

Integrated Reservoir Monitoring Using Seismic and Crosswell Electromagnetics

(Chevron, Electromagnetic Instruments, TomoSeis, LBNL, and SNL)

Report not received.

Frequency-Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands

(Baker-Atlas, Chevron, TomoSeis, Vastar, and LBNL)

Laboratory sonic frequency tests continued on dry and water-saturated sands to determine the P- and S-wave velocities and attenuation in unconsolidated sands with patchy saturation. These tests were conducted with LBNL's redesigned transducers, which incorporate both extensional and torsional piezoelectric crystals. An accelerometer aligned along the sample axis is used to measure the extensional wave, while two accelerometers oriented along the q-direction with opposite polarizations are used to measure the torsional wave. Differencing the output from the two q-oriented accelerometers results in effective noise reduction of spurious bending waves and electrical noise. However, due to the lighter mass of the new transducers, the end conditions on the sample can no longer be well-approximated as a rigid boundary. Correction factors for the added mass and stiffness of the transducers are being developed and will be tested against measurements on several standard materials.

The coding of the 2D dynamic poroelastic code was completed. This code is valid across the Biot transition frequency. Models representative of patchy water-gas saturation are being developed to study the effects of patch size and geometry on the velocities and attenuation of shear and compressional waves in unconsolidated sands.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

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

Over the past two months, the Full Waveform Seismic Inversion Project has concentrated on preparing and delivering two presentations at the 71st Annual International Meeting of the Society of Exploration Geophysicists in San Antonio, TX, in September. Our present efforts are devoted to preparing for a meeting with our industry participants prior to the DOE, NGOTP, DIT forum meeting in November. The project will seek third-year funding to continue development of the 3D inversion algorithm, as well as application of the algo-

rithm to field-recorded seismic datasets.

On the technical front, we are applying the full waveform inversion methodology to a synthetic 1D layered elastic medium, in order to understand how well the approach recovers layer parameters. Finally, ongoing testing of the algorithm is oriented toward understanding and correcting any amplitude scaling ambiguities.

High-Speed 3D Hybrid Elastic Seismic Modeling

(Burlington Resources, GX Technology, and LBNL)

Report not received.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco, Exxon, GECO-Prakla, Marathon, Mobil, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco, Union Pacific Resources, Unocal, Western Geophysical, Stanford, U of Houston, LANL, and LLNL)

Highlights:

- 3D elastic calculations completed for 50 shots over SEG/EAGE salt model.
- 2D elastic Marmousi model constructed.
- Amplitude-preserving wave-equation migration method being tested.

Using a 3D elastic version of the SEG/EAGE salt model, synthetic seismic data have been calculated for a total of 50 shots. Receiver traces were computed for marine streamers (1-C) and ocean bottom cable (4-C) receiver arrays. Shot spacing is 480 m. These calculations have used a total of 13,000 cpu-hours. Data are being converted to a standard format (SEGY) and will soon be made available on the project's web site.

An elastic version of the 2D Marmousi model structure was developed, and will be used for generating synthetic traces to test imaging and compare to the acoustic model results. Other 2D models are being constructed or acquired; some will be built along lines that real data has already been acquired from. Discussions are continuing with the companies that own these datasets to allow them to be provided to project participants.

An amplitude-preserving wave-equation migration method that was previously developed is being tested with a real 3D dataset. The testing involved regularization of the acquisition geometry using Azimuth Moveout (AMO) followed by true-amplitude migration.

Publications:

Larsen, S., R. Wiley, P. Roberts, and L. House. "Next-generation numerical modeling: incorporating elasticity, anisotropy and attenuation," *Experimental Abstracts of the Society of Exploration Geophysicists*, 71st Annual Meeting, p 1218–1221, 2001.

Sava, P., B. Biondi, and S. Fomel. "Amplitude-preserved common image gathers by wave-equation migration," *Experimental Abstracts of the Society of Exploration Geophysicists*, 71st Annual Meeting, p 296–299, 2001.

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

(BPAmoco, Chevron, JNOC, Landmark, Phillips,

RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

LBNL and Texas A&M have received a time-lapse 3D seismic dataset from a Gulf of Mexico field. LBNL has also obtained a preliminary reservoir model from an industry participant, based upon static log and seismic data and a geologic model. Starting from this initial distribution of porosity and permeability we inverted the water-cut data from a set of wells. Using our streamline inversion code, we obtained a relatively good match to the observed water-cut at all but one well.

We have begun to examine the time-lapse seismic data for properties, which we can use in an integrated inversion of seismic and production data. We are looking at both amplitude and phase data and some systematic variations across the reservoir are evident. At this point, we are trying to relate the changes in seismic attributes to changes in pressure and saturation within the reservoir, as predicted by the numerical simulator.

Work has commenced on relating electric log variations to reservoir properties. Using principle component and cluster analysis we can correlate electric log variations to porosity. This methodology is being applied to a gas field in Texas.

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, Texaco, TomoSeis, Unocal, Veritas DGC, and LANL)

LANL has used 2D synthetic data to verify a new migration algorithm. Preliminary migration results demonstrate the new migration algorithm termed the split-step Pade method provides images with much less artifacts than those obtained using the conventional finite-difference solution of the parabolic equation. For a given model, the split-step Pade method can use much larger grid spacings than the conventional finite-difference migration, and therefore, the former method can be much more efficient than the latter one. We will further test our new method using other data sets available. We will also investigate an optimized scheme and a hybrid algorithm.

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

(Deeplook, KMS Technologies, KJT Enterprises, LBNL, and SNL)

Seismic system integration began with conversion of the LBNL seismic system to a include a more stable fiber-optic pass through for the seismic and EM systems. This involves conversion from single mode to multi-mode in all down hole electronics, while maintaining the up hole link in single mode fiber.

Autonomous Monitoring of Production

(Aera Energy, Chevron, SteamTech Environmental Services, Texaco, TomoSeis, and LLNL)

Texaco Exploration and Production, Inc. joined the project. Texaco pro-