ACTIVITY REPORT

May 2004

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	Upstream Environmental Technology Downstream Environmental Technology Natural Gas Technology

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

Drilling, Completion, and Stimulation Technology

Seismic Source for Pore Pressure Prediction While Drilling

(Halliburton and INEEL)

Highlight:

- RMOTC data analysis complete

The Capacitive Discharge Downhole Source (CDDS) completed its final test series at the Department of Energy (DOE) Rocky Mountain Oilfield Testing Center (RMOTC) in Casper, WY on March 2, 2004. The objective of this last test was to attempt velocity contrast detection between shale and a sandstone unit located about 900 feet below the surface in an oil-bearing formation. Data analysis is complete and reflections related to the sandstone unit were not detectible by either the twelve hydrophones located down hole or the thirty-six geophones located on the surface. One hundred and eighty nine CDDS shots taken at regular intervals were used in the analysis. The final report is the last task to complete and constitutes close-out of this project.

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

Highlight:

- Final project report

1. Project overview

Shaped-charges are frequently used by the oil and gas industry to complete cased wells. Detonation of a shaped-charge creates a high velocity jet of metal that perforates the well casing and penetrates through the zone damaged by drilling, into the undamaged formation. The result is a debris-filled tunnel connecting the well bore and the formation with a zone of damaged rock surrounding the perforation tunnel. To enhance the efficiency of perforations, it is common to draw down the pressure in the well (underbalance) prior to detonation of the charges, resulting in a transient pressure surge from the formation to the well bore immediately following perforation. This pressure surge in turn drives damaged rock and charge debris from the perforation tunnel, improving flow through the perforation tunnel. However, recent experimental evidence suggests that the mobilization and entrapment of fine particles within the formation during the pressure surge and subsequent flow to the perforation can lead to a reduction in permeability in the rock surrounding the perforation tunnel. Thus, optimizing post-perforation permeability may require effectively balancing competing mechanisms, which requires understanding the combined influence of different parameters on the perforation process. These parameters include: 1) the size and geometry of the shaped-charge, 2) the mechanical and hydraulic properties of the rock and fluid in the reservoir, and 3) the degree of underbalance/overbalance employed during perforation.

We have undertaken an integrated experimental and computational investigation aimed at clarifying the roles of the interacting mechanisms that influence the efficiency of underbalanced perforations. Our computational efforts involved the development of a simulator that calculates the penetration of the shaped-charge jet and the resulting alteration of the permeability surrounding the perforation tunnel, the post-perforation pressure surge and resulting removal of tunnel debris, and the mobilization and entrappment of fines in the reservoir surrounding the perforation tunnel. The experimental efforts were aimed at providing quantitative results for evaluating our computational models and extending previous results to new rock and fluid combinations.

2. Summary of significant results

2.1 Experimental program

The experimental program capitalized on a combination of the high-resolution x-ray imaging capabilities at Penn State University (PSU) and the high throughput experimental capabilities of our industry partners at Jet Research Center (JRC) in Alvarado, Texas. Both these laboratories are equipped to conduct *API RP43, Section 4* flow tests on cores. These tests are designed to measure post-perforation permeability in cores under simulated downhole conditions in the laboratory. These tests provide an estimate of the core flow efficiency (CFE) or the ratio of the permeability of the perforated core to the idealized permeability of a core containing an identical perforation tunnel with no damaged zone. However, the API flow tests provide only a bulk measure of the relative effectiveness of different perforating schemes, such that it is difficult to interpret the relative importance of the interacting physical processes that lead to permeability loss. Thus, developing effective perforating schemes requires a costly trial and error approach.

The experimental facilities at PSU incorporate x-ray CT imaging in an effort to overcome the limitations of the standard API flow tests. X-ray CT scans are used to provide both undisturbed measurements of perforation tunnel geometry and measurements that are used to calculate the radial variation in permeability within the core. In addition to the image acquisition and analysis, a method has been developed for measuring the concentration of fine particles at different locations within the perforated core. The objectives of the experimental program were two-fold: 1) map the permeability and fines distribution surrounding perforations in Berea sandstone cores under a limited range of conditions and 2) characterize the damage and clean-up of a series of Berea sandstone and Bedford limestone cores perforated under a broad range of underbalance conditions at JRC. These experimental data were then used to evaluate our computational model.

The perforation experiments conducted at PSU yielded a set of permeability maps and measurements of the grain-size distributions in Berea sandstone cores perforated at different underbalances. The results suggest that a model relating grain size distribution to permeability can be used to effectively estimate permeability distribution within perforated cores [2]. This is a significant development because of the considerable experimental difficulty involved in mapping post-perforationi permeability using x-ray CT techniques.

A subset of the cores from the API flow tests conducted at JRC were sent to PSU for post-perforation x-ray scanning. These scans provided detailed, high-resolution measurements of the geometry of the perforation tunnels and the distribution of charge debris remaining in the tunnels. This approach provides insights into the perforation process that are lost in the conventional method of filling the perforation with liquid metal prior to splitting the sample in order to inspect the geometry of the perforation tunnel. Results of these experiments demonstrate a dramatic difference between perforations in sandstone and limestone cores, which underscores the importance of developing effective rock-specific models for use in evaluating perforation schemes [5].

2.2 Computational program

The computational program consisted of the development and evaluation of a multi-stage simulator that calculates shaped-charge perforation, post-perforation pressure surge and debris removal, and fines mobilization and entrappment. Due to the disparate time scales involved with each of these processes, they are calculated sequentially, resulting in a quantitative description of the entire perforation process that provides estimates of perforation tunnel geometry, extent of the damaged zone, and post-perforation permeability.

A fundamental advance of our modeling approach has been the development of a constitutive model relating changing stress in Berea sandstone to the evolution of permeability within the rock [3]. Coupling this new constitutive relationship with a hydrocode used for simulating deformations caused by shaped-charge jet penetration provides a tool for predicting the post-perforation distribution of permeability surrounding the perforation tunnel [1]. This is a significant improvement over previous models that have typically required that the perforation geometry and the nature and magnitude of the damaged zone be assumed. Our initial perforation model assumed a post-perforation tunnel geometry and calculated the mobilization and entrapment of fines during the quasi-steady flow that succeeded the post-perforation pressure surge and the resulting modification of permeabilities within the formation. The results exhibited qualitative agreement with previously reported experimental results that suggested that with increasing underbalance, a significant portion of fines were mobilized from distant regions of the core to become entrapped in a narrow region adjacent to the perforation tunnel. Thus, defining the optimal underbalance requires maximizing the amount of debris removed during the post-perforation pressure surge, while minimizing the mobilization and entrapment of fines [1].

The underbalance-induced pressure surge following perforation is thought to cause loosening and removal of damaged rock and charge debris from the perforation tunnel. Immediately following perforation, underbalance causes a steep pressure gradient at the entrance of the perforation tunnel. This results in a rapid transient pressure surge that propagates into the debris-filled tunnel and the formation surrounding the tunnel. We have modified the initial model to include a transient non-Darcy flow model to simulate this pressure surge and combined it with a model for the removal of debris from the tunnel [4]. The model combining a hydrocode and stress-porosity-permeability model with the transient, non-Darcy flow solver predicted the series of experimental results from JRC reasonably well. Furthermore, the simulations suggest that at low underbalance, most of the flow to perforation tunnels occurs toward the tip end of the tunnel, whereas at high underbalance, flow to the perforation tunnel is greater near the tunnel entrance. Thus, high CFEs measured at large underbalance may overestimate the increased productivity of a perforation under downhole conditions. Also, small changes in tunnel radius induced by variability in rock strength may lead to small alterations in the thickness of the damaged zone and significant variability in CFE estimates.

3. Recommendations for further work

The development of effective computational models of the perforating process is inherently constrained by the quality of the available models of material properties. For example, the relationships between the stress history of a volume of rock and the evolution of permeability and rock strength are fundamental to developing accurate perforation models. Our models are based on extensive experimental data available for Berea sandstone, however, these data are limited to quasi-steady deformations, requiring ad-hoc modifications for the dynamic loading experienced by rock exposed to a shaped-charge jet. Thus, in addition to developing the requisite material models for other rocks such as the Bedford limestone used in the JRC experiments, the development of an experimental data set relating dynamic deformations of these rocks to permeability evolution would significantly strengthen the foundation of these modeling approaches.

Despite significant efforts to quantify the role of fines in the post-perforation distribution of permeability surrounding the perforation tunnel, there remains uncertainty. There are two fundamental challenges to this problem: 1) quantifying the initial distribution of fines susceptible to mobilization and re-entrapment during post-perforation flow and 2) quantifying the distribution of fines in the perforated core at resolutions adequate to interpret the impact on permeability within the core. Developing an experimental approach for making these measurements would lead to improved understanding of the importance of fines during perforating and lead to improved incorporation of the process into computational models.

A potentially beneficial use of the modeling approach undertaken during this investigation is the extrapolation of laboratory flow tests to downhole conditions and flow geometries. As noted above, the two-dimensional simulations demonstrated the possibly significant influence of axial variations in damage removal on CFE estimates and on the utility of the CFE as a measure of downhole performance of a particular perforating scheme. Extending this modeling approach to three dimensions would permit the use of boundary conditions that are more representative of the downhole conditions during perforating, which would likely lead to further insights into the relative importance of different parameters and aid in optimizing perforating strategies.

4. Publications resulting from the project included:

[1] Morris, J.P., Lomov, I.N., and Glenn, L.A.: “Simulating ~~P~~perforation permeability damage and cleanup”, SPE 71316, 2002.

[2] Karacan, C.O. and P.M. Halleck, Correlating particle size distribution in a crushed zone to perforating permeability damage and modeling using fragmentation fractal theory, SPE 77365, SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 29 September–2 October 2002.

[3] Morris, J. P., I. N. Lomov, and L. A. Glenn, “A constitutive model for stress-induced permeability and porosity evolution of Berea sandstone”, J. Geophys. Res., 108(B10), 2485, doi:10.1029/2001JB000463, 2003.

[4] Detwiler, R.L., J.P. Morris, C.O. Karacan, P.M. Halleck, J.T. Hardesty, “Evaluation of the relative importance of parameters influencing perforation cleanup”, SPE 86538, SPE International Symposium and Exhibition on Formation Damage Control”, Lafayette, Louisiana, U.S.A., 18–20 February 2004.

[5] Halleck, P.M., C.O Karacan, J.T. Hardesty, R.L. Detwiler, “Changes in perforation-induced formation damage with degree of underbalance: comparison of sandstone and limestone formations”, SPE 86541, SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, 18–20 February 2004.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

Accomplishments: Significant progress has been made toward signing a CRADA agreement with University of Tulsa, our cost share partner, final negotiations are underway. An Invention disclosure record has been submitted covering our work to date on flaw detection algorithms in ferromagnetic materials via magnetic flux leakage. In addition, an initial draft of a peer-review paper covering our latest results has been prepared. Our current algorithmic results were presented to our cost share partner, University of Tulsa, at a meeting in Texas along with industrial representatives. The results were received as very good progress towards the project goals. We were able to automatically detect all flaws within our flaw library with at least one sensor, while only detecting 5 false positives. This results in 100% detectability for our sample set, an 8% false positive, and 0% false negatives. The results to date tell us that additional circumferential sensors need to be added to the system to help the next effort of sizing the flaws. This will be accomplished this summer.

Personnel News: We had planned on hiring one of our cost share partner's students this summer. The student applied to our fellowship and was accepted, we extended an offer, which he accepted, only to inform us a week before he was to start that he would not come. This has left us once again in a difficult position. We have chosen to fill this position internally by adding Dr. Steve Novascone to our team.

Significant Customer/Industry Contacts: We continue to negotiate a formal CRADA agreement with our industrial/university partner, University of Tulsa, pertaining to the Intellectual Property Rights being developed under this agreement. Furthermore, this agreement will ensure our industrial cost share base funding, as well as formally codify our relationship with our University of Tulsa.

Budget variance: Currently, being re-planned due to new FY04 money arrival, and new personnel on the project.

Milestones: Completed initial analysis of our flaw signal library, using the matched filter technique for all flaws.

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

(ChevronTexaco, Shell, and LBNL)

We are continuing to fabricate and test a model borehole within synthetic sandstone blocks made of silica sand and calcium aluminate cement. In the past months, we have improved the technique for fabricating samples that are less heterogeneous and contain less air bubbles. Using homogeneous samples is critical for studying the effect of in-situ stress and material properties of the rock on the breakout and sanding of a borehole. In particular, aligned air bubbles (in a localized, high porosity zone) can act as a weak spot on the bohehole wall, which triggers premature growth of "wormholes."

Currently, the tests are conducted using two pairs of aluminum internal-loading platens within a triaxial confining cell, which are x-ray transparent. One side of the platens has a curved surface so that the platens are attached to the four sides of a synthetic rock block to assume a cylindrical shape. This assembly is then placed in a rubber confining jacket and loads are applied independently to the each pair of the platens. Since these aluminum plates are rather compliant, there is a possibility that the stress within the sample is uneven. For experiments without the x-ray imaging, we are planning to conduct the tests using much stiffer, stainless steel platens of identical geometry. The results will be compared to the tests using the aluminum platens to identify any differences in the failure of the borehole.

Development of Smart-Proppant Technology for Hydraulic Fracturing

(U of Tulsa, Halliburton Energy Services, and INEEL)

Research specific to a volunteer organism capable of guar liquefaction continues. The organism has been tentatively identified as *Bacillus kaustophilus* through 16srRNA gene sequence similarity based on gene alignment profiles and phylogenetic analysis. The organism exhibited a 0.37% genetic difference from the sequence of *Bacillus kaustophilus*. Recently, *Bacillus kaustophilus* has been reclassified as *Geobacillus kaustophilus.* Importantly, a positive control isolate (*Bacillus subtilis*) exhibited 0.0% genetic difference from a known sequence of *Bacillus subtilis* utilizing the same analytical techniques.

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

(Halliburton Energy Services, PDVSA, Parker Geosciences, Colorado School of Mines, Wavefront Research and Gas Technology Institute, and ANL)

Highlights:

- Experimental work of using high power Nd:YAG laser beams to perforate reservoir rocks began. Preliminary results promising
- FY04 work planning meeting
- Four papers on laser well drilling and characterization of lased rocks prepared

As part of the process of drilling an oil or gas well, a steel production casing is often inserted to the bottom of the well and sealed with cement against the productive formation. Openings must be made through the steel casing wall and cement and into the rock formation to allow formation fluid to enter the well. Conventionally, a perforator is lowered through the casing on a wire line. When it is in the correct position, bullets are fired or explosive charges are set off to create an open path between the formation and the production string. As effective as those processes are in creating a hole or tunnel, they alter the surrounding rock and cause formation damage around the created tunnel. The permeability of the altered zone is significantly less than virgin formation by as much as 80%. New perforation technologies that not only create holes effectively but also minimize the formation damage are in demand.

Previous high power laser testing on rocks, both 10,640 nm wavelength CO_2 beam and 1064 nm Nd:YAG beam, showed that lasers could drill rocks efficiently as well as enhance the permeability of drilled rock. But for them to be used in perforating operation, the high power beams have to be delivered down to the wells as deep as 10,000 to 20,000 feet. In the laser perforation testing study of this period, the Nd:YAG laser beam is selected over CO_2 laser beam as the perforating laser source because the fiber optic cable allows the Nd:YAG laser beam to be used over long distances. The preliminary results show:

1. With the right beam energy flux and relaxation time, pulsed Nd:YAG laser beams perforate the rocks as efficiently as high power CO_2 laser beams.
2. The pulsed Nd:YAG laser beam loosened and fractured the borehole wall, indicating potential permeability enhancement.
3. The laser perforated holes tapered from 1” diameter at the opening to 0.5 “ diameter at a depth of 4”. This behavior seems to be caused initially by beam profile effects and then additional secondary effects. Techniques are being developed to reduce or eliminate hole tapering.

An FY04 work planning meeting was held at the Colorado School of Mines on May 17-18, 2004. During the meeting, a new team member, Wavefront Research Inc., was introduced to the team. The team finalized the scope of work for FY04 with timeline and budget breakdown by tasks.

The following papers were prepared and provided to team members at the May meeting:

"Spectral signatures and optic coefficients of surface and reservoir rocks at COIL, CO2 and Nd:YAG laser wavelengths", Ramona M. Graves and El Tahir Bailo, Petroleum Engineering Department, Colorado School of Mines, Golden, CO 80401 USA (to be published)

"Physio-chemical properties of porous media (rocks) after being drilled using high-power lasers: analytical techniques", El Tahir Bailo, Ramona M. Graves, and Kristina M. Loop, Petroleum Engineering Department, Colorado School of Mines, Golden, CO 80401 USA (to be published)

"Rock removal by laser: data analysis to identify trends and controlling factors", Zane L. Gordon, Ramona M. Graves, Petroleum Engineering Department, Colorado School of Mines, Golden, CO 80401 USA; Richard A. Parker, Parker Geoscience Consulting, 6346 Secrest St., Arvada, CO 80403 USA (to be published)

"Porosity and permeability changes in lased rocks calculated using fractal fragmentation theory", R.M. Graves, El Tahir Bailo, Colorado School of Mines, Golden, CO, 80401 USA - Presented at the Petroleum Society's 5th Canadian International Petroleum Conference (55th Annual Technical Meeting), Calgary, Alberta, Canada, June 8 – 10, 2004.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Shell Global Solutions U.S., Whitehill Manufacturing Corp., Puget Sound Rope, Petroleum Composites, and ORNL)

No report received.

Oil and Gas Recovery Technology

Measuring Sucker Rod Pump Parameters Downhole

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

Highlight:

- Instrumented pump for Texas Tech fabricated.

The instrumented pump fabricated by Harbison-Fischer for Texas Tech has been checked out and minor changes are being made. Miscellaneous parts are being acquired. The unit will be ready when Texas Tech plans field testing.

Direct Simulation of Near-Wellbore Mechanics

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

During this project period we have initiated new research directions that were suggested by our industry partners at the March 2004 project workshop. Specifically, we have begun the extension of our earlier sanding study to explore the effect of simulation size and the sensitivity of sanding results to the particle size / perforation diameter ratio. A new DEM model has been constructed with approximately

40,000 elements (roughly four times the size of the original models). As discussed at the meeting, there were several unresolved computational issues that impact the efficient scaling of the code and consequently significantly increased simulation times for these larger models. We have studied these issues and identified some algorithmic and modeling solutions that appear to resolve them satisfactorily; with these changes, we now believe that we can complete the larger simulations within a similar if not shorter time period than that required for the original simulations. We are in the process of implementing these code changes and hope to have preliminary simulation results to report for the next NGOTP update. Although we have focused on the 2D code during this project period, we have also come to closure on the initial 3D validation simulations, which confirm the accuracy of the 3D implementation of our coupling scheme between the DEM and fluid solvers. In the process of the 3D validation, several computational bottlenecks have been located that will be the focus of our efforts on the 3D code in the coming project period.

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

(BHP Billiton, BP, ChevronTexaco, ConocoPhillips, ExxonMobil, Kerr-McGee, Petrobras SA, Shell, and SNL)

Work has continued on the reservoir-scale finite element modeling work task that is focused on examining the response of adjacent and overlying salt diapers to pore pressure depletion and reservoir compaction. Work has also continued to extend the wellbore scale modeling effort to consider salt constitutive behavior, as well as additional casing/hole configurations. Finally, work continued on the task focused on constraining the constitutive properties of deepwater GoM salt diapers, with over one hundred analyses now completed. The database includes salt diapirs from six geographic regions within the Gulf of Mexico (Mississippi Canyon, Green Canyon, Walker Ridge, Ship Shoal, Ewing Bank, and Garden Banks), as well as several SPR sites located along the Gulf Coast. Several blinds were also ran to qualify the measurements that have been conducted by three separate laboratories. The final database for this work task should be ready for release to the partners later this summer.

J. T. Fredrich chaired an industry forum "Predicting and Responding to Subsalt and Near-salt Pore Pressures" that was held in Houston on May 27. The forum included invited talks by staff at Shell E&P, ChevronTexaco, BP America, ExxonMobil, Pioneer, and several other companies, with considerable discussion time. The forum was the last in a series of four roundtables that focused on pore pressure prediction in the Gulf of Mexico, and well attended with nearly 70 participants.

The Funds-In Agreement with Petrobras S.A. was formally executed, with funding received by Sandia. Dr. Alvaro Costa Maia of CENPES, Petrobras S.A. R&D center, visited Sandia on May 11-12 to jump-start their participation in the JIP.

Norsk Hydro E&P Americas is potentially interested in joining the JIP and at their request were provided with the Statement of Work for the JIP as well as contractual details.

An amendment to the Funding Agreement work was negotiated and executed with BHP Billiton to apply tools and work approaches developed under the JIP to well planning efforts for one of their deep-water GoM prospects. This increases to four the number of companies for which separate proprietary work agreements have been conducted for specific field interests. Additionally, proprietary amendments to the JIP are also currently being discussed with both ChevronTexaco and Petrobras S.A.

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)

Three more field experiments were conducted in the Central Valley oil fields of California. Two were conducted at the Elk Hills site operated by Occidental Petroleum and one at the Lost Hills site operated by ChevronTexaco. All three sites are being stimulated with the ASR source. All three monitoring experiments used a three component tool, (two geophones and a hydrophone) in wells at varying distances away from the stimulation well (1000 feet to 1500 feet). The monitoring was done at the depth of the production, in perforated production wells which were taken off line for this monitoring. In one case the stimulation tool was in a perforated well and in the two other cases the stimulation tool was in non-perforated wells. Energy was seen from the ASR source in all cases. When the source was in non-perforated wells, energy was only seen on the geophones. In the case of perforated wells, energy was seen on both the hydrophone and geophone, with the main energy seen on the hydrophone. The operators are reporting increased oil cut from the stimulation on the order of 5 to 20 percent. However, there are cases where no effect has been observed.

In the laboratory work being conducted at LANL, experiments to study particle effects on permeability during low-frequency stimulation are continuing. Effluent particle suspensions expelled from the sandstone core sample before, during, and after stimulation are currently being analyzed to determine changes in flux and retention induced. Colloid injection experiments will begin after these natural in-situ particle tests are completed.

The results of the recent field work were presented at the May 10, 2004 AAPG regional meeting in Bakersfield, CA. An invited paper reporting the major laboratory experimental results of this project to date is being prepared for the Russian Journal of AcousticalPhysics. The paper will be peer-reviewed by international experts in the field of seismic stimulation.

Direct Quantification of Uncertainties Associated with Reservoir Performance

(ChevronTexaco and LANL)

No work scheduled this reporting period.

Diagnostic and Imaging Technology

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP, 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, Society of Exploration Geophysicists [SEG], Unocal, Western Geco, Stanford, U of Houston, Veritas DGC, and LLNL)

Highlight:

- 172 shots completed in 3-D elastic SEG/EAEG Salt structure
- Results of elastic data computations to be presented at 2004 SEG meeting

3-D elastic synthetic data were computed for an additional 40 shots of a large survey over the SEG/EAEG salt structure. These additional shots bring the total number of shots completed in the Phase 2 calculations to 172. For each shot, synthetic traces are produced for 35,000 4-C receivers laid out in ocean bottom cables, 1,500 1-C receivers in marine streamers, and 3,800 4-C receivers in wells.

An expanded abstract describing the results of the Phase 2 model calculations has been reviewed and accepted for presentation at the 2004 annual meeting of the Society of Exploration Geophysicists.

Publication:

"Next-generation seismic modeling and imaging project: summary of elastic modeling results" - Accepted for presentation at 74th Annual Meeting, Society of Exploration Geophysicists, Denver, Colorado, October 10-15, 2004.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

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

No report received.

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)

Highlights:

- Progress made on improvement of accuracy, efficiency, and globalization

We continued investigating the optimal number of grid points along the cross-line offset dimension for the stationary-phase wave-equation migration method. Using more grid points can yield more accurate images but takes more computational time. On the other hand, using too many grid points along the cross-line offset dimension does not increase migration accuracy for the stationary-phase wave-equation migration method. Our impulse response studies demonstrate using too few cross-line offsets could produce incorrect results.

We continued research to further improve the migration efficiency of controlled-aperture wave-equation migration, which could dramatically reduce computational costs for 3D wave-equation migration using common-shot datasets while maintaining or even improving migration accuracy.

In addition, we also generalized our globally-optimized Fourier finite-difference migration method in the offset domain to three dimensions.

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

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

No report received.

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)

Clay anisotropy tests were performed in the ultrasonic phased array compaction cell on a kaolinite sample (Source Clay Minerals Repository KGa-1b). The sample started from a clay slurry condition (equal parts of clay and water by weight) and ended with a stiff clay condition at 3 MPa axial stress. The sample was subjected to uniaxial strain loading (i.e., 1-D consolidation) with the pore fluid open to atmospheric pressure. Ultrasonic data were collected at 1 MPa increments. Each dataset consists of 1 MHz P-wave propagating along bedding, 50 kHz S-wave propagating along bedding with polarization perpendicular to the bedding (SV), 50 kHz S-wave propagating along bedding with polarization parallel to the bedding (SH), and 1 MHz P-wave phased plane waves over a range of angles from 0º (perpendicular to bedding) to approximately 60º. From these measured phase slownesses, the following elastic constants were computed assuming a transversely isotropic medium with a vertical axis of symmetry (VTI). Below, we report 4 of the 5 VTI elastic constants (C_{13} requires processing that is in progress).

axial stress (MPa)	C_{11} (GPa)	C_{33} (GPa)	C_{55} (GPa)	C_{66} (GPa)
0.1	3.64	3.66	0.086	0.086
1	5.84	3.91	0.114	0.090
2	5.71	4.72	0.143	0.16
3	5.97	4.73	--	0.253

At 3 MPa, the properties of the clay are: density(saturated)=1.94 g/cc, density(dry)=1.55, porosity=0.42, P-wave anisotropy (Thomsen's e)=0.13, and S-wave anisotropy (Thomsen's g)=0.055. It should be noted that the P-wave anisotropy is significant, despite the relatively low stress levels.

Two difficulties were encountered in this test. The first, which will be corrected in future tests, was that the sample thickness was too small. For samples thinner than 1 cm, a significant SV-P wave reflection is generated off of the steel piston. This arrival obscures the direct SV wave and influences the accuracy by which C_{55} can be determined. The second difficulty was the loss of signal amplitude in the SH source. This problem was traced to the failure of the SH source transducer. A new transducer is in the process of being constructed. The next test will be a repeat of this test using a thicker kaolinite sample. Once repeatability and accuracy of the system have been fully characterized on this pure clay, we will commence measurements on marine clay samples provided by our industry partners BPAmoco and ChevronTexaco.

Realistic Anisotropic Velocity Estimation in Complex 3D Environments

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

No report received.

Joint Geophysical Imaging

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

A marine EM and seismic data set has been processed by two of our industrial partners (Shell and EMGS). This data set along with logs and interpreted seismic surfaces has been transferred to LBNL for inversion work. Work has begun using newly developed stochastic and deterministic joint inverse algorithms. Two papers on our joint inversion work have been accepted for presentation at the upcoming SEG meeting in Denver, where the results of the field data trial will be presented. Our development work to date was presented at the EAGE meeting in Paris (June 7-10) to a special workshop focusing on the application of marine electromagnetic geophysics in oil and gas exploration.

We have demonstrated that we can successfully estimate both the overburden conductivity profile and reservoir pressures (lithostatic and pore) while simultaneously estimating reservoir porosity and gas saturation in a synthetic example base on an actual marine gas discovery. The study clearly demonstrates the added resolution in fluid saturation estimates that can be obtained by incorporating the marine EM data with the industry standard AVO data. The results to date indicate that the stochastic inversion approach is more robust at reaching a global solution when compared to our deterministic inversions. However, in 3D the stochastic sampling required may be prohibitive so we are working on ways to produce a hybrid stochastic-deterministic inversion for the full 3D inversion of data sets.

From The Partnership Office

Upstream Environmental Technology Projects:

The proposals, presentations, recommendations and fiscal 2004 funding of the Upstream Environmental Technology Projects is now posted on the NGOTP website. The direct link is, http://132.175.127.176/ngotp/projects/UETforum2004.cfm . It can also be accessed by going to the NGOTP home page and clicking on the link titled: "**New!** Upstream Environmental Technology Forum 2004".