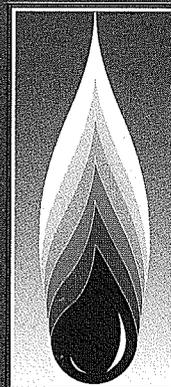


Partnership Progress



Natural
Gas &
Oil
Technology
Partnership

June 1997

No. 6

U.S. Department of Energy

National Laboratories

U.S. Petroleum Industry

Continuity

Project continuity has improved in FY 97. The Borehole Seismic Forum reviewed Borehole Seismic projects in February, and the Office of Fossil Energy approved funding for three continuing projects. Oil Recovery Technology projects were also extended until a review later in the year. The Computational Technology Industry Review Panel reviewed all Computational Technology projects in May; funding for some projects improved, thanks to the efforts of Defense Programs, Energy Research, and Fossil Energy.

The DOE Bartlesville Project Office moved to Tulsa, OK, and is now the National Petroleum Technology Office. We would also like to acknowledge funding support from the Federal Energy Technology Center through its gas programs office in Morgantown, WV.

Bob Hanold and
Dave Northrop.

The Partnership on the
World Wide Web:

<http://www.sandia.gov/ngotp/>

Featured Partnership Project

Advances in Marine Magnetotellurics for Subsalt Imaging

One of the most promising domestic areas of oil and natural gas production is beneath large, irregularly shaped salt structures in the Gulf of Mexico. Estimates of oil and gas reserves in these areas are in the range of 15 billion barrels of oil equivalent. However, wells in this new geologic province cost about \$12 to \$15 million each; therefore, it is extremely important to predict the location of oil and gas reserves beneath these salt bodies accurately in order to improve the success ratio of exploration wells.

(Continued on Page 2)



Photo by Steve Constable

Figure 1. The Marine MT device, developed at Scripps Institute of Oceanography, is lowered into the Gulf of Mexico for testing.



(Continued from Page 1)

To overcome limitations of conventional imaging techniques, the Subsalt Imaging with Marine Magnetotellurics project is investigating the feasibility of marine magnetotellurics (MT) as a technique for imaging the bottom of salt structures and determining their size and thickness.

Lawrence Berkeley National Laboratory (LBNL) geophysicists Michael Hoversten and Frank Morrison, and marine geophysicist Steven Constable, from the Scripps Institute of Oceanography at UC-San Diego, are developing a marine MT technology which is based on measurements of salt's electrical resistance to low-frequency electromagnetic radiation from the earth's ionosphere. MT is advantageous for subsalt imaging because salt is more electrically resistive than other sediments.

Objectives

- Combine seismic and gravity interpretations with marine MT to improve ability to image salt bottom and salt roots.
- Demonstrate the technical feasibility and economics of marine MT.

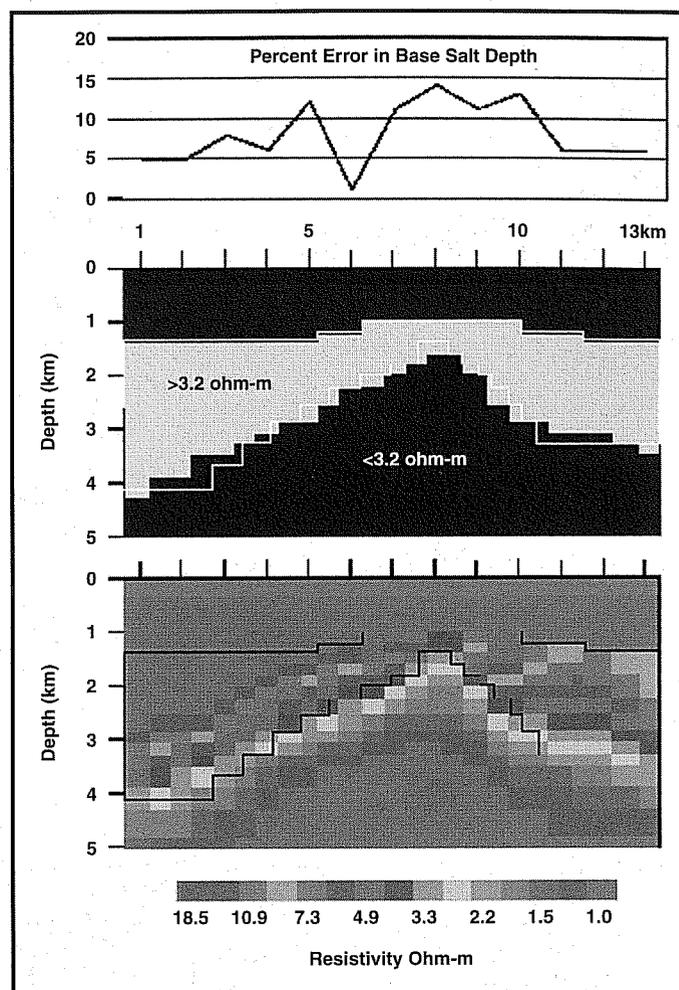


Figure 2. Smooth 2D inversion of numerical data from a salt structure.

MT Physics

The MT technique measures the earth's electrical impedance to naturally occurring, ultra-low-frequency electromagnetic waves generated when the flux of charged particles thrown off by the sun (the so-called solar wind) collides with and is blocked by the earth's magnetic field. Some of the kinetic energy causes magnetic field oscillations. Solar particles leaking into the ionosphere generate ionospheric currents. The resulting magnetic fields propagate into the earth, generating current flows that depend on the local electrical conductivity distribution. The frequency range is typically between 10^{-3} Hz and 1 Hz. As the currents penetrate the earth's surface they are met by subsurface resistivity changes which cause an electromagnetic wave to be reflected back toward the surface. By measuring these electric and magnetic fields at the surface, and processing the data through complex mathematical computations, resistivity models can be generated to augment seismic images.

The irregularly-shaped salt structures are difficult to image solely through the seismic imaging methods traditionally used for subsurface exploration. These salt structures sometimes cover hundreds of square miles in area and are excellent reflectors of soundwaves, preventing surveyors from obtaining accurate readings of structure shape and thickness. However, salt structures are also highly resistant to electrical currents, which allows geophysicists to take advantage of atmospheric electromagnetic radiation. Since salt can be 1000 times more resistive than the surrounding sediments, major salt structures can be mapped by observing the distortion in the flow of electrical currents through seawater and sediment.

Continued on Page 3



Submersible Equipment

The marine MT system is equipped with orthogonal pairs of electrodes and magnetic sensors. The electrodes are fixed to the ends of PVC pipe. The electrode separations are on the order of 3 m, much closer than those used in land surveys. Closer separations are possible because of the very low noise in the marine environment. The entire hardware system consists of seven sea-floor instrument packages developed at Scripps, plus two standard land-based 3-component magnetometers, and the data processing/data inversion software developed at LBNL and the UC-Berkeley.

Each sea-floor package also includes the data acquisition electronics, weights, a buoyancy chamber, and signal lights to aid in recovery. During a cruise, packages are dropped overboard at desired positions (see Figure 1), typically 1 km apart, and left on the sea-floor for 24 to 48 hours to record data. The ship circles back to the first site and begins package recovery, which is triggered by passing an electric current through a thin, exposed wire. In the presence of seawater, the wire quickly corrodes and breaks, releasing the weights. The buoyant package then floats to the surface.

Gulf of Mexico Tests

Tests were conducted in the Gulf of Mexico in a region where large oil and natural gas deposits are believed to be hidden beneath salt structures. The Mahogany and Gemini sites located off the Louisiana coast provided the team with an area that is potentially laden with petroleum reservoirs. Mahogany is about 100 m deep (relatively shallow), and Gemini is, in some places, 1.5 km deep (5000 ft).

In August 1996, nine sites at the Mahogany prospect were distributed in a north-south line through the well. Stations were spaced 2 km on-salt and 4 km off-salt. Another five sites were distributed along an east-west line through the well. At the Gemini prospect, 20 sites were clustered around the well and extended into a double line of stations to the northwest. Another line was oriented southwest-northeast just northwest of the well. Stations were situated on a 2-km orthogonal grid.

Data from the Mahogany and Gemini surveys are still being processed, but based on the numerical modeling, the team remains confident that marine MT can map the extent and thickness of salt structures with sufficient resolution to determine the prospects of finding new oil or gas deposits

(Continued on Page 4)

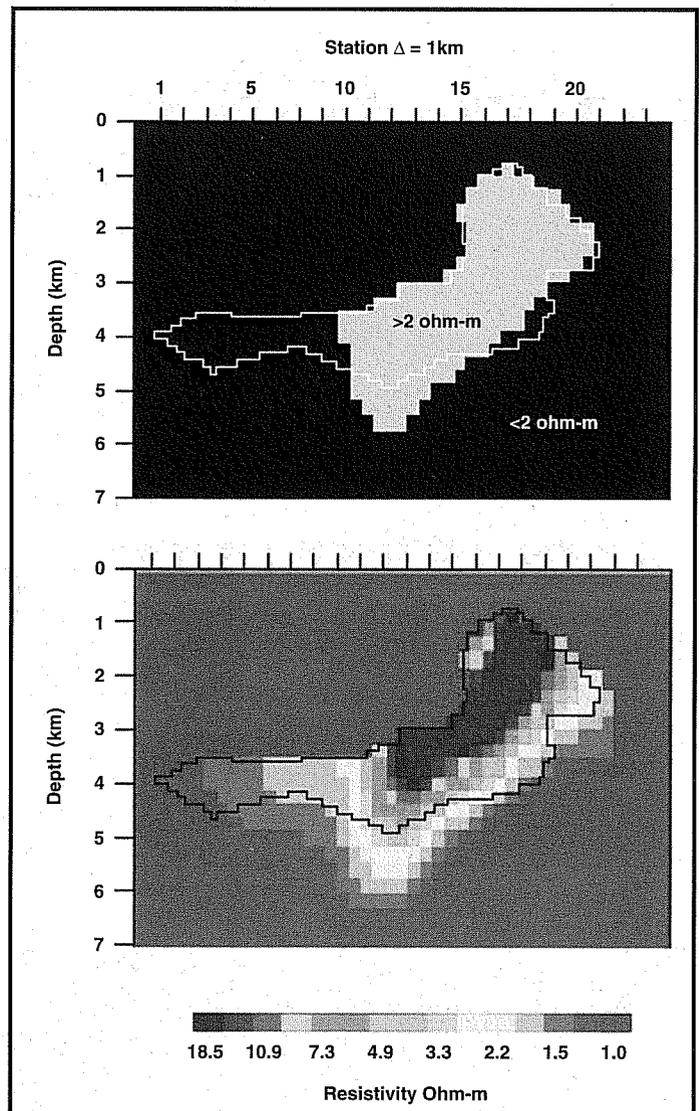
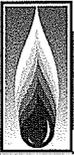


Figure 3. Smooth inversion of 2D rootless salt structure.

Further Discussion

- Constable, S., Orange, A., Hoversten, G.M., Morrison, H.F. "Marine magnetotellurics for petroleum exploration, Part I: A seafloor equipment system," *Geophysics*, "In Press."
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Continued from Page 3

deposits. Costs for marine MT is just a fraction of the cost of seismic tests. An average 30-image seismic survey will cost about \$500,000, while a marine MT survey over the same area will cost around \$50,000. The MT surveys of the Mahogany and Gemini sites were funded by project participants including Agip, Chevron, BP, BHP, and Texaco.

MT Modeling

To prepare for MT surveys in the Gulf of Mexico, project researchers ran a number of numerical simulations of 2D and 3D salt structures that demonstrated the capability of the marine MT technique as a means for mapping the base of salt structures.

During a 2D inversion of 2D anticline simulation, data were collected at 13 MT sites, spaced 1 km apart. Data were taken at 10 equally spaced frequencies ranging from 1.0 Hz down to 0.001 Hz. Figure 2 (bottom panel) shows the MT inverse model compared against the true model structure, shown in white. The comparison enabled quantitative interpretation of the inverse models for base of salt. The percent error plotted in the top panel of Figure 2 is the percent difference between the true model and the depths of the contour, shown in the middle panel, calculated at the MT sites.

The project team also ran 2D and 3D simulations to determine whether marine MT, coupled with seismic and gravity data, can provide additional independent interpretation of salt structures with deep roots. The model, taken from an actual structure in the Gulf of Mexico, includes versions of a salt structure with and without a deep root. The cross section of the structure is shown outlined in white in Figures 3 (no root) and 4 (rooted). The difference in the inverse models shown in the figures is a striking indication that the presence or absence of a deep root can be determined by marine MT.

These simulations indicated that marine MT can map base salt intrusions to within an average depth accuracy of better than 10 percent, and that marine MT data can distinguish between models which possess a deep root structure and those which do not. The most important conclusion to be drawn from these modeling efforts is the fact that MT can provide valuable data that complement data gained from seismic imaging to resolve ambiguities in mapping salt structures.

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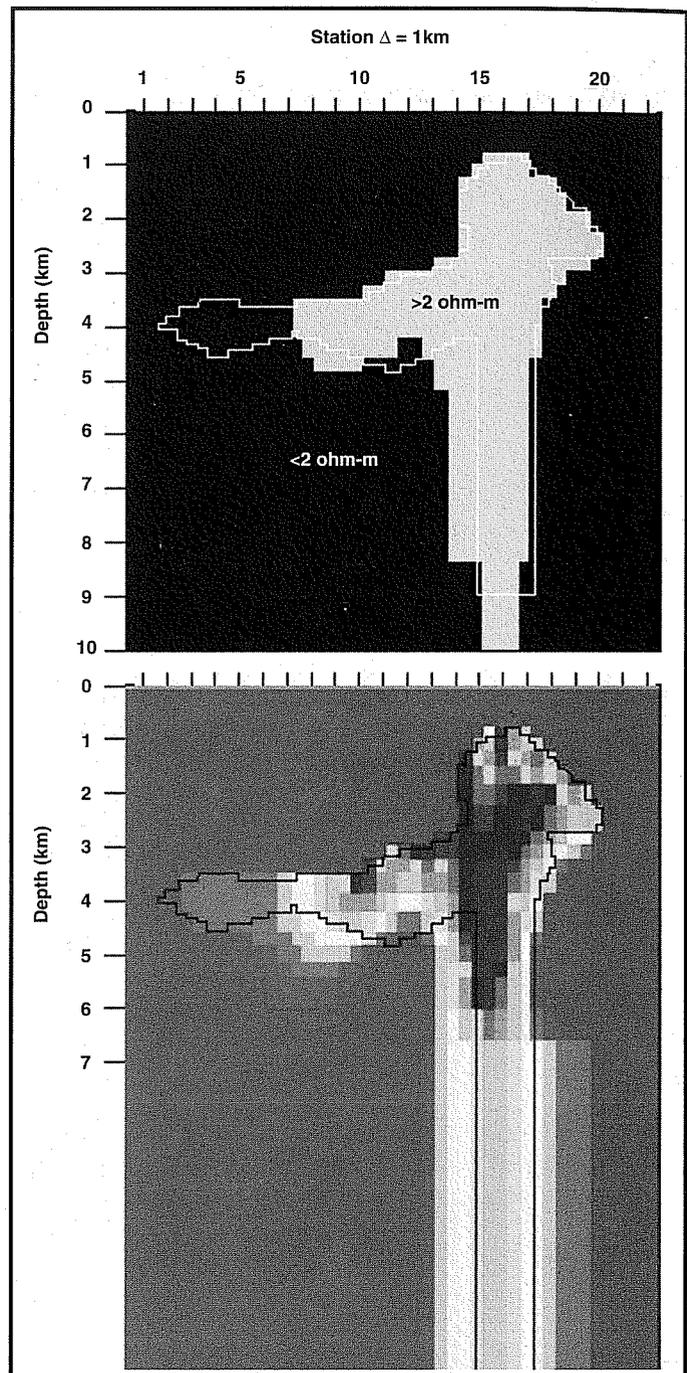


Figure 4. Smooth 2D inversion of rooted salt structure.

Acknowledgments

This research project is funded by the United States Department of Energy, Office of Energy Research, Laboratory Technology Research Division under Contract No. DE-AC03-76SF00098.



Partnership News

PTTC Resource Center Opens

Norman Goldstein (LBNL) represented the Partnership Office on December 6, at the official opening of the West Coast Petroleum Technology Transfer Council (PTTC) Resource Center, at the University of Southern California (USC), Los Angeles. Nearly 100 persons attended, including Art Hartstein (DOE/HQ) and representatives from the State Assembly and all California trade and regulatory agencies involved in oil and gas production.

Bob Whitsett (LLNL) and Norman Goldstein (LBNL) represented the Partnership Office at the PTTC Focused Technology Workshop, "California Geology with and without Computer Graphics," held January 15 at USC. Sandra Waisley (FE-30) gave the luncheon keynote address, emphasizing PTTC's importance to DOE's Oil and Gas Technologies Program. Jeff Wagoner (LLNL) and Oscar Nazario (LLNL) presented a talk entitled "California Geological and Reservoir Data Infrastructure," stressing the California aspects of their ACTI Oil and Gas Data Infrastructure Project.

Defense Programs Review

Diane Bird and members of her staff from DOE Defense Programs Technology Transfer Division were in Albuquerque on February 10-11 to review SNL's Technology Partnerships Program (TPP), formerly the Technology Transfer Initiative. Dave Northrop (SNL) presented a summary of the Partnership's Computational Technology (CT) projects at SNL which are supported by DP. As the President's FY98 budget currently includes \$5 million for "ACTI," Northrop emphasized what deliverables could be provided with continued funding and also the dual benefit nature of any further work. A similar review of LANL DP-supported CT projects was held in March.

Project Reviews

DOE's Oil Program has called its biennial Contractor's Review Meeting for June 16-20 in Houston. All FE-sponsored Partnership projects will be covered.

Also, the Industry Review Panel which evaluated the 122 ACTI proposals in Fall 1995 requested a review of the 31 projects that were initiated. This review occurred May 22 in Houston, where the industry partners gave the presentation for the majority of the projects.

Partnership Display

At the invitation of the Federal Energy Technology Center's (FETC), the Partnership had a display at DOE's Natural Gas Conference, held in Houston, March 24-27. The booth consisted of descriptions of the overall Partnership and selected projects. Dave Schmalzer, Bob Hanold, and Dave Northrop, from the Partnership Office attended the meeting.

Borehole Seismic Forum Meeting

The 11th meeting of the Borehole Seismic Forum was held February 19 in Houston. Three proposals for on-going projects were presented for industry review and evaluation. Based on the results, the microborehole seismic instrumentation and acquisition of seismic data through tubing projects were approved for continuation. Also, DOE approved a redirection of the single-well seismic imaging project (See pages 7 and 14).

Environmental Technology

DOE FE has given the go-ahead to initiate an E & P-related Environmental Technology area under the auspices of the Partnership. Dave Schmalzer (ANL), Dick Rice (INEEL), and Allen Goland (BNL) have taken the lead in forming a four-person industry review panel and developing a process for this new area. Two specific upstream environmental technology areas were selected by the review panel and DOE: produced water reduction and treatment, and stationary source emission control. Seven joint industry-national laboratory proposals were received by the April 8 deadline. The proposals were sent to a four-person industry review panel for evaluation. The result from the panel's review and evaluation has led to the approval of three new projects (to be described in the next issue).

Partnership Outreach

Dave Northrop (SNL), Bob Hanold (LANL), Dave Schmalzer (ANL), Allen Goland (BNL), and Alex Crawley (DOE) visited the Gas Research Institute (GRI) in Chicago on January 23 to present the Partnership—the first time that GRI had been so briefed. Over a dozen members of GRI's Upstream Research Program, headed by Myron Gottlieb, attended the full morning meeting where Partnership-GRI interactions were explored and discussed. Afternoon follow-up discussions focused on environmental and hydraulic fracture mapping activities.

Partnership Award

Partnership Progress, the Partnership's Web site, and the Partnership's brochure with the Computational Technology insert received awards from the New Mexico Kachina Chapter of the Society for Technical Communication (STC) during their annual awards meeting on February 8. The Web site received the Talavai Award of Merit in Online Communication. *Partnership Progress* received the Talavai Award of Merit in Technical Publications. The brochure received the Talavai Award of Achievement in Technical Publications. The awards identify five principals: four from Tech Reps, Inc., the Partnership's communication support contractor, and one from SNL.



Publications

Journal Articles

Lenhard, R.J., M. Oostrom, S.D. Robertson, and M. Delshad. 1997. "Relative-permeability-capillary pressure relations for mixed-wet NAPL-water systems," *EOS*, v. 77, no. 46.

O'Conner, R.M., J.R. Torczynski, D.S. Preece, J.T. Klonek, and J.R. Williams. 1997, "Discrete element modeling of sand production," *International Journal of Rock Mechanics and Mineral Science*, v. 34, no. 3-4, paper no. 231.

Technical Reports and Presentation

Albright, J.N., D. Dreesen, P. Harbin, D.W. Woo, H. Tan, and T.A. Fairbanks, "Retrievable 1/2" OD borehole seismic package," presented at the annual SEG meeting held in Denver, November 10-14, 1996.

Fredrich, J.T., J.G. Arguello, B.J. Thorne, W.R. Wawersik, G.L. Deitrick, E.P. de Rouffignac, L.R. Myer, and M.S. Brun., "Three-dimensional geomechanical simulation of reservoir compaction and implications for well failures in the Belridge diatomite," (SPE 36698) presented at the Western Regional SPE Meeting, Long Beach, CA, June 23-27, 1997. Previously presented at the 1996 SPE Annual Technical Conference and Exhibition.

Klosek, J.T., and J.R. Williams. *The integration of fluid dynamics with a discrete-element modeling system: algorithms, implementation, and applications*, (MIT Contractor Report to SNL). AS-2461. February, 1997.

Liu, G., and G. Medley. "Advanced compressible fluid model accounts for hydraulics behavior while drilling underbalanced," *Conference Papers, Drilling and Production Operations '97, Volume 1, Drilling Technology*, 1997, pp 10-14. Also presented at the ASME Energy Week Conference and Exhibition, Houston, TX, Jan 28-30, 1997.

Nikraves, M., C.A. Dobrre, and T.W. Patzek. "Field-wire waterflood management in low-permeability, fractured oil reservoirs: Neuro-fuzzy approach," (SPE 37523) presented at SPE International Thermal Operations and Heavy Oil Symposium, Bakersfield, CA, Feb. 10-12, 1997.

Nikraves, M., M. Soroush, R.M. Johnston, and T.W. Patzek. "Design of smart wellhead controllers for optimal fluid injection policy and producibility in petroleum reservoirs: A neuro-geometric approach," (SPE 37557) presented at SPE International Thermal Operations and Heavy Oil Symposium, Bakersfield, CA, February 10-12, 1997.

Nikraves, M., M. Soroush, R.M. Johnston, and T.W. Patzek. "Design of smart wellhead controllers for optimal fluid injection policy and producibility in petroleum reservoirs: A neural network-model predictive approach," (SPE 37445) presented at SPE Production Operations Symposium, Oklahoma City, OK, March 9-11, 1997.

Strickland, J.H., and R.S. Baty. *A Two-Dimensional Fast Solver for Arbitrary Vortex Distributions*, SAND97-0880, Sandia National Laboratories, April 1997.

Terralog Technologies USA, Inc., *Influences of pressure gradient and capillary pressure on sand production around a cavity: A discrete element model investigation*, (Contractor Report to SNL). AS-8955, February 1997.

Waggoner, J.R., "Insights from the Downhole Dynamometer Database," presented at the Southwestern Petroleum Short Course, Lubbock, TX, April 2-3, 1997.

Waggoner, J.R., and A.J. Mansure, "Development of the Downhole Dynamometer Database," (SPE 37500) presented to the SPE Production Operations Symposium, Oklahoma City, OK. March 9-12, 1997.

Wagoner, J., and O. Nazario. "California geological and reservoir data infrastructure," presented at the PTTC Focused Technology Workshop: California Geology with and without Computer Graphics, University of Southern California, January 15, 1997.

Womble, D., "3D seismic imaging on massively parallel computers," *Proceedings of the International Symposium on Parallel Computing in Engineering and Science*, Tokyo, Japan, January 27-28, 1997.

Zwahlen, E.D., and T.W. Patzek. "Linear transient flow solution for primary oil recovery with infill and conversion to water injection," (SPE 38920) presented at the 1997 SPE Western Regional Meeting, Long Beach, CA, June 25-27, 1997.



Project News

Borehole Seismic Technology



3-Component Vibratory Source

Tests of the overall seismic source system were conducted during February and March at Chevron's La Habra test site. During the tests, hardware performed very well and yielded excellent data. Testing allowed the development of operational procedures and minor modification of hardware and software. Additional tests of the source were conducted using a 50-level digital hydrophone array from Allied Signal, and a 6-level, all fiber-optic hydrophone array from Litton.

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Microborehole Seismic Instrumentation

The cause of leaks in the multi-level array tool was identified. New parts conforming to specifications were procured and tested, with improvements in the mechanical assembly of the tool enabling deployment to 2000'.

In other work, acceptance testing of the 2-level, 0.5" hydrophone was completed, the 4-level geophone array was successfully tested, and the microtool

platform was successfully tested to 100°C and 2000' hydrostatic pressure.

The Borehole Seismic Forum approved a proposal for field tests and tool hardening during the upcoming year. The proposal includes a field test to be conducted in collaboration with Texaco at their Humble field site.

"Retrievable 1/2" OD borehole seismic package," a progress report on microborehole tool development and testing was presented at the annual SEG meeting held in Denver, Nov. 10-14, 1996 (see "Publications" p. 6).

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Single Well Seismic Imaging Technology

Initial testing of the SNL/OYO receiver clamp with various compliant members between the clamp shoe and a test block showed very little degradation in signal bandwidth. Based on this testing, the prototype swing-arm clamp was designed, fabricated, and tested in the laboratory.

The universal analog-to-digital converter and fiber optic telemetry mod-

ule, fabricated by Amoco and OYO, was used in several field tests during February and March. The tests yielded excellent data and no down time.

Work continues on converting the Conoco AC orbital source to operate on the Gas Research Institute fiber optic wireline.

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Acquisition of Borehole Seismic Data Behind Production Tubing

Field deployment and data acquisition for a detailed cross-well test are being planned. Chevron will provide the field site and logistic support and TomoSeis will provide borehole source and sensors.

Tests will be performed with and without production tubing in the boreholes—two receiver and one source well.

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Applied Production Technology (APT)

Field Measurement of Oil Properties

Testing of graphical user interface (GUI) software for controlling the Cloud Point Detector began. A suite of cloud point determinations to investi-

gate the effects of cooling rate and stirring rate were conducted. Licensing discussions with Petrolite continue.

Sucker Rod Failures

Data from the final downhole dynamometer field test were delivered, processed, and incorporated into the Downhole Dynamometer Database,

which will be made available to industry.

A draft report of the sucker rod coupling analysis work was completed. "Development of the Downhole Dynamometer Database" was presented to the SPE Production Operations Sym-

(Continued on Page 8)



Project News (Continued from Page 7)

posium March 9–12, Oklahoma City, OK, and “Insights from the Downhole Dynamometer Database,” was presented at the Southwestern Petroleum Short Course, April 2-3, Lubbock, TX (see “Publications” p. 6).

Artificial Lift Using Foam Pigs

The task objective for this new APT project is to adapt pipeline pigging technology to artificial lift without requiring a “U-tube pipeline.” Initial laboratory tests identifying the optimum foam pig material properties and demonstrating several pig delivery concepts were completed. A demonstration was performed at the DOE Bartlesville office. Industrial partners are being sought to begin field tests.

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Optimizing Reservoir Production

Testing revealed subtle differences between the principal simulation tool and those used for comparison and validation. Differences were resolved by re-coding parts of our simulator.

The merged Chevron/BP code combines the BP technology for upscaling relative permeabilities with Chevron’s nonuniform, grid coarsening algorithm. At this point, the project team’s method uses 2D problems as a testbed, although the method may be most useful in 3D.

Findings indicate that in the isotropic case, in which the vertical and horizontal correlation lengths are equal, the merged code can have significant advantages over either method used separately. The anisotropic case in which the correlation length in the horizontal direction is much longer than that in the vertical direction has been studied.

Measurements began of the interfacial area and changes in interfacial area over time for simple systems using the Lattice-Boltzmann simulator. Of pri-

mary concern are capillary pressure-saturation-interfacial area relationships and the influence of including interfacial area on the extent of hysteresis. Runs comparing Lattice-Boltzmann-predicted values of interfacial area for oil displacement by water in sinusoidal tubes against analytic solutions have shown reasonable agreement.

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Ultrasonic Reduction of Formation Damage

The private investors who financed the North Central Texas field tests have formed Acoustical Well Service, Inc., with corporate goals to promote further field testing of the ultrasonic cleaning tool to determine the effectiveness and marketability of this technology. A field test proposal with the Rocky Mountain Oilfield Testing Center is being prepared.

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Fracture Mapping and Slimhole Geophone Array

Union Pacific Resources Company (UPRC) rescheduled the Cotton Valley Fracture Imaging Experiment for late-April to mid-May. To protect the array, the test well will be completed with a casing liner before deploying the permanent geophone array. Many receivers were lost in UPRC’s deployment of the first array set in the open-well interval. Newly configured locking arms for deployment in 2-7/8" tubing for the experiment were successfully tested for locking force and reliable, predicted, shear-pin release. Use of LANL’s two-level through-tubing geophone tool will allow filling in the gap in the array during both the cross-well and fracture monitoring phases of the experiments.

Tests on the newly configured Schlumberger 1-11/16", 7-conductor cable heads were completed, but repeatable, 100% reliability was not demonstrated. During recent downhole testing, the fully configured, 2-level tool and the rebuilt cable heads were used to determine what conductor-to-conductor impedances are tolerable for tool operation.

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Wireless Telemetry Tool

The prototype tool was completed and successfully bench tested. This tool is being attached to the 1400' production string at SNL’s Orpheus Facility with surface testing beginning in April. It will then be returned to Houston for testing in a well. Representatives from Baker Oil Tools and SNL met to discuss the licensing agreement.

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Reduction of Well Failures in Diatomite

Initial 2D geomechanical simulations were performed on an updated cross-sectional model of South Belridge CA, supplied by Shell E&P. The cross section is consistent both in geologic representation and reservoir pressure history with the 3D geomechanical model run by SNL. Data will be compared with results from running the 3D geomechanical model.

SNL completed the fourth 3D geomechanical simulation of South Belridge, Section 33. Preliminary analysis indicates that the new geomechanical simulation provides an overall better match to the observed subsidence rates derived from CalResources’ monument data.

Plans were made for concluding 2D and 3D modeling efforts at South Belridge and on carrying out the focus of

(Continued on Page 9)



Project News (Continued from Page 8)

work at Lost Hills.

"Three-dimensional geomechanical simulation of reservoir compaction and implications for well failures in the Belridge diatomite," was accepted for presentation at the 1997 Western Regional SPE Meeting held in Long Beach, CA, in June (see "Publications" p. 6).

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Extending Borehole EM Imaging

A numerical sensitivity study using the CAS4i code is being undertaken to determine how well formation resistivity can be determined from within cased holes. The Born approximation is used to compute the magnetic field inside casing due to an axially symmetric conductive layer. This exercise will provide important guidelines in terms of the limitation of EM measurements in cased boreholes and use them for extracting formation resistivity.

LBNL and Chevron have decided to conduct a crosswell EM survey between a fiberglassed hole and an open hole. The open hole would then be cased in steel, and the survey repeated.

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Fluid Injection into Tight Rocks

LBNL is combining its 3D visualization of the Shell Phase III pilot, showing the wells and fractures with a mapping of the various surface layers. The view can be rotated to give a visualization from any direction. Temperature data are being animated for this pilot to show the evolution of the temperature for the various layers as a function of time.

The team has continued work on the analytical solution for linear transient flow for primary oil recovery with infill and conversion to water flood. Paper SPE 38920, entitled "Linear transient flow solution for primary oil recovery with infill and conversion to water injection," will be presented at the SPE Western Regional Meeting, June 26-28, Long Beach, CA (see "Publications" p. 6).

The simple 1D model can match the pressure behavior for 30 years of a single well in the South Belridge diatomite of the Shell Phase III Pilot predicted by a THERM simulation. It can also match the entire field production for 15 years and injection for six years of the Crutcher-Tufts waterflood in the Middle Belridge diatomite.

The team has continued the visualization of the Shell Phase III pilot using various methods for plotting layer surfaces and presented these results at the June SPE meeting (SPE 38264) (see "Publications" p. 6).

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Mapping Steam and Water Flow in Diatomite

The waterflood data from Bakersfield Energy Resources were processed and are in the inversion and interpretation stage. The depth and low temperatures at this particular site have resulted in remarkably noise-free, repeatable datasets. Crosswell EM data in a steamflood in Chevron's Kern River Pilot have apparently detected the steam in an early stage of formation penetration. EM and seismic experiments also occurred in diatomite in April at CalResources' Belridge site and at Chevron's Lost Hills site.

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Tiltmeter Hydraulic Fracture Imaging

A 7,350'-deep frac was successfully monitored in December 1996, while Pinnacle Technologies successfully monitored a 7,200'-deep frac in January. In January, the technology moved into full commercial use.

Project personnel modified the communication circuit from the tiltmeter to the surface PC so that it can drive long lines. The circuit was tested with our 8,330'-long wireline cable, and there were no transmission problems. A vertical string of tiltmeters will be installed in a well at about 3,000' to monitor the initial motions of a fracture in another well 700' away.

A radio modem was tested for communication between a tiltmeter site and a central PC with the link working perfectly, enabling real-time data collection.

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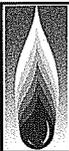
Improved Prediction of Multiphase Flow

Three-phase saturation-capillary pressure measurements were obtained on mixed-wet porous media. PNNL compared the measurements with theoretical predictions using the newly developed theory for multiphase flow in mixed-wet reservoirs. The comparison between theory and experimental data was quite good. In addition, a complete unique dataset was obtained for a water-wet sandpack.

Mobil Oil and Landmark Graphics joined this project bringing the total number of industrial partners to four.

"Relative-permeability-capillary pressure relations for mixed-wet NAPL-water systems," was published in the American Geophysical Union journal, *EOS* (see "Publications" p. 6)

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Project News



Drilling and Completion Technology

Advancing MWD into Ultra-Deepwater Drilling in the Gulf of Mexico

Modeling of seismic while drilling (SWD) and measurement while drilling (MWD) data started. Two goals of this modeling are characterizing the seismic information of a time series and compressing the file length of these data. Model-based signal processing techniques and time-frequency representations are under evaluation.

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CEA/DEA Projects

Rheology and Proppant Transport (CEA # 1)

Stim-Lab continues to study particle-fluid flow, providing valuable information for modeling proppant transport issues as well as modeling generic particle-fluid systems of interest. Current studies include proppant transport in thin fluids, which will provide information about systems when inertial forces become important. SNL will attempt to incorporate this and other information into its detailed models of particle migration caused by shear flow.

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Reduction of Bit Balling Using Electro-Osmosis (DEA # 70, Phase 2)

During borehole closure tests, the salt water slurry that yielded the best shear-strength results as a borehole fluid was found to be an attapulgitic clay suspension in 10% salt water.

Numerous experiments were per-

formed as part of the process to determine the optimal time and current levels for *in situ* casing consolidation by electrokinetics. The optimum level of charge for maximum increase in bearing capacity is at about 100,000 coulomb/sq.m.

In almost all cases, the bearing capacity of an electrically consolidated rod was enhanced over that of a rod receiving no current. The best result was achieved using a low current level for a longer period of time, increasing the bearing capacity by 250% over the non-treated control rod. All of the tests that supplied a level of charge around the optimum level yielded similarly good results.

This suite of experiments was repeated on bentonite clay samples of higher and lower water contents. The optimal charge/area increased for the higher water content clay and decreased for the lower water content clay.

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Air/Mist/Foam and Underbalanced Drilling (DEA #101)

Amoco drilled two shallow wells near Bakersfield, CA, using hollow glass spheres ("glass bubbles") to attain underbalanced conditions with mud. Results are encouraging.

Investigators are looking into novel fluids for underbalanced operations. A new lightweight fluid additive that encapsulates air bubbles (i.e., a non-breaking foamer) and reportedly can be used to lighten mud to weights as low as 6.5 ppg is being evaluated.

Maurer Engineering Inc. (MEI) engineers made several presentations

at the ASME Energy Week Conference and Exhibition in Houston on January 28-30. G. Liu and G. Medley presented "Advanced compressible fluid model accounts for hydraulics behavior while drilling underbalanced" (see "Publications" p. 6).

The first edition of the DEA-101 Underbalanced Drilling and Completion Manual was distributed to project participants. It will be translated into Spanish and along with the three DEA-101 software programs. The three user's manuals will be transferred to a single CD for ease of distribution within companies by DEA-101 participants.

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Coiled Tubing Fatigue Mechanisms (DEA # 104)

The final project review meeting was held in Houston, April 2. Project results include:

- coiled tubing test facility designed and built,
- tubing of various materials, diameters, and wall thicknesses tested,
- algorithm developed to apply the multiaxial cyclic plasticity model for engineering metals,
- rigorous analytical model developed to predict changes in tubing during fatigue testing, and
- windows® algorithm developed to enable sponsors to apply model to any case of interest.

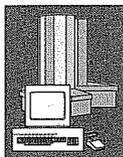
A second project, expected to start in June, will concentrate on the effects of surface flaws on coiled tubing life expectancy.

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Project News



Computational Technology

Models for Deep Water Oil and Gas Production

Task 1: Fluid/Structure Predictive Code Development

Work concluded on the wall-layer diffusion and geometry tasks, and also on the two-dimensional fast-solver algorithm required to efficiently compute the wake regions of the flow field. The work is documented in "A Two-Dimensional Fast Solver for Arbitrary Vortex Distributions" (see "Publications" p. 6). Work started on the wall-layer/free-vortex interface.

The benchmark comparisons with the exact analytical solution for an oscillating plate (Stokes' second problem) were completed and documentation is being prepared.

Task 2: Strength of Composite-to-Metal Joints

Details of a series of finite-element analyses were documented in a report distributed within the project. This marks the completion of this task.

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Perforation Dynamics in Geological Media

The Phase 1 effort was successfully completed, and a report (UCRL-ID-125571) was distributed to industry partners. Also distributed were copies of the PC-based well rework evaluation code (WELLREC) and a user's manual (UCRL-MA-125588).

Two samples taken from a Berea sandstone core that had been perforated by a shaped charge were imaged at 9 mm resolution by x-ray microtomography. The x-ray data were converted into a 3-D "voxelated" image of

the structure, where each voxel (or cubic volume element) is either rock or pore space. The lattice-Boltzmann method was then used to calculate the permeability of the sample.

Also in development is a technique for skeletonizing the pore structure by numerically thinning the pore walls without breaking any connectivity to calculate the permeability of larger samples.

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Well Log Imaging

MJ Systems is beta-testing indexing software from the University of California-Santa Barbara (UCSB) that allows rapid indexing of both microfiche strip and geophysical log header parameters. The UCSB has received a second batch of microfiche masters (~350 fiche) for the State of California which are being scanned and indexed, to be followed by microfiched geophysical logs for the State of Texas.

The initial CD product will be available in late May. An interface has been developed that allows images to be accessed and viewed remotely over the Internet. The project will end during the fourth quarter of 1997.

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Geologic Structure and Reservoir Mechanics

The release of the JAS3D code was installed at each partner's site with a significant amount of time being spent in support of its installation.

A new dynamic relaxation scheme was implemented in JAS3D which provides for fewer iterations to achieve

equilibrium based on a suite of test problems run to date. The scheme incorporates the best parts of two different theories for obtaining the optimum damping parameters. The mapped infinite element has been successfully tested using the dynamic relaxation solution scheme in JAS3D.

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Reducing Certain Seismic Data Acquisition Costs

The 2D simulation program, CALE, was used to model the operation of the platter charge using as-built dimensions and examining the details of the initial seismic wave generation into the earth. Modifications were made to the code to allow better modeling of the seismic wave forms produced by the three-charge arrays that were fired in the field tests. Also, the developers have installed a model for concrete in the code that has the proper form to allow porous geological media to be simulated, as was previously done in the 2D CALE calculations of single charges.

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Near Wellbore Mechanics

Documentation was completed on 2D discrete element modeling of sand production (see "Publications" p. 6).

Two project progress review meetings were held in Houston, on April 10 and 11. Dale Preece (SNL) and John R. Williams (MIT) gave a review of progress made during the first year. The basic discrete element capability was presented followed by some examples of the coupled fluid flow and

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Project News (Continued from Page 11)

particle motion. The final topic dealt with the large problems to be simulated next year, resulting in a group consensus to proceed with the sand production and the proppant flow simulations.

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Advanced Reservoir Management (ARM)

Pacific Operators Offshore, Inc. designed concept extended-reach wells for redeveloping the Carpinteria Offshore Field on the basis of the 3D geological model of the Carpinteria. The recent migration was a success.

Midland Resources, Inc. interpreted a 3D seismic survey shot over the Spraberry Cope Unit near Midland, TX. The new seismic depth maps were formed into a geological model.

Flying J Oil and Gas interpreted a 3D seismic survey of the Brorson Field in the Williston Basin, MT. The first generation geological model is bounded by depth maps from the survey. The project Web site is <http://ees.lanl.gov/EES5/arm/index.html>.

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Modeling and Processing Seismic Data

Testing began using the screen methods as modeling tools. Results obtained were compared with those obtained using fourth-order-in-space finite-difference calculations and good agreement was found.

A version of the 2D phase screen migration code was tested using the Marmousi dataset and an exploding reflector dataset developed for a 2D cross section of the SEG/EAGE subsalt model. Another migration method using windowed Fourier Transforms was tested using a 2D slice through the SEG/EAGE subsalt model. Modeling using the multiple forward single

backscattering approximation was done for a 2D slice of the SEG/EAGE model. Results compare favorably with those using finite difference.

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Velocity Analysis, Parameter Estimation, and Constraints on Lithology

Stanford and LLNL investigators found correlations between anisotropy parameters and methods for estimating rock properties from elastic moduli for certain models.

LLNL research activities included presenting a talk on effective medium theories at Amoco in Houston and on rock physics and anisotropy at the Colorado School of Mines (CSM), participating in the Gas Research Institute's permeability logging forum in Houston, and investigating correlations between anisotropy parameters for certain layered models.

A CSM researcher visited LLNL to present a talk on reflection coefficients and azimuthal amplitude-versus-offset (AVO) analysis in anisotropic media.

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Subsalt Imaging with Marine Magnetotellurics

Efforts are concentrated on interpreting the marine MT survey data. The report may be viewed on the Web at <http://horton.lbl.gov/users/mhovers/Survey.html>. Preparations for the June re-survey of the Gemini prospect are under way.

The 2D sharp boundary gravity inversion code has been tested for the first time and will be part of our joint seismic, MT, and gravity inversion work. Debugging and modifications are proceeding. Initial work has begun on the joint MT and gravity inversion.

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Subsidence, Analysis, and Control

Modeling of a subset of the steam flood in Fault Block II has continued. The numerical model, based upon data from the field operators and predictions from the TOUGH2 multiphase simulator, is in qualitative agreement with observed reservoir behavior.

A preliminary inversion of twenty years (1976–1996) of surface displacement data for reservoir volume changes was completed. A total of 12 time intervals, each 2–3 years in duration, were considered. With smooth spatial variations of reservoir volume change within the tar zone, we are able to match the observed surface displacements quite well.

The subsidence software module was delivered and demonstrated to industry partners. Funding for the project has ended. We are now preparing to complete the effort and hand the results over to the industry partners.

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Optimal Fluid Injection Policy and Producibility

In January, this project was presented to a DOE Office of Program Assessment Review Panel in Reston, VA. The panel was comprised of industry and academic earth sciences experts.

Three papers were presented at the SPE International Thermal Operations and Heavy Oil Symposium held Feb. 10–12 in Bakersfield, CA (see "Publications" p. 6, Nikraves).

In April, Tad Patzek (LBNL) gave a presentation to Mobil and CalResources in Bakersfield. The transient oil production on primary, efficiency of waterflood, evaluation of the Phase III steam drive pilot, the smart controller model, and its stability were discussed.

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Project News (Continued from Page 12)

Patzek and Pierre Emanuel Morilhat, a visitor from France, have analyzed the pressure and rate signals (30-second averages of 10 ms measurements) for the steam injectors to verify the model. The injector data were animated, resulting in a very efficient tool to view 2,000,000 data points for each well.

Dr. Ashok De (LBL) will continue developing the adaptive controller model.

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Innovative Gridding and Solution Techniques

The parallel linear equation solver for unstructured grids is being tested for multiple unknowns per node point. Initial results indicate that for highly heterogeneous problems, simple preconditioning schemes used for parallel applications are ineffective.

Researchers from Chevron and LANL met to discuss current unstructured grid generation algorithms and linear equation solvers for unstructured grids. LANL will make its software available, and Chevron will investigate reordering algorithms for unstructured linear solvers.

The anisotropic permeability algorithm was coded for 3D applications assuming the principal directions of permeability are orthogonal to the bedding plane. Using tetrahedral elements, the positivity constraints imposed on the transmissibilities were met.

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Synchrotron Computed Microtomography

A method to produce microtomographs from subvolumes has been developed that enables high-resolution analysis with shorter compute time and less memory. The instrumentation at the experiment was upgraded to

improve alignment and further automate taking of data.

A powerful processor for graphics computing was acquired, and codes are being migrated to this new machine. Better algorithms and instruments for producing microtomograms and 3D images will continue to be investigated. The goal is to speed up the graphical presentation to provide an element of "real time" analysis to the porosity and fluid flow investigations.

A Microtomography Workshop was held at BNL on May 19, which prominently featured results from this project.

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Advanced Computational Analysis of Drill Cutting

Non-wetting phase invasion, wetting phase imbibition, and intermediate loops as scanning curves were simulated during sensitivity studies of a graph-theory based algorithm for calculation of capillary pressure curves. Work also focused on exercising the graph-theory-based code for calculating relative permeability curves and on deriving input parameters for the code from images of reservoir rock pore space.

To derive input parameters for the code from images of reservoir rock pore space, SEM images are being used of Nugget sandstone into which Wood's metal was injected. Image processing is being carried out to derive effective hydraulic radii of the two dimensional pores in the images.

Comparison calculations generated by graph-theory-based approaches with calculations based on percolation theory began. Percolation-based calculations will be performed at the University of Southern California using some of the same networks being solved by graph theory methods.

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Gulf of Mexico Subsalt Seismic Imaging

The computational portion of the code is completed and validated, and the message passing portion of the code has been written and debugged. The project team has used real data to check the overall code, gridded a field velocity model provided to us by industry, and confirmed the reliability of our gridding. Results showed that the application of aperture in the migration calculation required modification. Several tests were conducted for different apertures. Modifications were made to the migration code to make the message passing more efficient, which has increased the overall computational speed of the imaging code.

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Vertical Seismic Profiling

This project successfully processed field data which had been provided by the industry partner, Utah Geophysical, Inc. This multichannel dataset had been recorded from geophones placed on the surface while the well was being drilled. Drill bit noise from 17 levels (between 1500 m and 2000 m depth) were processed with the prototype algorithms in conjunction with testing of these algorithms. These algorithms are being tested on synthetic data produced by finite-difference modeling of wave propagation from a random noise source to the sensors on the surface.

The project is evaluating a suite of adaptive noise cancellation algorithms to aid in reducing the large noise sources such as the mud pumps, generators, and other rig noises. The autocorrelation method is being used to develop the pilot signals that are needed in an adaptive noise canceler.

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Project News (Continued from Page 13)

Increased Effectiveness of Hydraulic Fracturing

This project was restarted in April, and approved work will focus on two tasks: (1) full interfacing of the AVS/Express output visualization capability and (2) development of an improved proppant flow model based on extensive SNL slurry flow analysis. The graphic user interface and visualization tasks began with a working/training meeting at SNL for TerraTek personnel, and a contract with TerraTek has been initiated. The proppant flow task has begun and will be coordinated with Rod Clifton, of Brown University.

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Multiphase Fluid Simulator for Underbalanced Drilling

A Maurer Engineering report summarizing their contributions to the project was reviewed and factored into project planning. This report focused on the rig measurements typically made on domestic (and Canadian) air and foam drilling operations. A revised project plan was reviewed, critiqued, and revised.

Representatives from major producers, service companies, and equipment manufacturers participated in a LANL-organized meeting on small-diameter drilling priorities that was held January 30 in Houston. Coiled tubing drilling with small diameter bottom hole assemblies was made a high priority item, and high vibration of bottom hole assembly (BHA) components used in air drilling was recognized as a major challenge impeding the successful application of directional drilling technology to air drilling and underbalanced drilling using foam or aerated mud.

A fluid forces model was adapted for incorporation in a tubing forces model. An analytical, but fairly com-

prehensive, tubing force model is needed to characterize the mechanical input for a drilling system simulation.

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3D Imaging of Complex Geologies

A project meeting on Feb. 6 in Dallas included technical presentations from SNL and UT-Dallas. The DOE's Naval Petroleum Reserve has requested that we process a dataset from a survey at Elk Hills, CA.

SNL has made substantial improvements to the interprocessor communication and I/O structure of Salvo, improving the portability and robustness of the code, but delaying the release until May.

David Womble gave a presentation at the International Symposium on Parallel Computing in Science and Engineering in Tokyo, Japan, on January 27 and 28 (see "Publications, p. 6).

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Single-Well Seismic Imaging of Salt Dome Flanks

This project is included in a coordinated national laboratory approach to single-well seismic imaging, which was presented to the Salt Imaging Consortium at a meeting in New Orleans on Jan. 16. The resulting proposal, prepared by SNL, LBNL, and INEEL, was presented for industry review at the 11th Borehole Seismic Forum meeting held Feb. 19 in Houston and has the support of 14 companies and three universities.

Borehole seismic data acquisition operations recommenced at the Bayou Choctaw, LA, field test site in late May. Paulsson Geophysical Services, Inc. will operate their axial hydraulic vibrator in a Hunt Petroleum Co. well

near the salt dome flank, recording reflected energy in a nearby well.

Chevron has initiated efforts to process and image the air-gun source data acquired at Bayou Choctaw during August, 1996. Trace editing has consumed most effort to date. The University of Utah continues development of an algorithm for modeling seismic wave propagation in a 3-D viscoelastic medium.

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Computer Simulation in Support of Nuclear-Well Logging Devices

Researchers will begin running QUAD code test problems within a few months. The new multidimensional tetrahedral radiation transport code, Attila, was released to the industry partner for testing and verification. The Monte Carlo code, MCNP, with accompanying databases was released. The neutron lifetime and die-away definitions were made consistent in the Monte Carlo and deterministic radiation transport codes. Some test problems were run on the LLNL code, TART, a mature, fully benchmarked Monte Carlo code.

New nuclear data evaluations for chlorine and nickel were made available to all of the industrial partners. New evaluations for chromium and iron are currently under way and should be released by end of the fiscal year.

LANL will be developing time-dependent variance reduction techniques to help explain the late behavior of pulsed tools and also to reduce the statistical noise associated with late times. Computalog has provided tool models and experimental data to help validate the new methods.

The test problems that were run on the ARDRA code are encouraging, but

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Project News (Continued from Page 14)

show the need for refinements already planned for the code. LLNL is in the process of adding routines for giving a better definition of material interface, redoing the first-scatter calculation, and improving the input options of the code.

The status and definition of this CRADA can be seen by visiting the Web site: <http://www-xdiv.lanl.gov/XTM/projects/acti/>.

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3D Seismic Analysis using SEG/EAGE Dataset

At LANL, a new seismic dataset was collected from the physical model that simulates the collection of marine reflection data using a vertical receiver cable. Funding was received to continue the project, however, a previous lack of funding prevented LLNL from continuing project work.

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Development of a New Generation Petroleum Reservoir Simulator

A prototype two-phase, multiblock simulator is being tested. This code solves the two-phase flow equations implicitly using domain decomposition.

The code is being tested on a typical injection/production well pattern. New nonlinear iterative strategies for multiphase, multiblock systems are being investigated. The code is being incorporated into the IPARS framework.

The fully implicit EOS compositional model described in last year's annual report has been implemented

into the IPARS framework. The PETSc package has been incorporated into the model to solve the linear systems. A 1D test case with dry gas injection was performed successfully using the six-component PR EOS for the phase behavior calculation. A 2D and 3D extension of the model is being tested.

The project Web site is <http://www.pe.utexas.edu/CPGE/ACTI/>.
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Oil and Gas Data Infrastructure (OGDIP)

Work continues on the new Internet prototype, available on the web at <http://wildcat.llnl.gov>. Mechanisms under development will allow users to customize reports to include only the desired information, reducing the amount of data transmitted over the Internet.

The project team met with the Texas Railroad Commission and planned the tasks needed to put Texas production data on line. LLNL is developing the needed software while the Railroad Commission prepares the database. The OGDIP will integrate the interface into the new and evolving Internet environment at the Railroad Commission to provide seamless access with other Texas functions. Modifications have begun on the California interface to accommodate Texas data.

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Coupled Rock/Fluid Mechanics

Mobil Technology Company provided 3D databases of grain pore structure for various producing sandstones. These data will form the basis for a computational configuration for the SPHINX code to model grain damage.

Software is being developed to use this database to obtain spatial information of grain edges and other statistical properties of the grain-pore space. Boundary condition problems are being addressed in the smooth particle hydrodynamic SPHINX code. Axisymmetric simulations of a penetrating jet interacting with grains with pore space treated as void and fluid-filled are being performed. Previous shock experiments at LLNL on representative rocks showed that the shock pressures of most interest in rock around drill holes are in the range 10–50 kbar.

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Web Changes

The Partnership's web was moved to a new server. If you are accessing the web using a bookmark, make sure the URL listed in the location field is:

<http://132.175.127.176/ngotp/ngotp.htm>.

If you have a different URL is listed in the location field, enter the Partnership URL (<http://www.sandia.gov/ngotp/>) in the location field and press enter. Be sure to replace your old bookmark with a bookmark to this new page.

Industry Participants

The Partnership's World Wide Web site includes a complete list of industry participants. See:

<http://www.sandia.gov/ngotp/>



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