Partnership Progress

Natural Gas & Oil Technology Partnership

February 1997 No. 5

U.S. Department of Energy ■ National Laboratories ■ U.S. Petroleum Industry

Changes

Good news! After the interruption in funding experienced by some projects last year, FY97 funds have been issued to keep those projects on track.

The Partnership program is in its ninth year, and we can be proud of its progress. However, things change—and changes will be seen in the coming year. Two or three projects addressing upstream environmental issues will be initiated soon, marking the start of a new technology focus area. Also, the Partnership projects and technology areas will be shifted and better aligned with DOE's oil and gas program structure. These and other changes will be described in future issues, as we look toward next year and beyond.

Please join us!

Dave Northrop and Bob Hanold

Inside

The Partnership on the World Wide Web:
http://www.sandia.gov/ngotp/

Featured Partnership Project

Salvo, the Next Step in 3D Imaging of Complex Geologies

Key to reducing the risk and cost associated with oil and gas exploration is the ability to image complex geologies, such as salt domes in the Gulf of Mexico and thrusts in mountainous regions. Imaging these structures, however, is computationally intensive. Datasets can be terabytes in size, and the processing time required for the multiple iterations needed to produce a model can take months, even with the massively parallel computers available today.

Seismic imaging technology based on high-performance computing can revitalize domestic oil and gas production and reduce U.S. dependence on foreign oil. Seismic imaging methods, such as 3D, prestack, depth migration, have been developed for subsurface exploration of complex geologies. However, the computational demands for these methods have prevented their use in a production environment.

Currently, the primary algorithm used by the oil industry for 3D imaging is the Kirchhoff algorithm. Researchers have discovered that this algorithm does not image complex structures to the degree of accuracy that they require; multiple arrivals present a particular difficulty. To rectify that and many other situations, the 3D Imaging of Complex Geologies project was organized to develop an algorithm that can image complex geologies more accurately than the Kirchhoff algorithm. Salvo, the result of their work, was released to project members in October, and preliminary results are promising. The Web site for this project is **http://www.cs.sandia.gov/~dewombl/ACTI16.html**.

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Objectives

- **Finite-difference algorithms for 3D, prestack, depth migration**
- **Efficient computational approaches for seismic imaging and processing terabyte datasets on MPPs**
- **A modular, portable seismic imaging code**

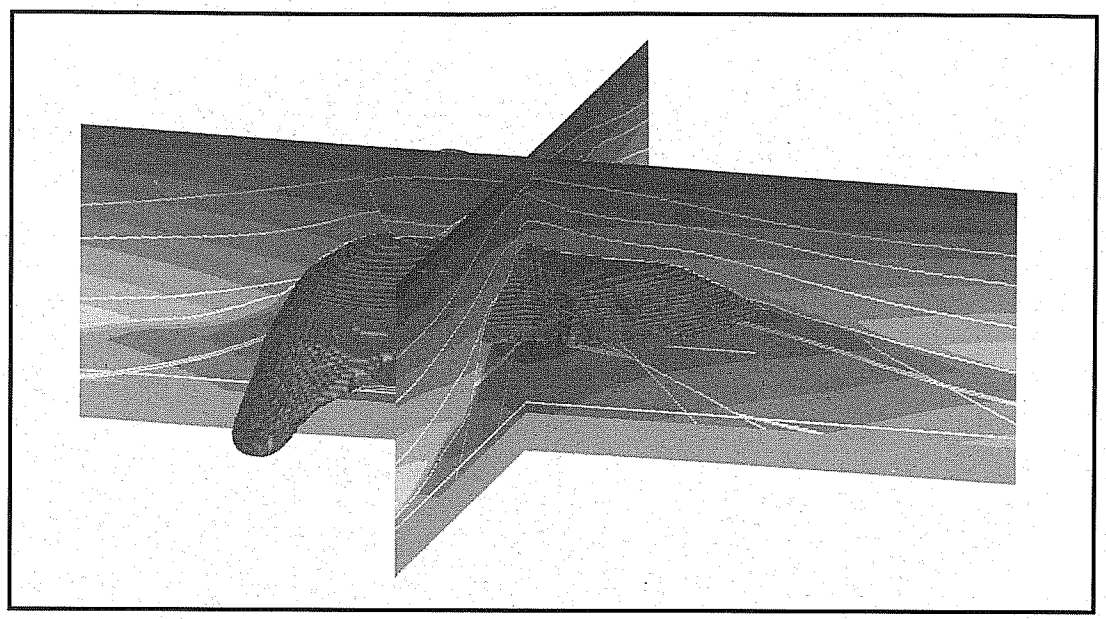

Figure 1: The SEG/EAGE salt model. The greyscale indicates the speed of sound at each point.

Salvo and the 3D Imaging Project Organization

Sandia National Laboratories (SNL) researchers developed Salvo and continue to improve the algorithm. Along with its ability to generate 3D images quickly, it can be modified to run on several different platforms and can be ported to other locations.

The project is an integrated effort that is funded by the Department of Energy (DOE) and includes SNL, Arco Oil and Gas, Conoco Inc., Cray Research Inc., Golden Geophysical Corp., IBM, Intel SSD, Oryx Energy Company, PGS Tensor, Providence Technologies Inc., TGS Calibre Geophysical, and the University of Texas-Dallas. David Womble proposed the project in November 1994; project goals were to develop finite-difference algorithms for 3D, prestack, depth migration; efficient computational approaches for seismic imaging and for processing terabyte datasets on massively parallel computers; and a modular, portable seismic imaging code.

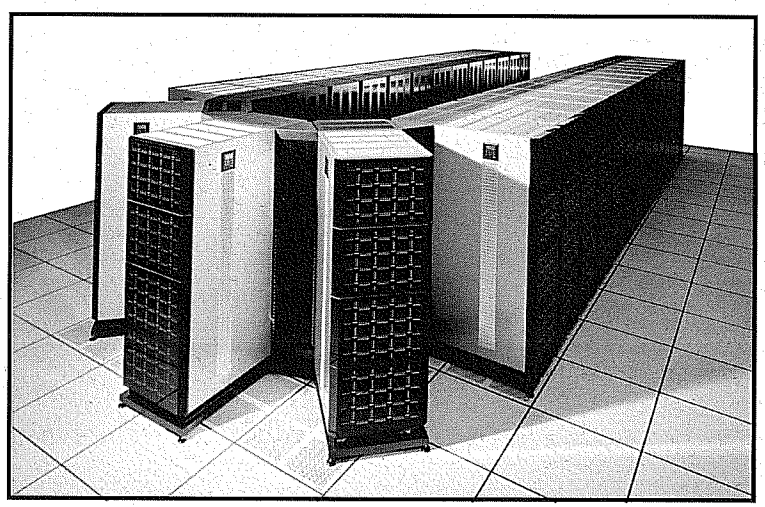

Figure 2: Sandia National Laboratories' Intel Paragon computer.

Massively Parallel Computers (MPP)

The MPP computers utilized in this project are the Intel Paragon, Cray T3D, and IBM SP2. These machines contain many processors (nodes) that can compute on separate portions of a larger problem and communicate the data to generate an overall solution.

Salvo runs efficiently on these and other platforms, including a network of workstations. It also runs on several symmetric multiprocessor (SMP) platforms, including the DEC AlphaServer and SGI Power Challenge. Salvo has a JAVA™ interface for remote processing and viewing output.

Input/Output (I/O)

To a large extent, the computational challenge is based on the volume of data to be processed, i.e., the size of the problem. A typical marine seismic survey ranges between 10,000 and 100,000 shots. For each shot, there are between 1500 and 3500 receiver traces which typically contain 2500 samples. Thus, the input dataset can contain over 10 megabytes of data for each shot and over 1 terabyte (10^{12} bytes) of data for the whole survey. The time required to read the initial seismic data, read the velocity models, and write the images can be substantial, creating an I/O "bottleneck."

In Salvo, the input is performed by a subset of available nodes assigned to handle the I/O; each of these I/O nodes is assigned I/O from one file system. The remaining nodes perform the pre-computations in the background, thereby mitigating the I/O bottleneck by performing preliminary computations and data redistributions using nodes not directly involved in I/O. The trace dataset is distributed across many disks to increase the total disk-to-memory bandwidth.

The remaining nodes, termed compute nodes, complete computations and communications necessary before the migration can begin. Each compute node is assigned an I/O node, and performs the pre-computations on the data read by its I/O node. Currently, the pre-computation comprises fast Fourier transforms (FFTs), but other computations can be performed. If a sufficient number of compute nodes are assigned to each I/O node, the time to read a block of seismic data will be greater than the time required to compute the FFTs and distribute the frequencies to the correct nodes for later computations. Thus, the computation time will be hidden behind the I/O time.

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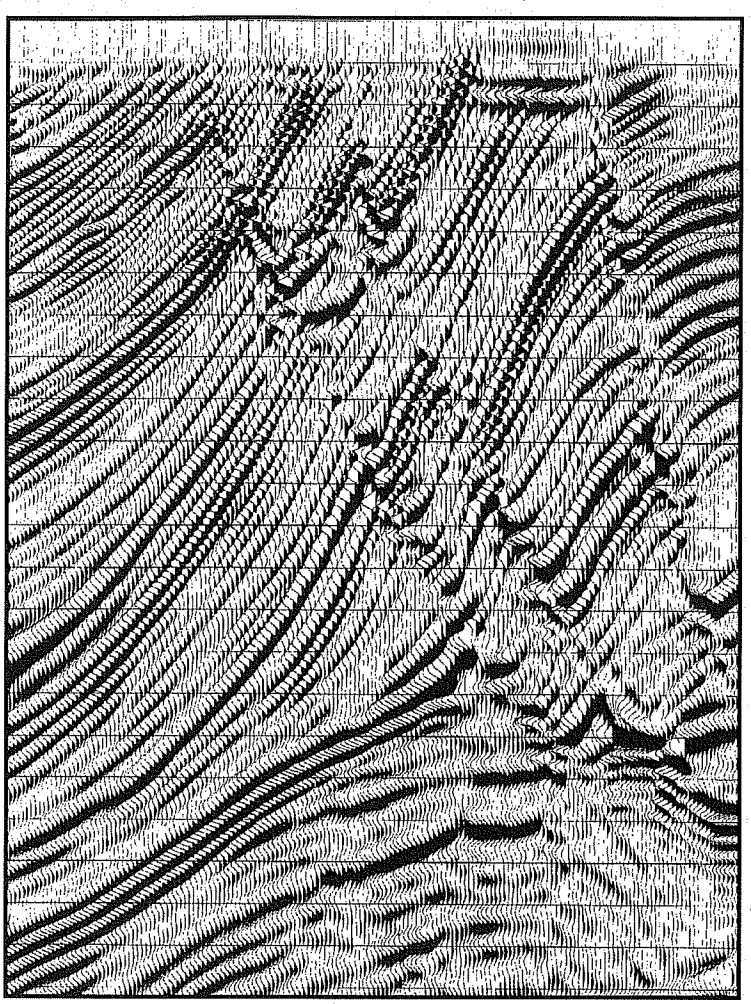

Figure 3: Salvo image of Marmousi model.

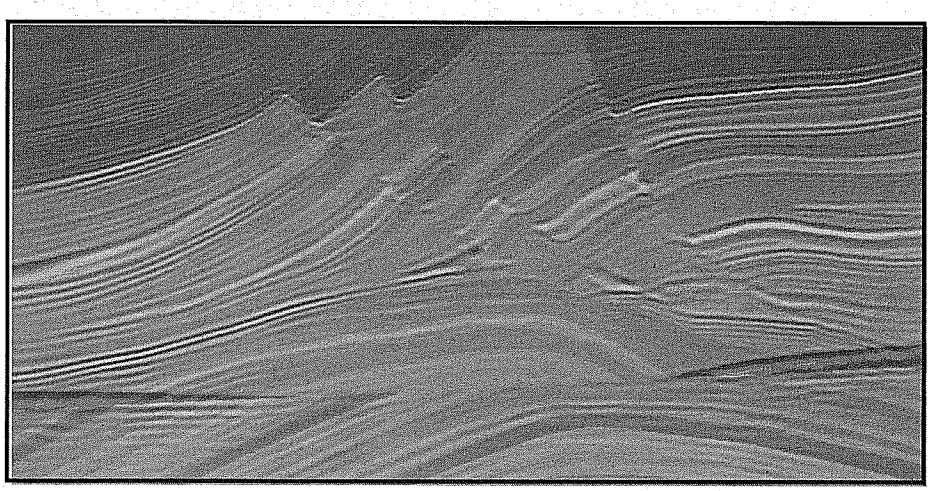

Figure 4: Marmousi model with image.

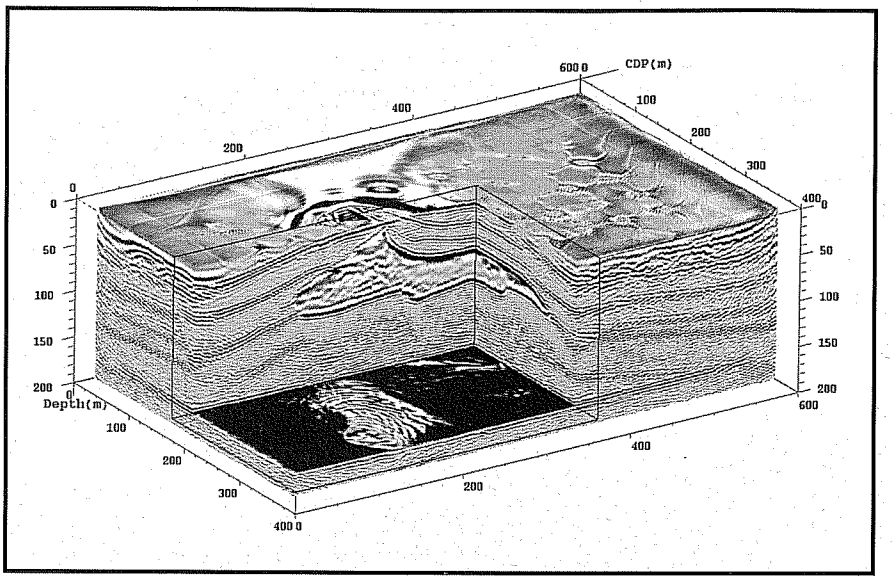

Figure 5: A corner-cut view of the image produced by Salvo.

Testing of Salvo

To validate Salvo, tests were performed to ensure accurate imaging of reflecting layers. The problems selected for the test cases included a simple impulse response from a hemispherical reflector, the ARCO-French model, the Marmousi model, the SEG/EAGE 3D overthrust model, the SEG/EAGE 3D salt model, and real data.

The 3D SEG/EAGE salt model is an example of a Salvo migration. This synthetic model with synthetic receiver data is available through the SEG Internet home page at **http://www.seg.org/research/3Dmodel/SALTHOME/segsalt.html**.

Figure 5 shows a corner-cut view of the image produced by Salvo. The top and bottom of the salt structure are clearly imaged, as well as the flat reference reflector near the bottom of the model indicated by the black plane within the corner cut. It also shows several faults which are visible on the left side of the Salvo image. The gray region within the black plane is a shadow zone, caused by the salt structure above it. The 600 x 600 x 210 image is a stack of 45 shots, each processed on a 200 x 200 x 210 grid with a surface grid fully populated with receivers. For this image Dx = Dy = Dz = 20 meters. The receiver traces contain 626 samples with Dt = 0.004 seconds; 511 frequencies were migrated. ARCO and Oryx Energy Company performed additional postprocessing of the images.

The input dataset can contain over 10 megabytes of data for each shot and over 1 terabyte (10^{12} bytes) of data for the whole survey.

The Future

Advanced computational techniques and algorithms developed in this project will reduce analysis time, increase accuracy, allow inclusion of refinements such as AVO/inversion and multiple suppression, and be made accessible by the creation of an infrastructure for remote seismic processing. Partners continue to develop computational and algorithmic approaches for 3D seismic imaging, working on the efficient use of Massively Parallel computers, utilizing computational techniques and scalable I/O. Algorithmic improvements to be investigated include boundary and imaging conditions, frequency selection, high-order discretizations, and computations on wavelet-compressed data. One of the most promising new algorithmic 'variants,' a multiple-scale approach to wave propagation matching frequencies to grids, has the potential to bring substantial reduction of computational requirements while maintaining image quality.

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Publications

Ober, C., R. Oldfield, J. Van Dyke, and D. Womble. 1996. *Seismic Imaging on Massively Parallel Computers*. SAND96-1112. Albuquerque, NM: Sandia National Laboratories.

Partnership News

- Partnership Office representatives met with Fossil Energy personnel from Department of Energy (DOE) Headquarters, the National Petroleum Technology Office, and the Federal Energy Technology Center (FETC) on September 10-12 to define action items, including marshalling proactive industry support for DOE's FY98 Oil Program and taking steps to improve the Partnership's interactions with FETC, Gas Research Institute, the Petroleum Technology Transfer Council (PTTC), the Interstate Oil and Gas Compact Commission (IOGCC), and other industry organizations.
- Bob Hanold and Dave Northrop joined Tom Wesson, Director of the National Petroleum Technology Office, on November 7 to visit Christine Hansen, Executive Director, at the IOGCC in Oklahoma City, to describe the Partnership and explore mutually beneficial efforts.
- Norman Goldstein, Tad Patzek, and George Cooper, LBNL, and Jeff Wagoner, LLNL, presented talks about their projects to the West Coast PTTC Problem Identification Workshop, held November 20, in Bakersfield, CA. George Cooper and Tad Patzek also represented the Partnership at the West Coast Problem Identification Workshops held in Long Beach and Ventura, CA, on November 25 and 26 and met with the directors of the ten Regional Lead Organizations of the PTTC in Washington DC, on December 12. Three objectives were offered: increased national laboratory participation in PTTC technology workshops, development of Partnership project(s) based on PTTC identified needs, and improvement of PTTC/Partnership mutual communications through websites, newsletters, meetings, etc.
- Bob Hanold and Dave Northrop developed and manned a booth at the annual meeting of the IOGCC in Las Vegas, NV, held December 8-10. The booth, together with displays from DOE Oil and Gas Program, the Rocky Mountain Oil Field Testing Center, and the PTTC, presented the varied DOE outreach programs to the nation's petroleum industry representatives. There were a record 475 registrants, including four state governors. The IOGCC has advanced a U.S. energy policy that has five key points, the second of which is "Promote the expansion of research to recover domestic oil and gas resources."
- A 12-page document relating the compelling story of the Partnership and its role within DOE's Oil and Gas Program is being developed. February publication is targeted.
- Many efforts have been undertaken to obtain FY97 funding for the Computational Technology (CT, formerly ACTI) projects. Some level of funding has been obtained for all Defense Programs-assigned projects and for most Energy Research-assigned projects. The Partnership Office assisted members of the CT Industry Review Panel in reviewing the seven FE-assigned CT projects and two other currently unfunded CT projects at a meeting at Chevron's Drilling Technology Center in Houston, on December 4. The Panel unanimously stated ". . . that these projects and all ACTI projects should, without reservation, be included in the budget funding for 1997, to continue the ACTI program at the strongest level the available ACTI budget allows." Two programs have recently received funding.

Publications

Journal Articles

Anderson, J., T. Alkhalifah, and I. Tsvankin. 1996. "Fowler DMO and time migration for transversely isotropic media," *Geophysics*, vol. 61, pp. 835-844.

Elata, D., and J. G. Berryman. 1996. "Contact force-displacement laws and the mechanical behavior of random packs of identical spheres," *Mechanics of Materials*, vol. 24, pp. 229-240.

Kovscek, A.R., R.M. Johnston, and T.W. Patzek. 1996. "Interpretation of hydrofracture geometry during steam injection using temperature transients. Part I: Model formulation and verification," *In Situ*, vol. 20, no. 3, pp. 251-288.

Kovscek, A.R., R.M. Johnston, and T.W. Patzek. 1996. "Interpretation of hydrofracture geometry during steam injection using temperature transients. Part II: Asymmetric hydrofractures," *In Situ*, vol. 20, no. 3, pp. 289-309.

Tsvankin, I. 1996, "P-wave signatures and notation for transversely isotropicmedia; An overview," *Geophysics*, vol. 61, pp. 467-483.

Wiley, R.W., R.S. McKnight, and K.K. Sekharan. 1996. "Salt canopy 3-D physical modeling project," *Leading Edge*, vol. 15, no. 11, pp. 1249-1251.

Technical Reports and Presentations

Phillips, W.S., J.T. Rutledge, T.D. Fairbanks, T.L. Gardner, M.E. Miller, and B.K. Schuessler. 1996. "Reservoir fracture mapping using microearthquakes: Austin Chalk, Giddings Field, TX and 76 Field, Clinton Co., KY," (SPE 36651), presented at the annual meeting of the SEG held November in Denver.

Project News

Borehole Seismic Technology

September-December 1996

3-Component Vibratory Source

The completed source tool was tested on the bench, and E-Systems is fabricating high-temperature versions of the circuit boards. The tool will be re-assembled, sealed, and then shipped to Chevron's La Habra test site for initial tool checkout and geophysical tests.

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Microborehole Seismic Instrumentation

An abandoned, shallow well near Los Alamos, NM, was completed with 1" tubing for conducting microtool tests. Leak and pressure integrity testing was performed incorporating reliability improvements in the tool design and hardware. The results were presented to the Society of Exploration Geophysicists (SEG) on November 11 in Denver (See "Publications," p. 5). Designs are being finalized for a digital version of the microtool, as well as specifications for the final cable configuration to be used with the microtool. A meeting was held with LLNL personnel in preparation for further testing of accelerometers in the microtool platform and for final design and fabrication of the analog-to-digital signal converter to be incorporated in the array. Mark Products will produce a prototype horizontal microgeophone for testing.

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Single Well Seismic Imaging Technology

SNL met with OYO Geospace to discuss how their fiber optic formatter could be modified to provide an interface for the existing Exxon receiver. SNL continued drawings to incorporate the Conoco orbital vibrator in a single-well system, which would include fiber optic telemetry. Quality assurance tests of the GRI/Chevron fiber optic wireline/telemetry system were performed by SNL at E-Systems. The first model of the SNL/OYO receiver clamp was sent to MIT to investigate its potential for attenuating tube waves.

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Acquisition of Borehole Seismic Data Behind Production Tubing

Acquisition and modeling technology to collect borehole seismic data behind production tubing is being developed. A small field survey demonstrating hydrophone acquisition is planned.

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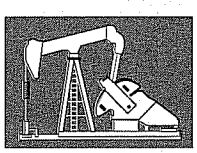

Oil Recovery Technology

September-December 1996

Applied Production Technology (APT)

Tech Transfer Including Paraffin Control

The APT project had its own booth at the Permian Basin Oil Show, October 16-18 in Odessa, TX, resulting in a significant number of requests for information on paraffin control, plunger lift testing, and the Downhole Dynamometer Database.

Testing and analysis techniques developed for the Automatic Casing Swab (a completed APT task) have been applied to "pig-lift" technology (*JPT*, October 1996, p. 930-31), and several ways to improve the use of pigs as an artificial lift mechanism, especially on low-production wells, were identified.

Sucker Rod Failures

Beta testing of the Downhole Dynamometer Database by select members of the Sucker Rod Working Group was completed. Modifications were made according to comments received, and it should be ready for distribution early in 1997. The database was presented to the Artificial Lift Forum, September 24-25 in Midland, TX, and demon-

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strated at the Permian Basin Oil Show, October 16-18 in Odessa, TX. Response was favorable, and SNL has initiated discussions with Texas Tech University, the University of Texas, and New Mexico Tech in an effort to involve students in the data analysis.

Field Measurement of Oil Properties

Petrolite's testing of the Cloud Point Detector was completed; the device was returned to SNL. A Visual Basic program has been developed to communicate with the Cloud Point Detector microprocessor. Use of Visual Basic allows use of any PC, and the communications software can be customized. Further work is on hold, awaiting completion of licensing arrangements with Petrolite.

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Wireless Telemetry Tool

Several design modifications were incorporated for recent bench testing of the push-pull tank circuit, demonstrating that the electrical noise from the power circuit can be successfully isolated from the logic circuits. The final microprocessor design will be incorporated into a new circuit board, retested in Houston, then shipped to Albuquerque, NM, for testing on the horizontal, 1400' production string at SNL's Orpheus facility.

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Optimizing Reservoir Production

A study has begun that compares fracture permeability calculated using the Lattice-Boltzmann permeameter (LBP) against simple aperture-based permeability estimates. The computed permeabilities from the LBP were much smaller than those predicted by the simple parallel plate assumption based on the average aperture. The project team is now comparing flow fields and permeabilities from the LBP against the flow experimental results from the digitized fractures.

Pore to core upscaling work continued by testing the 3D renormalization group (RGT) approach applied to one of the high-resolution, digitized sandstone samples. For the 64 x 64 x 64 sub-blocks, error between predicted and calculated values was only 10%. The RGT process will be applied to other high-resolution, digital pore spaces to confirm these results.

Low capillary number (Nca) waterflood displacement simulations are running in a sandstone sample to provide data for computing changes in interfacial area between fluids as input to an alternate scale-up approach. The simulation is also being used for comparison against a high-resolution digitalization of the end state of a coreflood. It will be compared with results from higher Nca simulations.

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Ultrasonic Reduction of Formation Damage

Five wells located in the Bend Arch region of North Central Texas were treated with the prototype ultrasonic cleaning tool. These wells were chosen based on their steadily declining production rates. Four of the five were in the same production field and were fairly low-volume producers. The combined daily production data for the first four wells show that, after an initial pump stabilization period of four to five days, oil production is steadily rising relative to the pre-treatment rates. Post-treatment water production rose sharply at first and is now gradually declining. Further tests involve treating a newly-completed well and a separate set of eight wells that all produce into the same tank battery. The private investors and the producers believe that the initial results are encouraging enough to warrant further testing.

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Fracture Mapping and Slimhole Geophone Array

Progress has slowed on a third set of electronics being bench- and oven-tested because of continued telemetry problems attributed to the cable heads. LANL and Schlumberger personnel met to review and update the design and materials used. Schlumberger supplied new materials, and the array tool is being prepared for comprehensive field testing.

"Reservoir fracture mapping using microearthquakes: Austin Chalk, Giddings Field, TX and 76 field, Clinton, Co., KY," was presented at the SPE and SEG annual meetings. (See "Publications," p. 5).

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Reduction of Well Failures in Diatomite

SNL completed the third baseline, 3D geomechanical simulation in South Belridge, Section 33, with three slip surfaces in the overburden activated.

The nine layers of the diatomite reservoir were modeled using the same Drucker-Prager/Cap material model used in the second baseline simulation. 2D analyses investigated the effects of slip-line location in the overburden and of discontinuous slip lines. Maximum slip occurred on a slip line located at the top of the diatomite reservoir, while less slip occurred if the slip line were located higher in the overburden. Discontinuous slip lines resulted in localization of slip.The LBNL 2D geomechanical analysis of a model with flat-lying geology was

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Project News (Continued from Page 7)

largely completed. Approximately the same amount of slip will occur on discontinuous slip lines as on continuous slip lines. If multiple slip lines are present, deformation will localize on the one closest to the diatomite. Comparison with displacements in regions where no slip lines are present suggest that well failure may not occur and displacements actually localize over very thin layers.

"Three-dimensional geomechanical simulation of reservoir compaction and implications for well failures in the Belridge diatomite," was presented at the 1996 SPE Annual Technical Conference and Exhibition and submitted for presentation at the SPE Western Regional Meeting to be held in Long Beach, CA, in June 1997.

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Extending Borehole EM Imaging

Results of cased borehole experiments from the UC Richmond Field Station (RFS) and a numerical scheme to estimate casing properties by means of the low-frequency electromagnetic (EM) data were presented at the industry participants' meeting on November 12. Proposed work for studying EM field propagation through cased boreholes in complex geologic environments, and the testing of an innovative cross-borehole imaging scheme that utilizes the wavefield transformation technique were discussed.

Crosshole EM field data collected at the Bakersfield, CA, site yielded excellent results. Baseline measurements are completed, and data interpretation is underway. Steel-cased wells will be used within the next year.

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Fluid Injection into Tight Rocks

A 3D, virtual-reality model of the Phase III steam-drive pilot operated by Shell in the South Belridge diatomite is in progress, as well as an analysis of Crutcher-Tufts' waterflood in the Middle Belridge diatomite. A joint paper on this work will be presented at SPE's Regional Workshop in June 1997.

"Interpretation of hydrofracture geometry during steam injection using temperature transients. Part I: Model formulation and verification" and "Part II: Asymmetric hydrofractures" were published in *In Situ* (vol. 20, no. 3). (See "Publications" p. 5).

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Improved Prediction of Multiphase Flow

UT-Austin completed a report on the implementation and testing of the two-phase theoretical capillary pressure relative permeability model in the UTCHEM code. The code was successfully tested against experimental data provided by industry and PNNL. They are currently modifying the model to include three-phase flow phenomena pertinent to petroleum reservoirs. A three-phase experimental apparatus for simultaneous measurements of capillary pressure and relative permeability was successfully tested with a branched alkane.

A December 13 meeting in Houston was convened to brief Landmark Graphics Corporation, Westport Technology Center International, and Mobil Oil, companies interested in becoming partners in this project. Presentations were given on the theoretical, experimental, and numerical aspects of the project.

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Tiltmeter Hydraulic Fracture Imaging

Pinnacle Technologies completed construction of 20 new-generation tiltmeters. This "slimhole" design features a new leveling device and an outer diameter of 2.5". The smaller diameter of the instrument will reduce the cost of the deployment hole and require less grout.

A second-generation datalogger printed circuit board for the tiltmeter was tested, showing that the circuitry works correctly. Designed to fit in the tiltmeter, it will take the place of the surface datalogger.

We are preparing to monitor a 7,500'-deep frac in mid-December. Success at this depth will be followed by an attempt to image a 10,000'-deep frac.

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Mapping Steam and Water Flow in Diatomite

Bakersfield Energy is performing log and core studies to better understand the mechanisms of water displacement in very tight formations. They will employ crosshole EM techniques to study resistivity changes caused by the displacement of oil by injected water.

EM surveys will be made using two fiberglass-cased observation wells and several steel-cased production boreholes. Data will be collected before initial water injection and, subsequently, at six-month intervals during the waterflood.

Seismic data from CalResources' Belridge site is being processed. Major differences, attributable to fluid saturation conditions, can be seen between the pre-flood and the post-flood seismograms.

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Project News

Drilling and Completion Technology

September-December 1996

CEA/DEA Projects

Rheology and Proppant Transport (CEA # 101)

Interaction with this Stim-Lab-led consortium continues.

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Improvements in Drilling Using Electro-Osmosis (DEA # 70, Phase 2)

A question about the effectiveness of casing consolidation by electrokinetics at low (4°C) temperatures resulted in plots being obtained to compare current to applied voltage at room temperature (25°C) and 4°C. A fall-off in current of only 10-15% was observed at the lower temperature.

Borehole closure experiments, performed at 4°C with sea water as the annular fluid at a minimal current density (2A/sq.m) and for only three hours, achieved a shear strength of 0.33 psi. This experiment was then repeated with other annular fluids to simulate a field situation where a fluid is pumped around the casing to control the over-pressurized zones and to maintain a hydrostatic head. The best fluid tested was a 6 wt% bentonite fresh water slurry, weighted to 12 ppg with barite. Shear strength achieved was about 1.5 psi. For a 36", 300' casing, this is equivalent to a bearing capacity of 600,000 lbs. The combined weight of the structural casing and the following conductor casing is usually no more than 300,000 lbs. At greater depths, standard cementing methods can be employed.

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

MUDLITE handles hydraulics for air, mist, foam, and aerated fluid drilling. This underbalanced drilling fluid design code is being modified to include air volume requirements and cuttings transport in horizontal wells. "Pressure matching" is being added to allow users to adjust constants in the hydraulics model automatically or manually, so that calculated values match actual measured values. The first official release of MUDLITE 1.0 was made to DEA-101 participants.

The underbalanced drilling cost comparison model, UBCOST, is being developed to help the users compare costs of underbalanced drilling to conventional mud drilling. This program requires only minimal data input and shows cost distributions for the major cost items and the cost/depth curves for different drilling methods.

NITRO analyzes costs related to the use of nitrogen at the wellsite. It compares the costs of using liquid nitrogen to compressor/membrane generated nitrogen.

The DEA-101 manual promises to be a useful tool for designing underbalanced drilling and completion operations. Publication and distribution are scheduled for winter 1996-97.

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Coiled Tubing Fatigue Mechanisms (DEA # 104)

Constant pressure tests measured diametral growth from coiled tubing samples, with data from these tests serving as input for fine-tuning a plasticity routine in the predictive/analytical model. Also, initial results from the collection and analysis of data from bend-straighten-pull load scenarios indicate that the plastic axial strain imposed by an axial load is affected by the subsequent bending cycle. The tubing tends to shorten, following the bending load, reducing the net permanent elongation. This observation is consistent with the analytical model being developed for this project. The current plasticity model falsely predicts this shortening tendency, but the newer model should provide more accurate results. The results indicate that the transient softening behavior of the tubing material could be more important than initially was predicted.

A final meeting will be scheduled to coincide with the World Oil Coiled Tubing Conference to be held in Houston, February 1997.

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Advanced Synthetic-Diamond Bit Technology

Work on this project in the past year has been supported solely by DOE's Geothermal program. Aspects of the various partnered subprojects will continue; however, results will no longer be reported here, and the project no longer will be considered an active Partnership project.

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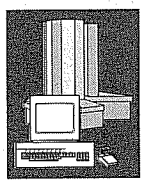
Project News



Computational Technology

September-December 1996

Models for Deep Water Oil and Gas Production

Work on both subtasks was suspended on October 1. Partial FY97 funding was received in late December, so limited efforts on Subtask 1 will be resumed.

Subtask 1: Fluid/Structure Predictive Code Development

SNL personnel presented a status report on the code development at the DeepStar Vessel and Riser Committee Meeting on August 27, in Houston. A draft technical report covering the progress for FY96 was prepared and submitted to Paul Devlin of DeepStar.

The Lagrangian remapping modules were verified. Methodologies for transition between the wall and the outer regions have been formulated and need to be coded. Geometry modules were completed that allow easy definition of complicated riser geometries by the user.

Subtask 2: Strength of Composite-to-Metal Joints

A series of detailed, finite-element analyses showed how the terminations (i.e., composite-to-metal joints) under development for use in composite risers will perform. Details of these analyses are proprietary and were documented in a report with limited distribution within the project.

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Well Log Imaging

University of California-Santa Barbara (UCSB) personnel have finalized indexing software that allows rapid indexing of both microfiche strip and geophysical log header parameters. The software was tested using scanned images of geophysical logs from Illinois and Kansas. UCSB has received microfiche masters from the state of California, and these fiche are currently being scanned.

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Geologic Structure and Reservoir Mechanics

A representative from each industrial partner attended a JAS3D code training session held in Albuquerque, October 21-24. Some development also continued on the 3D mapped infinite element. A better estimate of the diagonal mass for the infinite element is needed for the dynamic relaxation solution scheme in JAS3D. The JAS3D code was transferred to the partners at the end of October.

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Reducing Certain Seismic Data Acquisition Costs

Prototype platter charges, designed and fabricated at LLNL, were loaded with explosives at Austin Powder Company and then shipped to a survey site. Western Geophysical then tested them in the field as part of a set of tests being conducted during the course of a 3D survey. Austin Powder Company's commercial charges were tested in August, and modifications were made. In December, the platter charge was tested with the same sort of comparison to the commercial charge, firing first one and then the other in the same location. The first run of data processing was completed, but additional processing will be required to look at the detailed differences among the surface dynamite charges.

The prototypes have a mild steel platter with fairly sturdy plastic parts for the back and sides to hold two pounds of explosive plus the detonator or cap and to provide the needed standoff. Eventually, the plastic parts could be replaced with lighter materials, such as cardboard.

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Perforation Dynamics in Geological Media

A natural-gas-storage well evaluation method was developed and tested. It uses wellhead pressure and gas flow measurements from the past 30-90 days and is based on modern adaptive filter technology.

Originally implemented on a MatLab™ platform, the algorithmic code was rewritten in C, which requires ASCII files as input and output.

An extensive series of hydrodynamic simulations were performed in preparation for Phase II of this project. The results suggest that the reduction in permeability observed in the crushed zone surrounding the perforation tunnel is caused largely by a stress cage. In addition, x-ray tomography has been employed to examine Berea sandstone core, fractured by a shaped charge.

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Project News (Continued from Page 10)

Near Wellbore Mechanics

The final impact tests on the API concrete and the Castlegate sandstone are completed. The velocity profiles appear adequate to yield clean data for shock-loading properties, Hugoniot, and release properties required for perforation calculations. CAT scanning of the perforated API-43 concrete and Castlegate sandstone samples at Chevron was completed, in addition to flash x-ray characterizations of both types of shaped charges fired into air. Halliburton has sent SNL results of quasi-static yield and compression tests on the API concrete.

Discrete Element Modeling Team

A number of test simulations are in progress to exercise the capability to model sandgrain-shaped particles with coupled fluid flow and particle motion.

Near Wellbore Stress Modeling Team

The results of hydrostatic compression experiments on Castlegate sandstone indicate two different curvatures in a pressure versus volumetric compaction plot.

Perforation Induced Damage Team

The initial objective is CTH modeling of compact shaped charges into air, which were compared with flash x-rays acquired at SNL. The comparison indicates that the jet velocity is off by a factor of approximately two.

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Reservoir Studies and Information Delivery Tools

This project was integrated into the Advanced Reservoir Management (ARM) project. No additional separate reporting on this project will take place.

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Advanced Reservoir Management (ARM)

On October 16, the project partners, the Minerals Management Service, State Lands Commission of California, and LANL met at the Pacific Operators Offshore, Inc. Operations Office in Ventura, CA to review the geological modeling effort and to detail plans for the simulation phase of the project.

The Carpinteria Reservoir Redevelopment Project (CRRP) has defined a complex geological model that incorporates carefully chosen oil-water contacts and major faults. Volumetric calculations on the model were performed. This information supports the go-ahead decision, made year-end 1996, to redevelop the field.

The model will be exported from its current form in one geological modeling software package to another such package, to demonstrate the archival worth and transferability of electronic models. The conversion will not be aided by POSC-compliant packages. The conceptual basis for the models and the supporting data are the same.

The modeling work for the CRRP was shown at the Petroleum Technology Transfer Council's Focused Technology Workshop, at the University of Southern California, January 15.

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Subsalt Imaging with Marine Magnetotellurics

Work on our new 2D transverse magnetic mode (TM) sharp-boundary inverse program continued. The algorithm is being tested on 3D numerical data generated to simulate the Mahogany Prospect in the Gulf of Mexico. Tests show that the new algorithm is significantly better at imaging the base of the 3D salt structure than are existing smooth 2D magnetotellurics (MT) inverse algorithms.

Processing of the Gulf of Mexico marine MT data continued. The Mahogany sites have been processed using both land magnetic fields and sea floor electric fields as remote references. It appears that the sea floor E fields yield the more reliable impedance estimates. The Gemini sites are being processed.

The sharp-boundary, inverse program is being improved to accommodate different numbers of nodes on different boundaries while allowing different relative smoothing. This should improve its ability to accommodate surface statics by allowing relatively little smoothing of near-surface conductivities. The Motif graphical-user interface has been modified to accommodate the sharp-boundary inverse along with the other existing inversion algorithms.

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Modeling and Processing Seismic Data

The accuracy of the generalized screen propagators was studied, and further quantitative assessment is underway. The quality of the 3D image of the prestack depth migration using the pseudo-screen method was improved, and interferences in the near source regions were removed.

Tests were made of phase screen and wide-angle screen modeling methods using realistic 2D models. Results were compared using fourth-order finite-difference calculations of the wave equation for the same models. The wide-angle screen method performs well, even when velocity contrasts are as large as a factor of three in one horizon. Phase screen method results were not as good, demonstrating the advantage of the new wide-angle screen method.

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Project News (Continued from Page 11)

Velocity Analysis, Parameter Estimation, and Constraints on Lithology

Colorado School of Mines (CSM) researchers developed a new 3D NMO processing technique for orthorhombic media and also processed a new anisotropic data set from Amoco Production Company.

In recognition of their research contributions, three CSM professors received prestigious awards at the 1996 annual Society of Exploration Geophysicists (SEG) meeting in Denver, held November 10-14. CSM professors and students working on this project presented several talks describing various advances in seismic reflection processing for anisotropic media. Participants held a project meeting during the SEG to discuss theoretical constraints on anisotropy parameters from the LLNL/Stanford research group and to plan the future direction of this project.

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Subsidence, Analysis, and Control

Coupling of the TOUGH2 multiphase fluid flow code to a routine for calculating surface displacements was successful. The pressure field produced by the program becomes the input for the surface displacement program.

Also developed and applied is a program for using surface displacement data to infer fluid volume changes within a reservoir. The routine has been applied to leveling data from the Wilmington field taken during 1995. These data have been used to map volume changes within the reservoir.

Debugging and testing of the finite-difference code for computing surface displacement in an arbitrary 3D medium was completed. It proved to be efficient and has been used to predict surface displacements based on net injected volume at the Wilmington field at Long Beach, CA. The reservoir simulator was modified to output thermal changes, in addition to pressure variations. The project team is preparing to model a subset of a steamflood from Fault Block II at the Wilmington field.

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Optimal Fluid Injection Policy and Producibility

Controller codes and software-hardware computer interfaces were successfully debugged. Several new controller options are: a Neural-Network-Internal-Model Control Strategy, a DNNC Control Strategy, the Digital PID Controller, and a Direct Neural Network Control Strategy. The off-line implementation of the smart controller is no longer an issue.

Development is underway for a numerical algorithm for computing incompressible, discontinuous, two-phase flows in 2D, inhomogeneous, and isotropic porous media.

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Advanced Visualization and Virtual Reality

This project was completed.

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Advanced Computational Analysis of Drill Cutting

Sensitivity studies were performed using an updated graph-theory-based algorithm for calculation of non-wetting phase flow in a 3D pore network. The algorithm is about one order of magnitude faster than the first generation algorithm previously released to participants.

Of particular concern was the size of the model required to assure that the results of different statistical realizations yielded the same value. It was found that a grid size of 32 x 32 x 32 was sufficient to assume invariance of results for models with correlation lengths of about three or less. In the model, each node of the grid is occupied by a pore, and a correlation length of one is equivalent to one grid spacing.

Analysis of results was carried out on Wood's metal injection into Nugget sandstone samples. Wood's metal is a non-wetting fluid at 100°C which can be frozen in place to reveal connected pore pathways accessible at a given capillary pressure. In one sample, a Wood's metal saturation of about 13% resulted in a permeability in the wafer of 25 md as opposed to a whole sample permeability (without Wood's metal) of 65 md. SEM images showed a heterogeneous distribution of Wood's metal at two scales. Nugget sandstone is finely bedded such that several beds were contained in a 1"-diameter sample (cored parallel to bedding). The Wood's metal was confined to the coarse grained bedding. Within these beds a second level of heterogeneity was evident with interconnectivity controlling access of pores of a given size.

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Synchrotron Computed Microtomography

Work to date has included analysis at the Brookhaven National Synchrotron Light Source of core samples provided by Mobil, production of high-quality microtomographs on BNL computers, installation of a stereo display facility where core samples can be viewed and navigated, and reduction of time used by linking instruments and analytic tools on a high-speed network.

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Project News (Continued from Page 12)

Tomograph resolutions achieved have been below three micrometers. A method of producing microtomographs with subvolumes was developed that enables high-resolution analysis with shorter compute time and less memory than previously required.

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Innovative Gridding and Solution Techniques

Work continues on incorporation of faulted surfaces as part of the 2D and 3D grids. The project team has successfully generated 2D triangular and 3D tetrahedral grids from stratigraphic models produced in Lynx software by SNL. Preprocessors were written that allow use of the output from Lynx as input to the GEOMESH/X3D grid generation package. This enables model building and geologic interpretation in Lynx and grid generation/optimization in GEOMESH/X3D.

The models built include all the faults with thin but finite thickness in the Lynx model. The final grid treats the fault as a separate material so that different material properties can be applied to the fault.

An automatic script was developed to run a simple finite-element heat and mass transfer (FEHM) code heat flow solution on grids after they are generated.

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Coupled Rock/Fluid Mechanics

Acquisition of three-dimensional databases for grain morphology and pore structure is forthcoming. Also, a serial sectioning approach is being pursued with images of shock minerals obtained from a scanning electron microscope. A series of grain-grain interaction micro-mechanic calculations is underway where the pore space is treated as a void, fluid-filled, clay-filled, or a combination of void, fluid, and clay. Damage model characterization and schemes to provide particle-particle separation are being addressed. Considerable improvement

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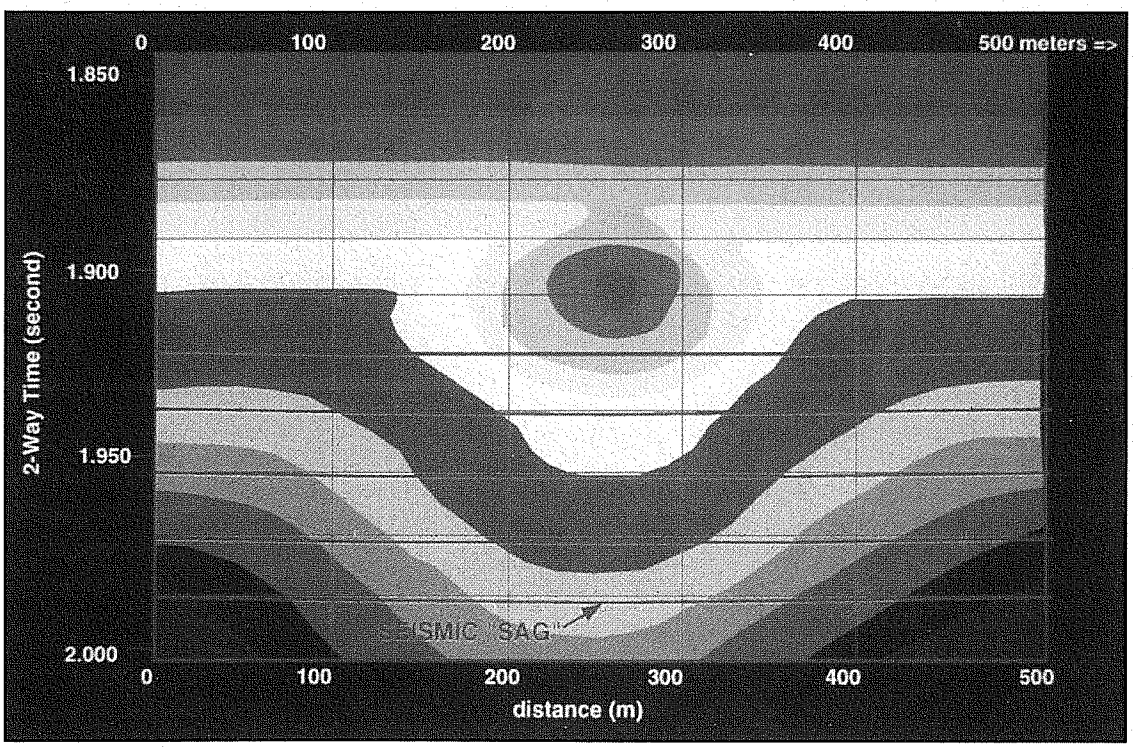

Figure 1: The Locating Geopressured Hydrocarbon Reservoirs in Soft Clastic Sediments through Identifying Associated Pressure Seals project is learning to understand the relationship between geopressured and commercial hydrocarbon accumulation. In order to determine how the pressure seal, which restricts upward flow, affects seismic traveltime, the time model for flat geologic horizons adds a series of flat reflecting horizons to the velocity model and calculates two-way travel times along each horizon. The deeper horizons below the seal appear to "sag" in time, producing a false syncline.

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Project News (Continued from Page 13)

to the Discrete Element Model (DEM) code has been made in creating clusters of particles to represent grains. This valuable feature provides a way for SPH simulations to be checked and mimicked by DEM simulations and vice versa. Improvements are underway in the particle bond modeling in the DEM code to account for rate dependence .

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Gulf of Mexico Subsalt Seismic Imaging

The code for doing prestack Kirchhoff migration on the Cray T3D was pieced together, and preliminary benchmarks of the message passing code were completed. Computational portions of the code were written and tested, and a velocity model for a field dataset was obtained and gridded. Traveltimes for imaging all source and receiver data were calculated for imaging two orthogonal image planes as a test of the code. A traveltime interpolation scheme was developed and tested, allowing reliable calculation of traveltimes on a coarse grid while maintaining the reliability of fine image grid traveltimes.

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Vertical Seismic Profiling

Utah Geophysical, Inc. provided seismic field data acquired during drilling at a depth of two km. Data from a single depth of the drill bit were processed to evaluate signal and noise characteristics. Results from the velocity analysis are consistent with the velocities provided by the sonic log data. Autocorrelations of the individual traces of the "bit noise" data set appear consistent from trace to trace in the seismic sections produced by the autocorrelation of the transmission signals, but more filtering is required to remove excess noise.

The project is taking advantage of some of the unique capabilities of MatLab™ as a prototyping tool for faster development of software codes.

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Increased Effectiveness of Hydraulic Fracturing

A modified second year proposal was presented before the ACTI Industry Review Panel in Houston on December 4. The Panel endorsed all nine such proposals presented as worthy of receiving funds, with amounts to be based on available DOE resources.

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Multiphase Fluid Simulator for Underbalanced Drilling

A proposal with an updated and modified project agenda was presented to the ACTI Review Panel.

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Single-Well Seismic Imaging of Salt Dome Flanks

Borehole seismic data were collected at the Bayou Choctaw, LA, field test site in November using the Exxon piezoelectric source. Exxon is analyzing the data set which includes several fans taken with a true single-well configuration.

SNL is continuing to work with the University of Utah to define and implement standards, specifications, and options within a 3D viscoelastic seismic wavefield modeling algorithm.

Administrative efforts underway at SNL include placing a contract with Paulsson Geophysical Services to operate the axial hydraulic vibrator at the Bayou Choctaw site, finalizing the Site Access Agreement between SNL and Hunt Petroleum, and amending the CRADA to make Hunt Petroleum a full member.

Aspects of this project are being included in a proposal for a coordinated national laboratory approach to single-well seismic imaging.

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Computer Simulation in Support of Nuclear-Well Logging Devices

The ARDRA code, running on the Cray T3D computer, is being tested with a series of calculations on realistic models of nuclear porosity tools. Comparable calculations are being performed with Monte Carlo codes, notably TART and MCNP. Initial results show reasonable agreement. It will be necessary to run a series of calculations to discover whether the agreement holds for different types of problems.

The QUAD code, designed to run on powerful work stations, can now run large, very idealized problems on SGI and DEC work stations. However, the coding needed to model logging tools has not yet been written.

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Oil and Gas Data Infrastructure

The Petroleum Technology Transfer Council (West Cost Region) hosted a meeting of California and Texas petroleum agencies to review the new OGDIP interfaces. Participants agreed that the states should adopt this tech nology to provide Internet access to

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Project News (Continued from Page 14)

their clients. Alaska has sent sample data for the OGDIP database and would like to provide manpower for the project.

Work continues on the new Internet prototype, available on the Web at **http://wildcat.llnl.gov**. Mechanisms are being developed to allow users to customize reports to include only the desired information and to reduce the amount of data transmitted over the Internet. A meeting was organized with the Texas Railroad Commission and the California Division of Oil and Gas to explore how those agencies can best adopt the OGDIP technology.

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Development of a New Generation Petroleum Reservoir Simulator

Significant progress was made on the enhancement of DAGH for support for multiple fault-blocks. A version with this feature is expected to be completed soon.

The fully implicit 3D equation-of-state (EOS) compositional model has been integrated into the IPARS framework. Testing of the model on a serial computer is underway; a test on a parallel machine will also be performed.

A multiblock domain decomposition procedure for treating the coupled nonlinear multiphase, multicomponent system is being investigated using the EOS compositional model. A parallel implementation of the approach is also under investigation.

Testing of the IPARS framework by porting the compositional chemical simulator, UTCHEM, made promising progress. Preliminary results should be available soon.

The project Web site is **http://www.pe.utexas.edu/CPGE/ACTI/**.

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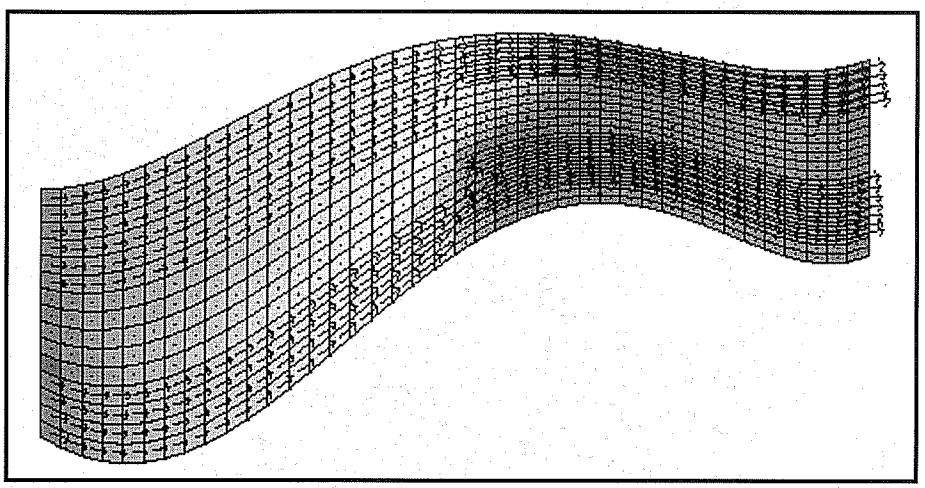

Figure 2: The Development of a New Generation Petroleum Reservoir Simulator project is producing a new-generation framework for reservoir simulation suitable for massively parallel computers and clusters of workstations. The prototype code developed through the project was used to model flow through a matching across the fault. See additional modeling results on the World Wide Web, **http://www.pe.utexas.edu/CPGE/ACTI/**.

3D Seismic Analysis using SEG/EAGE Dataset

Testing continued on a combined amplitude move-out (AMO) and common-azimuth migration procedure. Testing has shown that AMO is an effective technique for carrying out partial prestacking of real data that may have few drawbacks.

Results from many of the project's tasks were presented at the annual meeting of the Society of Exploration Geophysicists in November. Those presentations summarized much of the project's technical progress during its first year and a half.

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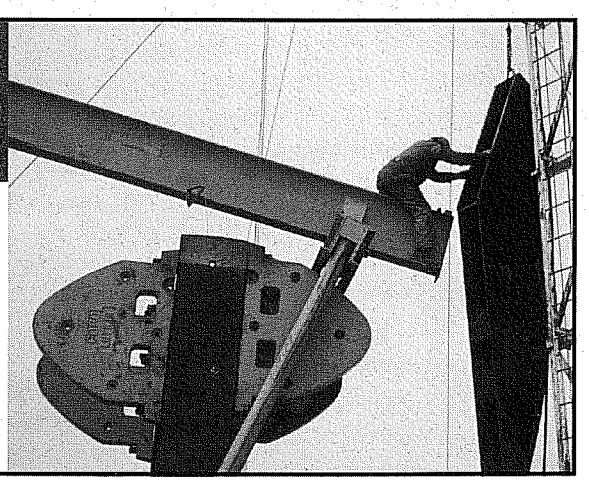
Industry Partners

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

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



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