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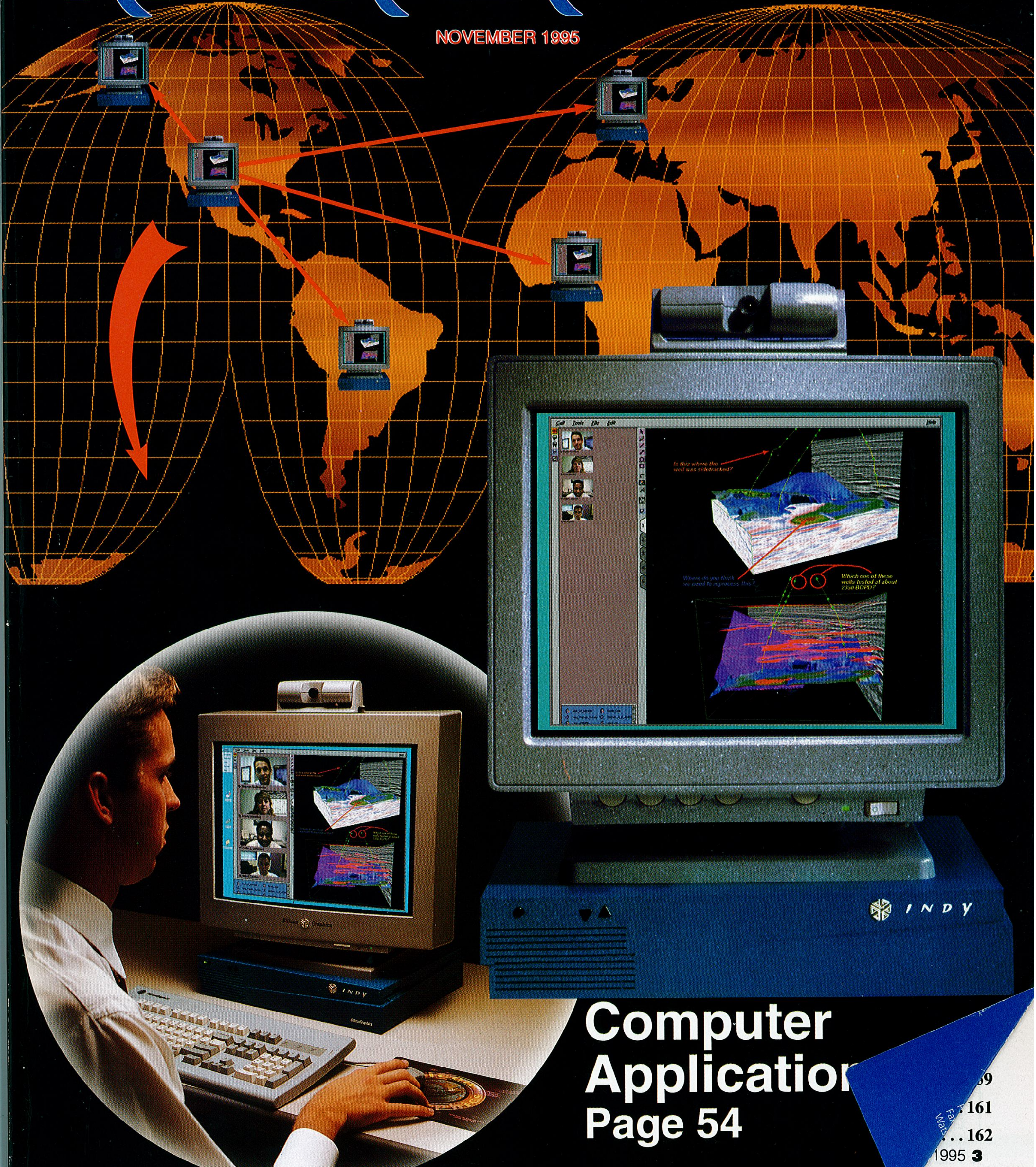

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O[illegible] greatest ironies of the subs[illegible] is that exploration in the Gulf has always revolved around features related to salt structure, but lacking the capability to clearly peer through a virtual veil of salt reserves on the under side of salt formations went undetected. As it appears to be playing out, the catalyst that is serving to resurrect the Gulf of Mexico and return it to the status of a world-class oil and gas domain was there all along; it was simply a matter of leveraging technology to find it.

According to Paul R. Leibman, a principal with the Denver-based energy investment banking firm Petrie Parkman & Co., the intriguing notion that vast hydrocarbon reserves are trapped beneath layers of salt waiting to be released by the drill bit is one of the reasons the subsalt has attracted the attention of the investment community. And as investors see it, that notion combined with the idea that the subsalt play could be opened to a large number of companies, gives the subsalt a tremendous allure, he said.

"There is some exciting exposure for numerous companies as the play matures, because it is so vast and overlaps so much existing acreage," commented Leibman.

However, it was the runaway excitement generated in the aftermath of the Mahogany discovery by Phillips and partners that has accounted for perhaps the largest negative the subsalt has working against it, he pointed out. "The dominant perception of the subsalt is that it has been over-hyped, and a certain amount of disillusionment has set in on Wall Street as investors track the results of wells drilled in the subsalt," Leibman said. "The bloom is clearly off the rose. But I would say this disappointment is largely the result of excessive expectations to begin with."

In retrospect, Leibman noted that the prolific Mahogany find might have been the subsalt play's own worst enemy in the eyes of investors. "We had a major commercial discovery right out of the box, and what can you do for an encore when you start with something that good?" he asked. "Mahogany spoiled everyone."

Other problems relating to the widespread disillusionment were the time delays and high costs necessary to minimize the geological and engineering risks and explore successfully in the subsalt, and the fact that not enough companies were active in the subsalt to make Wall Street take [illegible] suddenly it is being perceived negatively that the industry has stepped back to employ better depth imaging technology on the front end before drilling wildcats–to better understand the challenges before drilling these deep, high-cost wells," he offered.

Leibman went on to relate that investor excitement over the subsalt was beginning to swell again, although this time the euphoria appeared tempered by realism. "I think we are about to move into another phase where reality will dominate, and there isn't going to be such an intense focus on every subsalt well that gets drilled."

But he was nevertheless quick to add that stock market excitement could be rekindled when Phillips, Anadarko, and Amoco spudded the Alexandrite wildcat on Ship Shoal Block 337, scheduled for November. "We have heard a lot about the reservoir potential of Alexandrite–plus or minus 300 million barrels–and it is certainly going to be a key event in how Wall Street looks at the subsalt play," he predicted.

Additional exploratory subsalt test wells scheduled to be spudded in the near future by the Phillips-Anadarko partnership include the Agate prospect on Ship Shoal 361 and the Monazite prospect on Vermilion 375. "The industry is poised for another round of wildcatting that will provide a good indication of how the technology has evolved, both in regard to seismic depth imaging and in terms of mechanical drilling risk," Leibman concluded. "You can bet investors will be paying very close attention." ❐

'Virtual' Reservoir Development A Reality On Prototype System

By Janet Jacobsen,
Wes Bethel,
Akhil Datta-Gupta
and Preston Holland

BERKELEY, CA.–Virtual reality is a term that conjures up navigating through a virtual battlefield, piloting a virtual spaceship, or dueling with virtual monsters. The power of the software and hardware that make these kind of fantastical excursions possible may also be harnessed to create tools that reservoir engineers can use to easily and quickly explore different field development strategies.

Incorporating virtual reality (VR) technology into a reservoir simulator minimizes machine-human interface barriers and provides engineers with the opportunity to interact with simulation programs. Enhanced interactivity leads to greater productivity because the use of VR creates a working environment that maximizes the use of an engineer's intuition for formulating different strategies for solving reservoir problems.

In a prototype desktop visualization/virtual reality system developed at Lawrence Berkeley National Laboratory, users are able to visualize simulation results while the simulator is running. Input errors or poorly-formulated solutions strategies can be detected early in the simulation run, thereby saving compute cycles and time for users. In addition, being able to watch the simulation run sparks the user's curiosity about what would be the effect of changing one or more parameters, and keeps the user's attention focused on the development strategy being investigated.

A key feature of the prototype system is the use of a virtual reality input device to specify three-dimensional input parameters. For example, while exploring different infill drilling strategies, the VR input device may be used to add or reposition wells interactively without having to type in numbers or characters at a keyboard, and without having to exit the visualization/simulation environment.

Given that, at present, most domestic oil production is from mature or partially-depleted reservoirs, VR technology offers tremendous potential to provide a forum to bring together the expertise of geologists, geophysicists and reservoir engineers to characterize and model reservoirs in order to maximize oil recovery. The interactive capability of VR technology allows geologists to incorporate qualitative knowledge into reservoir models and facilitates the integration of cores, logs, 3-D seismic, and production/tracer data into a comprehensive reservoir description.

Interacting With 3-D Models

In the world of computers, the underlying concept of virtual reality is that, given today's technological advances in software and hardware, computer users may easily interact with 3-D computer models. Conventional workstation configurations typically include a CRT (the output device), a mouse and keyboard (input devices), and computer hardware. Virtual reality technology replaces those input/output devices with more advanced hardware. With VR, binocular displays such as head-mounted display (HMD) devices replace monocular CRTs, and position and orientation trackers such as data gloves replace the keyboard and mouse.

Two approaches exist for implementing VR technology: the immersive environment, provided by expensive trackers and HMD devices, or the less-costly and more practical desktop VR system.

Immersive VR technology is called such because the user is immersed in a virtual world, and a simple turn of the head results in a new view of the virtual world. This new view may result from the user being surrounded by arrays of high-resolution display monitors (the CAVE experience), or by being outfitted with an HMD device, which places small display devices in front of the user's eyes. Immersive VR technology may give users the feel of being immersed in, or being part of, a computer-generated world. For certain applications such as battlefield simulations, the immersive experience is highly desirable.

In terms of cost and ergonomics, the disadvantages of immersive VR technology are considerable. The cost of military-grade HMD devices are expensive (close to $100,000) and potentially hazardous. Clinical studies on military personnel have shown that currently available HMD devices result in impaired vision and limbic system dysfunction even after short periods of use.

Discomfort and cost aside, immersive VR systems are of questionable practicality. "Suiting up," that is, strapping on a data glove and donning an HMD device, takes time and interferes with working in a normal work environment in which phones ring, fire alarms go off, and meetings are called on short notice. Moreover, reservoir engineers need to be able to work with simulators for long periods of time– far longer than a user could bear the discomfort and inconvenience of wearing an HMD device and a data glove.

VR On The Desktop

The prototype desktop system developed at Lawrence Berkeley Lab combines reservoir simulation with 3-D visualization and VR technology. The system consists of:

- A high-performance, desktop graphics workstation;
- A stereo CRT;
- Three-dimensional scientific visualization software;
- A VR input device; and

- A reservoir simulation program.

The visualization software consists of a collection of separate software modules that pass input parameters to the reservoir simulator, get the output from the simulator, and use different visualization techniques to display and view the simulation results. Visual programming through the use of a point-and-click interface is used to link the modules together into a visualization program.

Most important is the fact that the visualization environment is extensible. That is, the reservoir simulator has been incorporated into the visualization environment as just another module. As a result, simulation results can be visualized as soon as they have been calculated, which represents a tremendous advantage over visualizing the results as a post-processing step because detecting poorly-formulated field development strategies or input errors can occur early in the simulation.

Another key feature of the visualization software is that it is possible to run the simulation program on a platform different from the one on which the visualization software is running. For users, this means being able to run the simulation program on a super computer or multiprocessor machine, and then have the simulation results–at each time step in the calculation–transmitted back to the visualization environment for display.

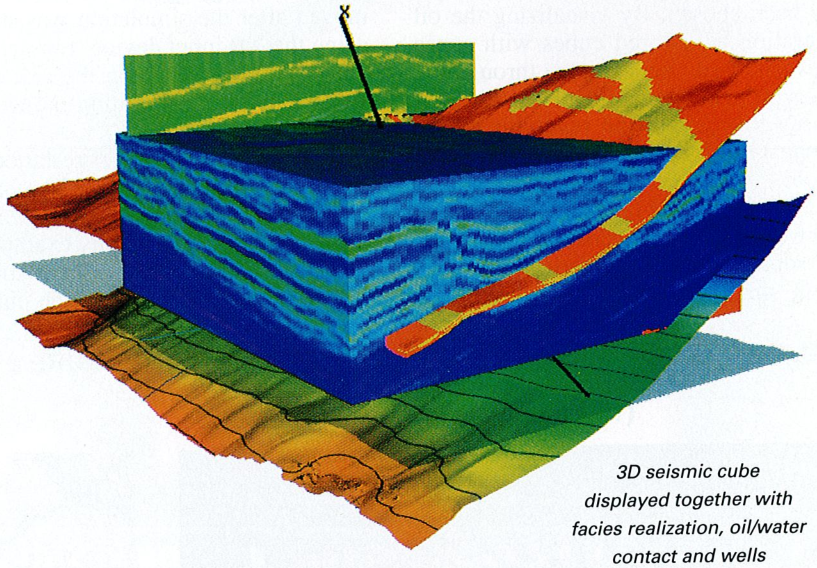
The VR input device that is being used with the system is a relatively low-cost device (on the order of $1,000) that users operate by touching (rotating, pushing or pulling) rather than actually wearing. The result is that users suffer from no additional fatigue when working with the device.

The VR input device is used in two ways. First, it is used to "navigate" through the reservoir. Using the input device, users may change the perspective from which they view simulation results. In a sense, the VR input device functions as a camera. As the user manipulates the VR input device, the view of the simulation results changes. The user can translate or rotate the view of the reservoir in order to see simulation results from a particular vantage point, or he can zoom in on a selected region of the reservoir for a close-up view.

Second, and more importantly for oil field applications, the VR input device may be used to place or reposition wells. The user indicates which well is to be moved, and then uses the VR input device to reposition the well within the numerical grid on which the simulation results are being calculated. The practical advantage of this approach for reservoir engineers is that wells may be quickly and easily moved or added to a simulation run. The need to count grid blocks in order to determine the coordinates of the new well location is eliminated, and the new well coordinates are passed to the simulation program without requiring users to edit input files.

VR-Simulated Waterflood

The following example is an application of the prototype visualization/VR system to simulating waterflooding in a heterogeneous reservoir. The geometry under consideration is a five-spot pattern in the presence of spatially-correlated, but heterogeneous permeabilities generated using a geostatistical method. The reservoir simulation program incorporated in the prototype system is a multi-compo-



nent, multi-phase compositional simulator developed at the University of Texas, and widely used in the oil and gas industry. The parameters for the simulation are:

- The injection rate for the central well is 10 percent pore volumes a year;
- Pattern balance is maintained by setting the production rate for each well at 25 percent of the injection rate;
- Each well is perforated along its entire length; and
- The reservoir has a uniform porosity of 20 percent and an initial oil saturation of 70 percent.

Figure 1 shows the saturation distribution at an early time in the simulation. The cubes represent the value of the oil saturation at the grid points in the numerical grid. Rather than showing the oil saturation as a solid volume, which could then be sliced to get a two-dimensional cross-section, a different visualization technique has been chosen. By visualizing the oil saturation as colored cubes with space between them, users can see through the reservoir and get an idea of what is happening throughout the reservoir rather than just in a 2-D cross-section of the reservoir.

Also shown in Figure 1 are the injection well, production wells, and a wireline grid representing the numerical grid used by the simulator. The blue surface in the center of the reservoir is an isosurface of the waterflood.

Figure 2 shows a close-up view of the central injection well at an early simulation time. The waterflood is shown as a blue, translucent isosurface. The preferential water movement in high-permeability channels is apparent. This view of the waterflood was obtained by using the VR input device to navigate into the center of the reservoir.

There are two important features of Figure 3 to note. The first is that the oil saturation has been contoured, with the reddish surface representing the location of an isosurface of oil saturation at a value near the initial value of 70 percent. Second, there is a finger of oil located just left of the center of the image. This finger of oil persists in time if the simulation is allowed to continue to run. The production well, highlighted in yellow, was moved after the simulation was stopped using the VR input device from its original position centered on the side of the wireline grid to the position shown in the figure.

When the simulation is restarted with the production well in the off-center location, the finger of oil disappears, as shown in Figure 4. In this example, by being able to visualize the simulation results early on, the user had the opportunity to stop the simulation, reposition one of the producing wells, and then restart the simulation. All of these steps were taken within the visualization environment.

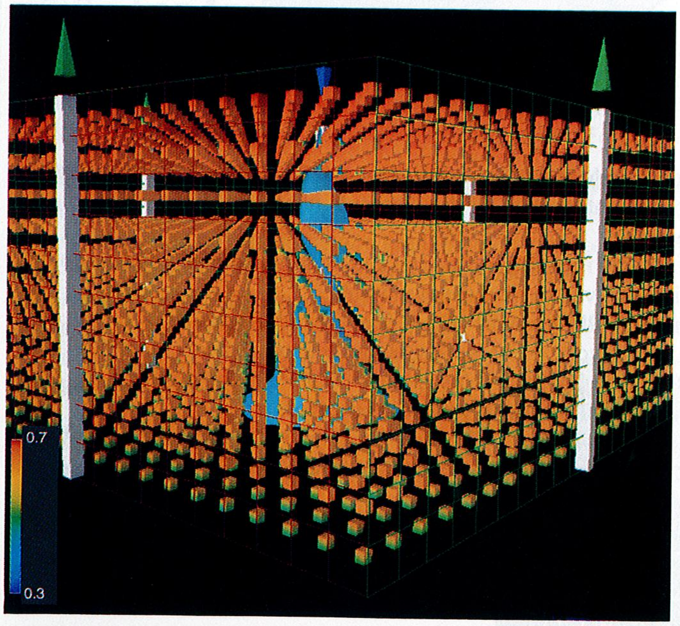
Future Uses

Virtual reality technology facilitates specifying 3-D input parameters, such as well placement. Although not yet implemented, the VR input device could also be used to indicate where a well should be perforated. For example, the user could position a 3-D cursor on a well and, by moving the cursor along the well, indicate the location of the perforated zone or zones. Similarly, grid blocks representing regions of high permeability, such as fracture zones, could be selected using the VR input device and the values of permeability input using a graphical user interface.

Other uses for the VR input device have also been developed, and could be implemented in reservoir simulation programs. For example, applied as a 3-D cursor, the VR input device can place a "probe" within the numerical grid. Numeric values of important parameters are then displayed in a window so that the user has a continuous readout of parameters values as the simulation runs. The location of the probe also can be changed between time steps or other probes added to

FIGURE 1

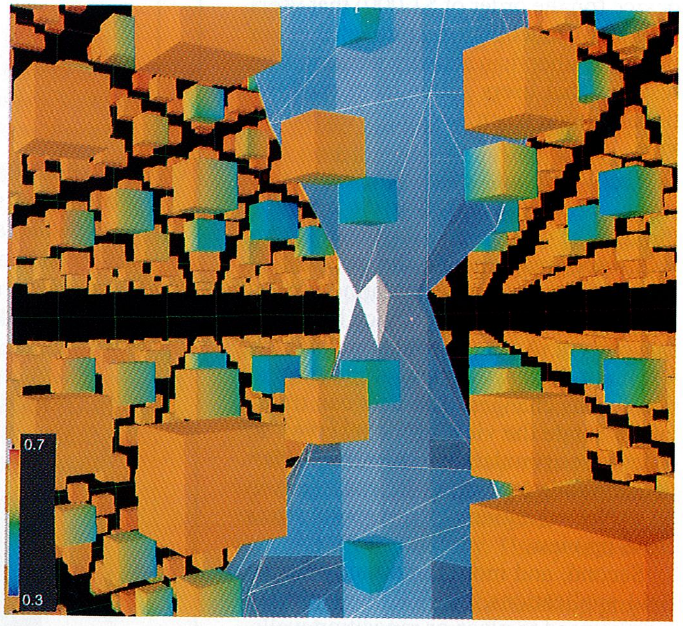
Off-Center View
(Time Step 26.44)



LEFT: The off-center view of the reservoir shows the oil saturation, represented by color cubes, and the waterflood, shown as a blue isosurface, with an isoconcentration equal to 60 percent in the center of the reservoir. The blue post symbol indicates the location of the injection well, while the green post symbolizes producing wells.

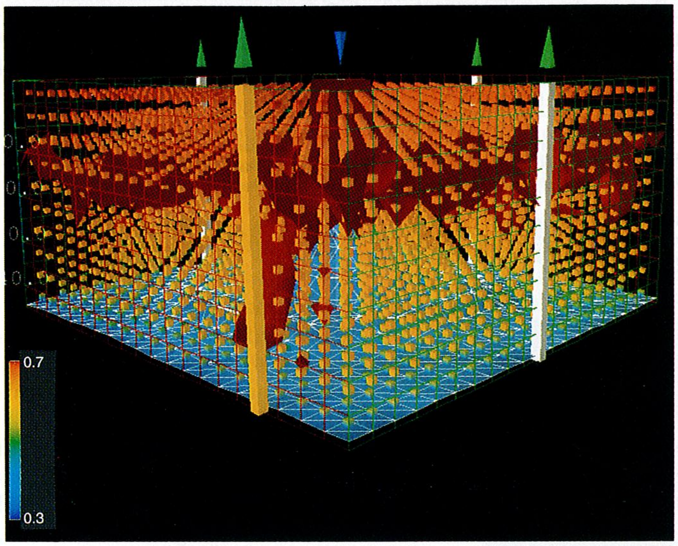
FIGURE 2

Close-Up View
(Time Step 26.44)



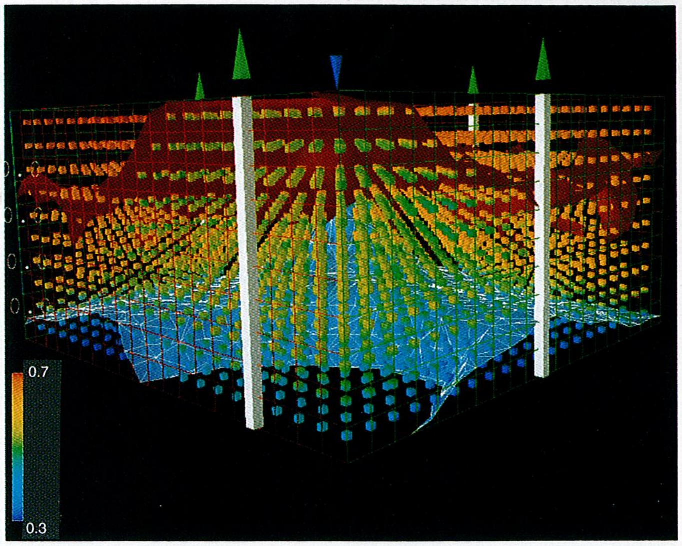
Right: A close-up view of the region of the reservoir near the injection well depicts the waterflood as a blue isosurface with an isoconcentration equal to 60 percent. The asymmetry in the waterflood is a result of heterogeneities in permeability.

FIGURE 3


Time Step 75.44

LEFT: The isosurface of high oil saturation (69 percent) is shown by a dark red horizontal surface and a vertical finger in Figure 3. The producing well highlighted in yellow was repositioned after the simulation was stopped at a simulation time of 75 days.

FIGURE 4


Time Step 75.65

RIGHT: The effect of repositioning the production well on the region of high oil saturation is displayed here The simulation is shown at a time comparable to that of Figure 3. The prominent oil finger, evident in Figure 3, has vanished.

the grid.

The VR input device also can be used to indicate one or more locations within the numerical grid at which to release imaginary particles. Tracking the particles, which travel along stream lines, shows the fast paths for movement of a tracer or solute.

As a final example, consider how all of these uses could be combined into a simulation in which a reservoir engineer is trying to optimize the injection of a gel to reduce the permeability of high-permeability zones prior to a water or chemical flood.

First, the user would use the VR input device to specify 3-D initial conditions such as high-permeability zones, the locations of injection and producing wells, and perforation zones. Once the simulation starts to run, the VR input device could be used to change the viewpoint from which the simulation results are being viewed, and to place probes at selected points within the reservoir in order to monitor parameter values. The user also could seed the reservoir with imaginary particles in order to track the movement of the gel being injected.

After the permeability has been satisfactorily reduced in the high-permeability zones, the user could start the simulation of the water or chemical flood. Again, the VR input device could be used to add production wells, place probes, and seed the grid with particles for tracking fluid movement. At some point, the user could stop the simulation and reformulate the input based on what he has learned to that point from the simulation.

The beauty of this approach is that specifying the well locations, the location of perforated zones in multiple wells, where to inject seed points, or where to place probes becomes easy when the VR input device is used because the user no longer needs to count grid blocks. The software interface passes the spatial information from the VR input device to the simulation program. As a result, more field development strategies can be tried in a shorter amount of time.

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VR Technology Benefits

The visualization/VR system provides reservoir engineers with the opportunity to interact with the simulation program in a number of ways. First, engineers are able to visualize different kinds of 3-D output parameters calculated by the simulator. A graphical user interface provides easy access to a rich assortment of visualization techniques, and a virtual reality input device provides a simple way to manipulate the visual display. An added benefit of the visualization is the ability to communicate simulation results to colleagues and managers by using 3-D visualizations.

Second, the VR input device provides a means to input 3-D parameters to the simulator without having to type in numbers or characters at a keyboard, and without having to exit the visualization environment. Examples of 3-D parameters accessible using a VR input device include well locations, well perforations, and regions of high or low permeability. Other uses of the VR input device, which have been developed but not implemented in the prototype system, include placing probes to get information about parameter values at given locations while the simulation is running, and injecting imaginary particles to track flow paths.

Taken together, these uses of the VR input device greatly enhance the working environment of reservoir engineers by providing easy-to-use tools that promote the understanding of reservoir dynamics through 3-D visualization, and that provide the means to quickly try out new development strategies. ❐

Numerical Simulation System Allows 3-D Modeling Of Basins

By Annette A. Walsh

DALLAS–A critical element in successfully exploring for oil and gas is gaining an understanding of the petroleum system, from source to trap. Basin modeling is a tool used by geoscientists to help quantify and understand the geological, geophysical and geochemical processes that affect oil and gas generation, expulsion and accumulation.

When assessing the prospectivity of a play, explorationists should ask questions such as:

- Is the source rock mature enough to have generated hydrocarbons?
- What is the timing of generation relative to trap formation?
- Could an economic quantity of hydrocarbons have been generated?
- Did the generated hydrocarbons migrate to the trap/play of interest?

Through the interative use of basin modeling, exploring multiple hypotheses about source rock richness, timing and removal amount during unconformities, and lithofacies variations, explorationists can develop a set of reasonable bounding cases upon which a decision can be made about whether to bid on a block or drill a well.

In 1985, Mobil began developing its first three-dimensional numerical basin modeling simulator. While many efforts