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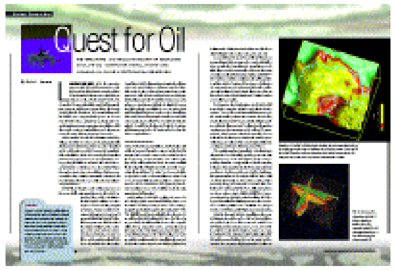


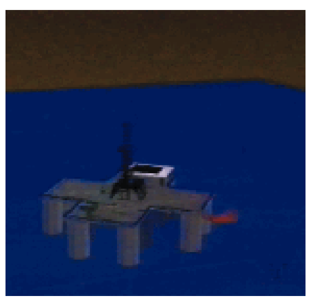
Quest for Oil

By Eric J. Lerner

Re-creating 170 million years of geologic evolution, computer simulations are homing in on new petroleum reserves.

In Brief:

Software tools that simulate realistically how oil is generated, and how it migrates through sediment and accumulates in oil fields, can reduce the costs of oil exploration and production. Pioneering simulation methods developed at IBM Research are able to model complex geological processes such as the dynamics of entire sedimentary basins. The tools are poised both to guide oil companies to new reserves and to help them pump more out of old ones.



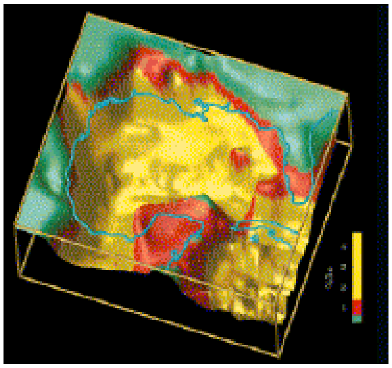
Looking for new oil is an expensive process. With a dwindling number of easily accessible oil fields to be found on land, oil production has come to rely heavily on offshore wells, which must be drilled in deeper and deeper water. Each such drilling operation costs $20 million to $50 million, and in the United States an average of 10 dry exploratory wells are drilled for every producing one. In view of numbers like these, petroleum geologists are increasingly turning to computer simulations that can cut the costs of exploration or help squeeze more oil out of each underground reservoir.

Ulisses Mello, a researcher at IBM's Thomas J. Watson Research Center, is developing tools that can assist on both fronts. Mello is on the vanguard of the relatively new field known as integrated basin simulation, which is becoming an important risk-assessment resource for oil exploration. Using geological data, scientists in this field can reconstruct the evolution of sedimentary basins through geologic time, simulating earth processes such as sedimentation, structural evolution, heat flow, fluid flow and the generation and migration of hydrocarbons.

Mello has developed novel solutions to some of the more challenging problems in this field, including large-scale simulation and the representation of evolving three-dimensional geological structures. Using innovative techniques and up to 200 nodes of a powerful IBM RS/6000® SP™ parallel computer, Mello has created the first simulation of the evolution of the oil-rich Gulf of Mexico. By modeling how sediment laden with organic material has been deposited since the Gulf's formation, Mello attempts to pinpoint locations where the combination of heat, pressure and time has "cooked" the sediment into petroleum. In the process, he has devised techniques for modeling the shifts that occur in the boundaries between moving masses -- techniques that can be applied in geological research generally and even in other fields such as materials science. Another set of simulations can model how oil is pumped out of a reservoir, and where pockets of oil have been inadvertently bypassed.

Overall, Mello aims to "help the decision-making process in the oil business and reduce the risks of exploration."

A "LIVING MODEL"



In his Gulf of Mexico simulation, Mello began with what is known about the region today and attempted to infer the course of its evolution since the beginning of its drift phase 170 million years ago, in the Late Jurassic Period, when the Yucatan block was pulled away from North America. "In geological simulations," he says, "we know what the end point is -- the sediments that now exist -- but we need to simulate how they got there, so as to determine where conditions were right for petroleum to mature. Once we know that, we can identify promising drilling sites."

Mello started with data -- gathered from seismic imaging and from actual drilling sites -- on the thickness and porosity of sediments of each geological epoch at many points throughout the Gulf. The data allowed him to calculate the rate of sedimentation at each location and time, and thereby to generate a simulation that shows sediment gradually being deposited in the correct amounts throughout the Gulf. Taking into account the present characteristics of the various layers of sediment and resulting rock, the simulation then models how the rock compresses underlying layers, how heat from the earth's interior is transferred and how water trapped in the sediment is squeezed out.

As one part of the model generates a history of temperatures and pressures, a second part takes these results and simulates the formation of oil. Each layer of sediment contains a known amount of organic material. It is this organic material -- the remains of marine organisms as well as organic matter washed out to sea by rivers -- that gives rise to petroleum. The transformation takes place when this matter is buried by the layers of sediment above and cooked by heat from the earth's interior over millions of years.

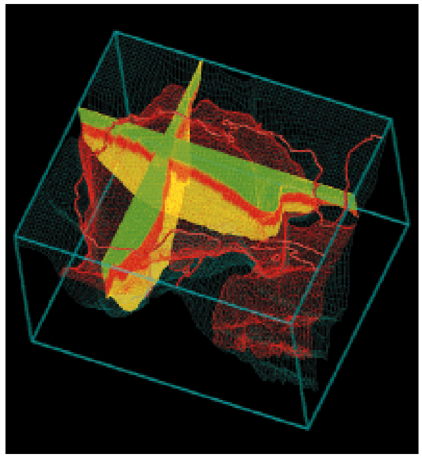
To determine the distribution of oil, Mello had to model the complex dynamics of heat flow in the region. "One of the most important processes in the Gulf," Mello points out,"occurs when heavy mud is laid down and becomes shale, trapping water within the layers of rock." As layers build up, they exert tremendous pressure on the water. The pressurized water in turn retards the upward flow of heat. This is because pores in the rock remain open, retaining more water, which effectively insulates the overlying rock from heat rising from below.

The resulting map of simulated oil maturity is, says Mello, "in reasonably good agreement" with what is known of oil distribution in the Gulf -- perhaps accurate enough "to allow an oil company to assume a most optimistic and a most pessimistic scenario in deciding whether to drill in a particular spot." But a model is only as reliable as the data on which it is built. And knowledge of the Gulf's present geology is incomplete -- most detailed in areas where many wells have been drilled, much less so where only seismic data is available. Consequently, Mello regards his Gulf simulation as a "living model" that links data to processes: as new seismic or drilling data becomes available, he plugs it into the simulation, gradually improving accuracy.

Already, though, Mello's simulations are contributing to knowledge of the Gulf of Mexico basin. They have helped researchers to understand how the basin produced its known reserves of 112 billion barrels of oil and 524 trillion cubic feet of gas, as well as to begin quantifying and locating large additional reserves that are believed to exist. And the work on the effects of highly pressurized water on oil maturation has earned Mello and a colleague -- Garry D. Karner, of Columbia University's Lamont-Doherty Earth Observatory -- the Wallace Pratt Memorial Award of the American Association of Petroleum Geologists.

SHIFTING BOUNDARIES

While developing the Gulf simulation, Mello has also been hard at work on a problem that has long plagued geological modeling: how to represent the formation of new faults and other moving boundaries over time. Simulating a process such as flight is relatively easy, because it involves variables that change smoothly and continuously within fixed boundaries (an airplane wing). But in geology, faulting causes sedimentary blocks to slip past each other, sedimentary layers deform and buckle; and salt or magma can intrude on the layers from below. For a model to reflect this changing topology adds formidable levels of complexity.



Applying geometric modeling tools developed by various researchers over the past 15 years, Mello and Watson researchers Mike Henderson and Paulo Cavalcanti have produced a novel three-dimensional geological model that is topologically flexible. The basic unit of the model is a geological block, defined by topological entities representing faults and surfaces between different sedimentary layers. This block, which incorporates both geometrical and geological characteristics, is depicted by a mesh of elements that deform in response to the modeled forces that act on the block.

To solve the problem of how to create new topological blocks when a fault develops, the model incorporates all the existing geological boundaries within a given region. At the start of the simulation, before present-day faults have formed, the boundaries are inactive. They remain in this latent state until geological forces are strong enough to initiate the fault. At that point, the model activates the fault boundary and the blocks on either side of the fault are free to move as separate entities.

To simulate these dynamic conditions, Mello had to develop a means of handling the often severe distortion in the numerical meshes as the rocks move. Mello defined discrete fault zones, narrow areas where the mesh distortion occurs. Meanwhile, the meshes in the blocks moving on each side of the fault are almost undisturbed. This mirrors the real world, where geological blocks can move past each other for hundreds of miles without major distortion.

Mello envisions uses for this flexible modeling technique far outside petroleum geology -- in simulating the dynamics of continental drift, for example. Modeling the motion of geological plates requires just the sort of shifting boundaries and changing alignments that Mello's simulation tools provide. Farther afield, many problems that involve large deformations -- such as studies of metal failure in bridge collapses or car collisions -- might benefit from such tools.

So far, however, Mello has restricted his use of the new technique to the pursuit of oil. He has, for example, successfully modeled the formation of salt domes -- a process that often entails just the kind of deformation the model can handle well -- and their effect on oil generation. Salt domes are formed when salt rock moves upward because of its buoyancy with respect to the surrounding rocks. Because they efficiently transport heat from the rock below to the rock above, salt domes exert a major effect on temperatures. Mello's work has shown, for example, that, contrary to prior assumptions, oil could still be forming beneath salt domes in areas previously considered overcooked, and may prove accessible to future drilling.

GETTING THE OIL OUT

Finding the oil is only half the battle. As petroleum is pumped out of a field, the natural gas (formed with the oil) that drives it toward the wells exerts less and less pressure. Inevitably, pockets of oil are left behind. If the pockets are large enough, new wells can be drilled to tap them, but it's crucial to learn where the oil is and how much is left. The standard way of determining this is to make seismic maps of a region and compare them with similar maps made when the fields were new. Since petroleum in the rock affects the speed of seismic signals traveling through them, changes in those speeds can in theory produce a map of changes in oil distribution, and thus point to missed pockets.

But, says Mello, there's a big problem with comparing seismic images. "The older images were made, in some cases, decades ago with different technology, often with a different amount of spacing between receiving stations. These differences can produce artifacts when the images are compared -- places where there appear to have been changes in the oil distribution but really there are just changes in how you got the data."

To provide a check on this data, Mello, together with scientists led by Roger

Anderson at Lamont-Doherty, is working to integrate a set of simulations that models how oil should flow, given the initial conditions and the wells drilled, and where it should be at present. First, a stochastic, or probability-based, simulation takes the old seismic imaging data and calculates the likely distribution of oil before well production. A second, fluid-flow simulation models how the oil would move as it was pumped. And a third simulation models how the oil motion affects the seismic image.

A component of this technology -- "time-lapse seismic" -- has already been pressed into service. Texaco has drilled a well in the Gulf of Mexico that pumps out 1,500 barrels of bypassed oil per day. The well has so far yielded 1.4 million barrels, worth some $24 million. Besides helping to zero in on bypassed oil, the technology lets the oil companies continuously monitor production.

Currently, Mello is working with oil and service companies, including Petrobras -- the national oil company of his native Brazil -- and Western Geophysical to develop still more sophisticated models. Mello believes that this is just the beginning. New advances taking place at IBM Research in simulation, visualization and data mining, he predicts, will achieve more and more realistic pictures of the subsurface and make hunting for oil a more exact and less costly proposition.

FYI: http://www.research.ibm.com/imaging/#geo

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More Information:

Simulating Nature

Computer simulations attempt to emulate nature by breaking up continuous space and time into discrete units. Space is defined as a mesh and time as individual time steps, like the frames in a motion picture. In certain simulations, including some created by Ulisses Mello, the mesh elements are not fixed in space; instead, they migrate as the material they represent shifts about. The simulation keeps track of a set of conditions at each mesh point - pressure, heat, chemical composition, rate of deposition of sediment and so on.

The physical and chemical laws governing the geological processes are approximated by a set of mathematical and computational rules that allow the computer to calculate the conditions at each mesh point at one time step, given the conditions at all mesh points from previously calculated time steps. The initial set of conditions must be provided by whoever is performing the simulation.

Generally, conditions at one mesh element depend mainly on conditions at nearby elements. As a result, a simulation's space domain can be split up into many subdomains to run on hundreds of processors in parallel.

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