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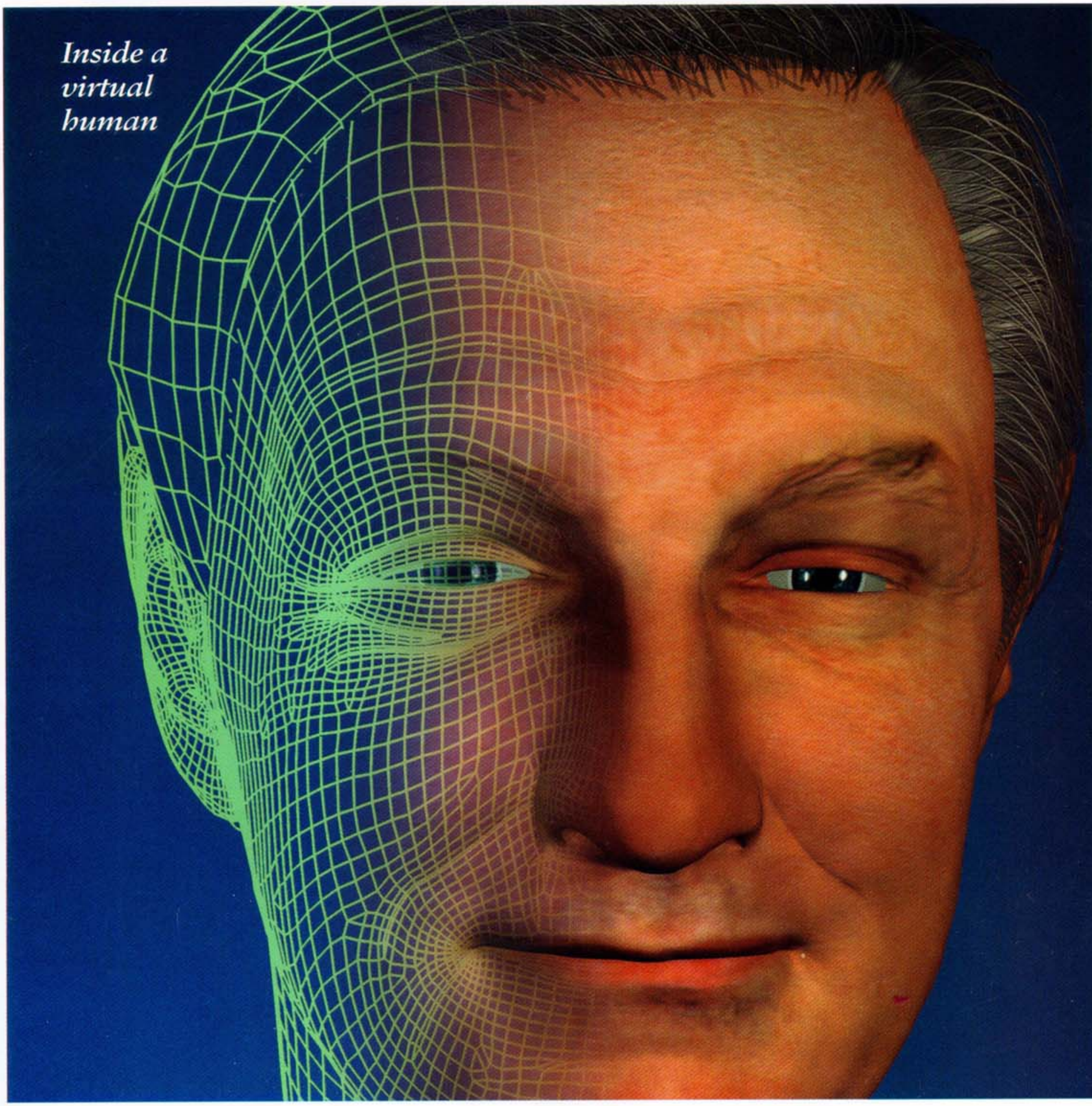
SPECIAL REPORT:

THE END OF CHEAP OIL

It's Coming Fast. But New Technologies Might Prevent an Energy Crisis



Oil Production in the 21st Century

Recent innovations in underground imaging, steerable drilling and deepwater oil production could recover more of what lies below

by Roger N. Anderson

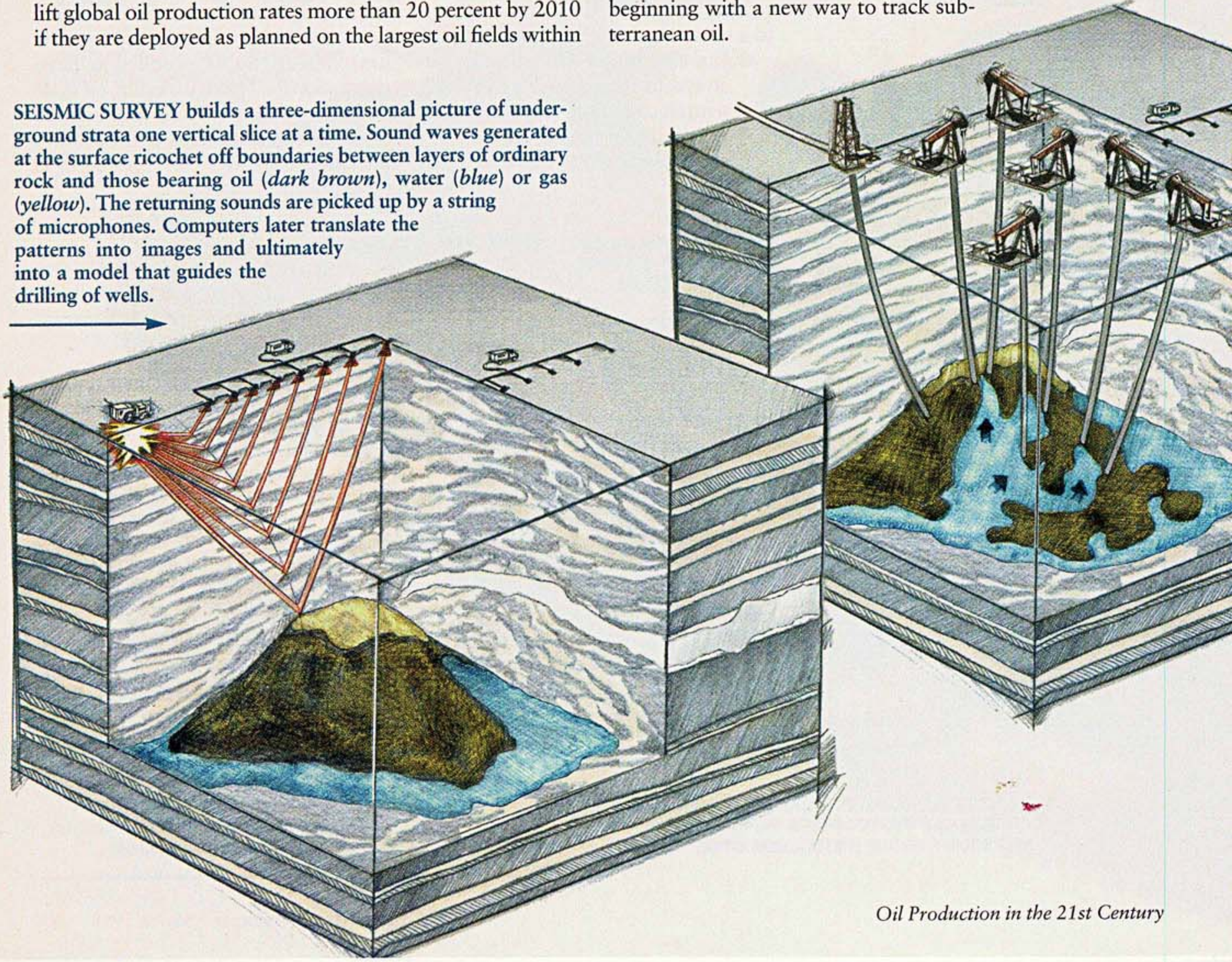
On the face of it, the outlook for conventional oil—the cheap, easily recovered crude that has furnished more than 95 percent of all oil to date—seems grim. In 2010, according to forecasts, the world's oil-thirsty economies will demand about 10 billion more barrels than the industry will be able to produce. A supply shortfall that large, equal to almost half of all the oil extracted in 1997, could lead to price shocks, economic recession and even wars.

Fortunately, four major technological advances are ready to fill much of the gap by accelerating the discovery of new oil reservoirs and by dramatically increasing the fraction of oil within existing fields that can be removed economically, a ratio known as the recovery factor. These technologies could lift global oil production rates more than 20 percent by 2010 if they are deployed as planned on the largest oil fields within three to five years. Such rapid adoption may seem ambitious for an industry that traditionally has taken 10 to 20 years to put new inventions to use. But in this case, change will be spurred by formidable economic forces.

For example, in the past two years, the French oil company Elf has discovered giant deposits off the coast of West Africa. In the same period, the company's stock doubled, as industry analysts forecasted that Elf's production would increase by 8 percent in 2001. If the other major oil producers follow suit, they should be able by 2010 to provide an extra five billion barrels of oil each year, closing perhaps half the gap between global supply and demand.

This article will cover the four advances in turn, beginning with a new way to track subterranean oil.

SEISMIC SURVEY builds a three-dimensional picture of underground strata one vertical slice at a time. Sound waves generated at the surface ricochet off boundaries between layers of ordinary rock and those bearing oil (*dark brown*), water (*blue*) or gas (*yellow*). The returning sounds are picked up by a string of microphones. Computers later translate the patterns into images and ultimately into a model that guides the drilling of wells.



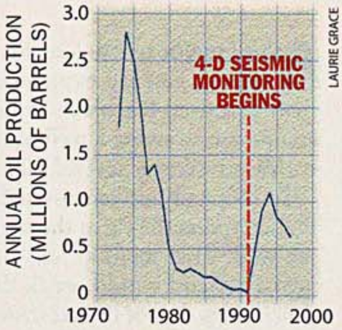
DANIELS & DANIELS

Tracking Oil in Four Dimensions

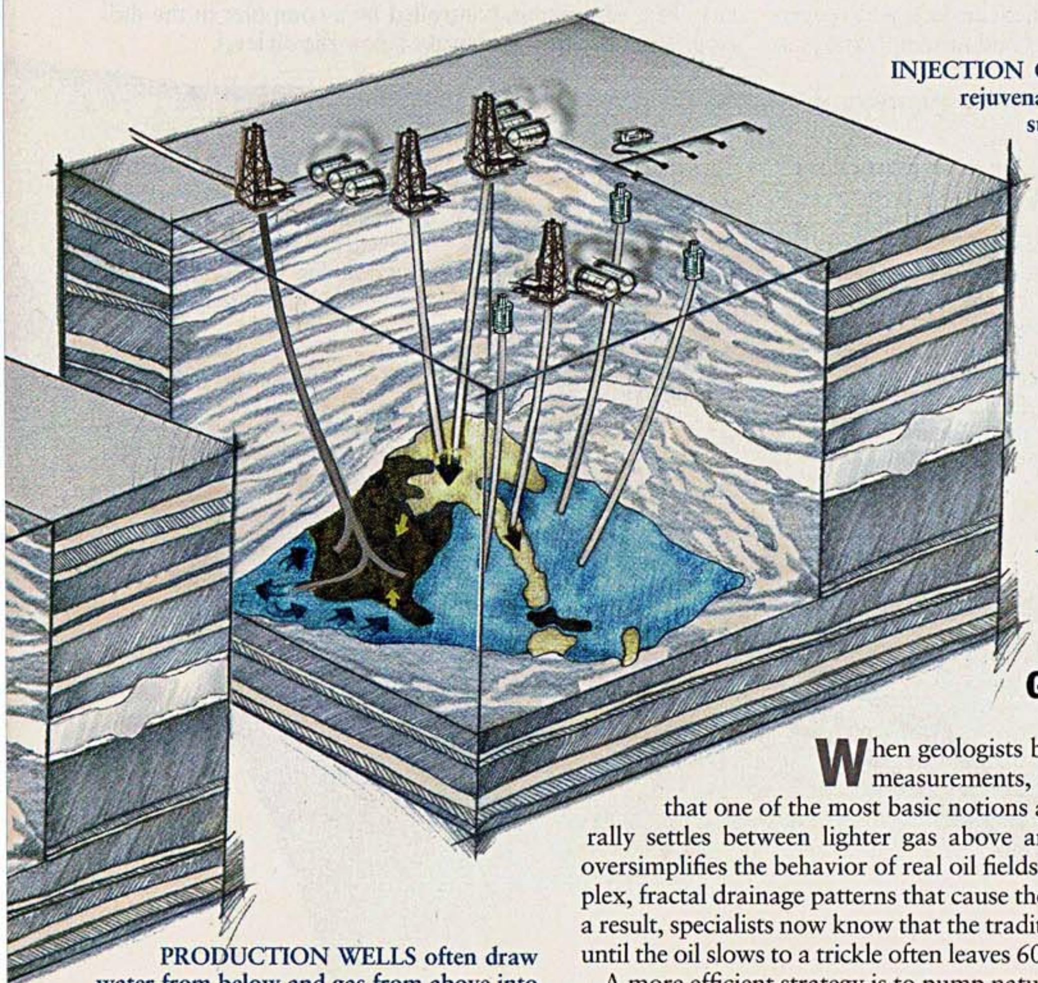
Finding oil became much more efficient after 1927, when geologists first successfully translated acoustic reflections into detailed cross sections of the earth's crust. Seismologists later learned how to piece together several such snapshots to create three-dimensional models of the oil locked inside layers of porous rock. Although this technique, known as 3-D seismic analysis, took more than a decade to become standard practice, it is now credited with increasing oil discovery and recovery rates by 20 percent.

In recent years, scientists in my laboratory at Columbia University and elsewhere have developed even more powerful techniques capable of tracking the movement of oil, gas and water as drilled wells drain the subterranean strata—a "4-D" scheme that includes the added dimension of time. This information can then be used to do a "what if" analysis on the oil field, designing ways to extract as much of the oil as quickly and cheaply as possible.

Compared with its predecessor, the 4-D approach seems to be catching on quickly: the number of oil fields benefiting from it has doubled in each of the past four years and now stands at about 60. Such monitoring can boost recovery factors by 10 to 15 percentage points. Unfortunately, the technique will work in only about half the world's major fields, those where relatively soft rock is suffused with oil and natural gas.



FLOW OF OIL from a reservoir in the largest field off the Louisiana shore resurged in 1992, shortly after operators began using 4-D seismic monitoring to locate hidden caches of oil.



INJECTION OF LIQUID CARBON DIOXIDE can rejuvenate dying oil fields. Pumped at high pressure from tanks into wells that have ceased producing oil, the carbon dioxide flows through the reservoir and, if all goes well, pushes the remaining oil down toward active wells. Steam and natural gas are sometimes also used for this purpose. Alternatively, water can be injected below a pocket of bypassed crude in order to shepherd the oil into a well. In the future, "smart" wells currently under development will be able to retrieve oil simultaneously from some branches of the well while using other branches to pump water out of the oil stream and back into the formation from which it came.

PRODUCTION WELLS often draw water from below and gas from above into pore spaces once full of oil. This complex flow strands pockets of crude far from wells; traditional drilling techniques thus miss up to two thirds of the oil in a reservoir. But repeated seismic surveys can now be assembled into a 4-D model that not only tracks where oil, gas and water in the field are located but also predicts where they will go next. Advanced seismic monitoring works well on about half the world's oil fields, but it fails on oil buried in very hard rock or beneath beds of salt (*thick white layer*).

Gassing Things Up

When geologists began studying the new time-lapse measurements, they were surprised to discover that one of the most basic notions about oil movement—that it naturally settles between lighter gas above and heavier groundwater below—oversimplifies the behavior of real oil fields. In fact, most wells produce complex, fractal drainage patterns that cause the oil to mix with gas and water. As a result, specialists now know that the traditional technique of pumping a well until the oil slows to a trickle often leaves 60 percent or more of the oil behind.

A more efficient strategy is to pump natural gas, steam or liquid carbon dioxide into dead wells. The infusion then spreads downward through pores in the rock and, if one has planned carefully, pushes oil that otherwise would have been abandoned toward a neighboring well. Alternatively, water is often pumped below the oil to increase its pressure, helping it flow up to the surface.

Injections of steam and carbon dioxide have been shown to increase recovery factors by 10 to 15 percentage points. Unfortunately, they also raise the cost of oil production by 50 to 100 percent—and that added expense falls on top of a 10 to 25 percent surcharge for 4-D seismic monitoring. So unless carbon dioxide becomes much cheaper (perhaps because global-warming treaties restrict its release) these techniques will probably continue to serve only as a last resort.

Steering to Missed Oil

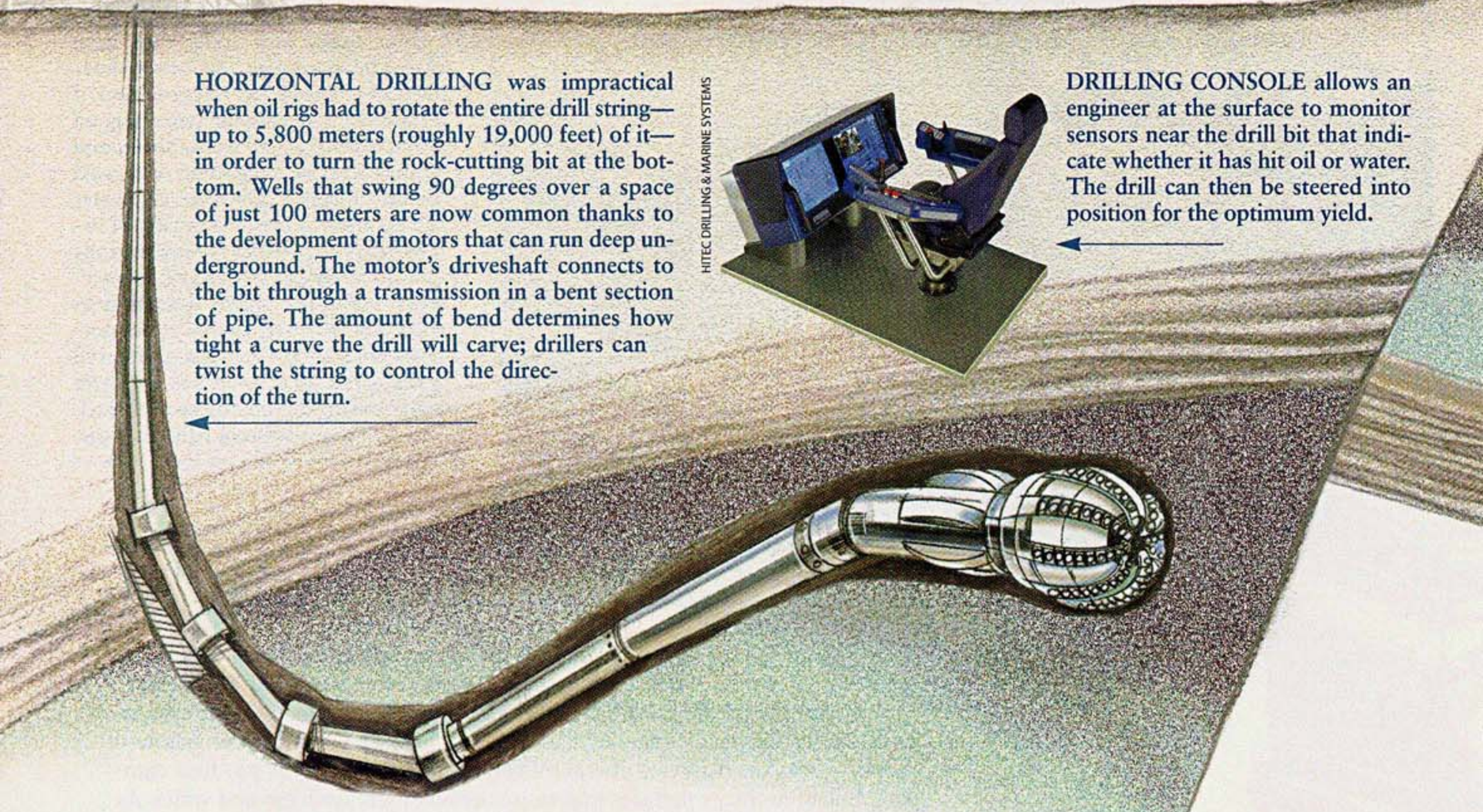
A third major technological advance, known as directional drilling, can tap bypassed deposits of oil at less expense than injection. Petroleum engineers can use a variety of new equipment to swing a well from vertical to entirely horizontal within a reservoir several kilometers underground.

Traditionally, drillers rotated the long steel pipe, or "string," that connects the rig at the surface to the bit at the bottom of the well. That method fails when the pipe must turn a corner—the bend would break the rotating string. So steerable drill strings do not rotate; instead a mud-driven motor inserted near the bit turns only the diamond-tipped teeth that do the digging. An elbow of pipe placed between the mud motor and the bit controls the direction of drilling.

Threading a hole through kilometers of rock into a typical oil zone 30 meters (about 100 feet) thick is precise work. Schlumberger, Halliburton and other international companies have developed sophisticated sensors that significantly improve the accuracy of drilling. These devices, which operate at depths of up to 6,000 meters and at temperatures as high as 200 degrees Celsius (400 degrees Fahrenheit), attach to the drill pipe just above or below the mud motor. Some measure the electrical resistance of the surrounding rock. Others send out neutrons and gamma rays; then they count the number that are scattered back by the rock and pore fluids. These measurements and the current position of the bit (calculated by an inertial guidance system) are sent back to the surface through pulses in the flow of the very mud used to turn the motor and lubricate the well bore. Engineers can adjust the path of the drill accordingly, thus snaking their way to the most oil-rich part of the formation.

Once the hole is completed, drillers typically erect production equipment on top of the wellhead. But several companies are now developing sensors that can detect the mix of oil, gas and water near its point of entry deep within the well. "Smart" wells with such equipment will be able to separate water out of the well stream so that it never goes to the surface. Instead a pump, controlled by a computer in the drill pipe, will inject the wastewater below the oil level.

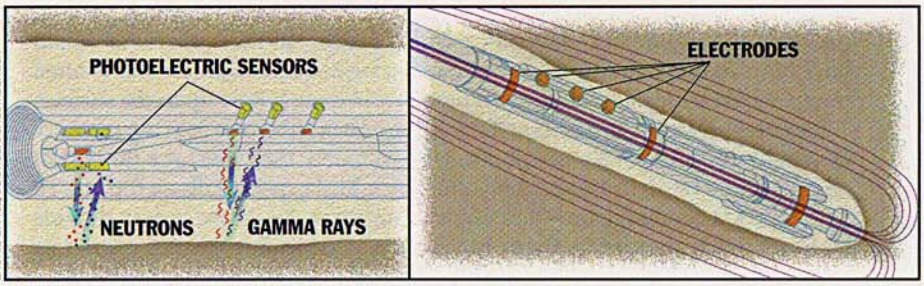
DANIELS & DANIELS (background illustration)



HORIZONTAL DRILLING was impractical when oil rigs had to rotate the entire drill string—up to 5,800 meters (roughly 19,000 feet) of it—in order to turn the rock-cutting bit at the bottom. Wells that swing 90 degrees over a space of just 100 meters are now common thanks to the development of motors that can run deep underground. The motor's driveshaft connects to the bit through a transmission in a bent section of pipe. The amount of bend determines how tight a curve the drill will carve; drillers can twist the string to control the direction of the turn.

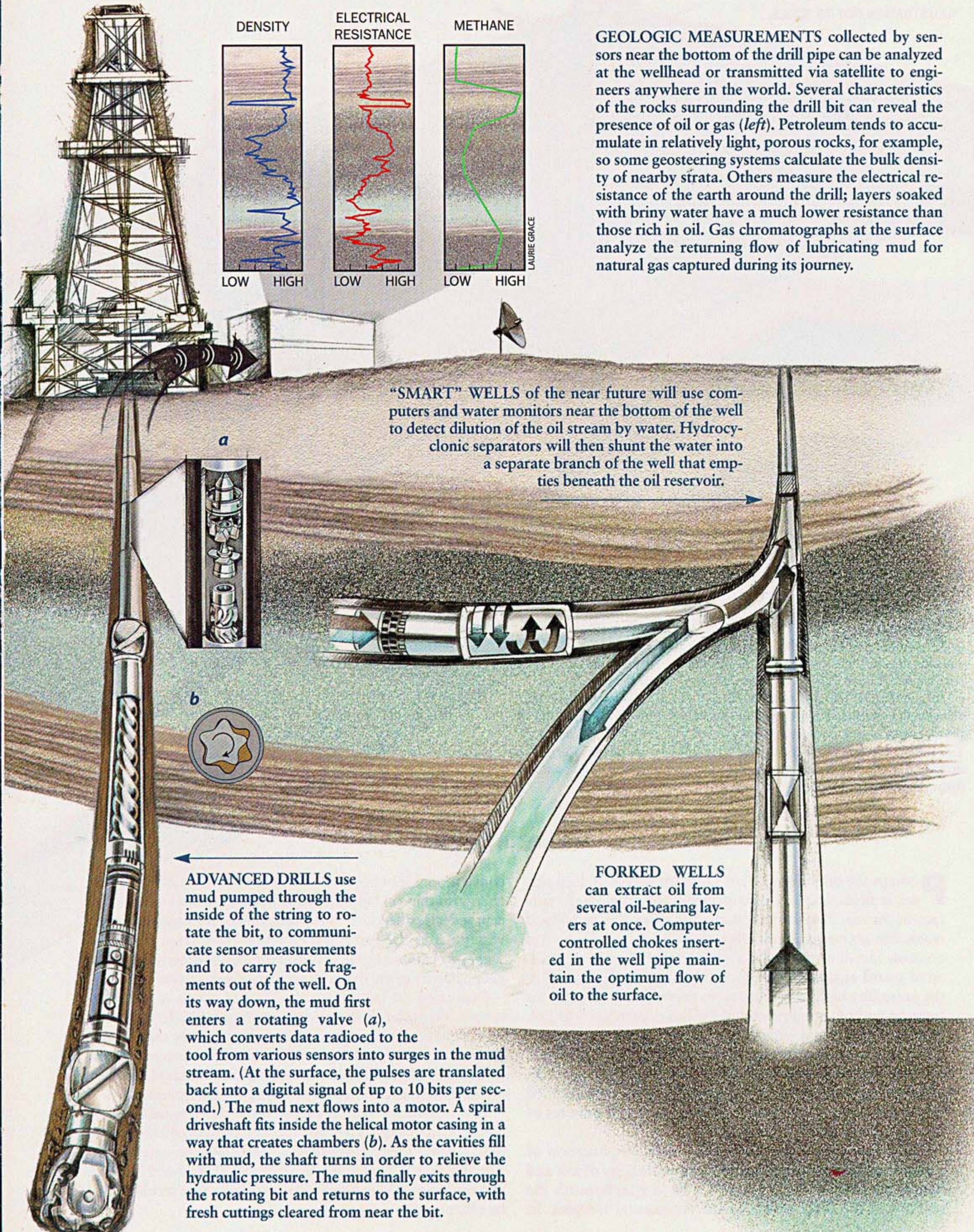
HITEC DRILLING & MARINE SYSTEMS

DRILLING CONSOLE allows an engineer at the surface to monitor sensors near the drill bit that indicate whether it has hit oil or water. The drill can then be steered into position for the optimum yield.



LAURIE GRACE; SOURCE: SCHLUMBERGER

SENSORS near the bit can detect oil, water and gas. One device measures the porosity of the surrounding rock by emitting neutrons, which scatter off hydrogen atoms. Another takes a density reading by shooting out gamma rays that interact with adjacent electrons. Oil and water also affect electrical resistance, measured from a current passed through the bit, the rock and nearby electrodes.

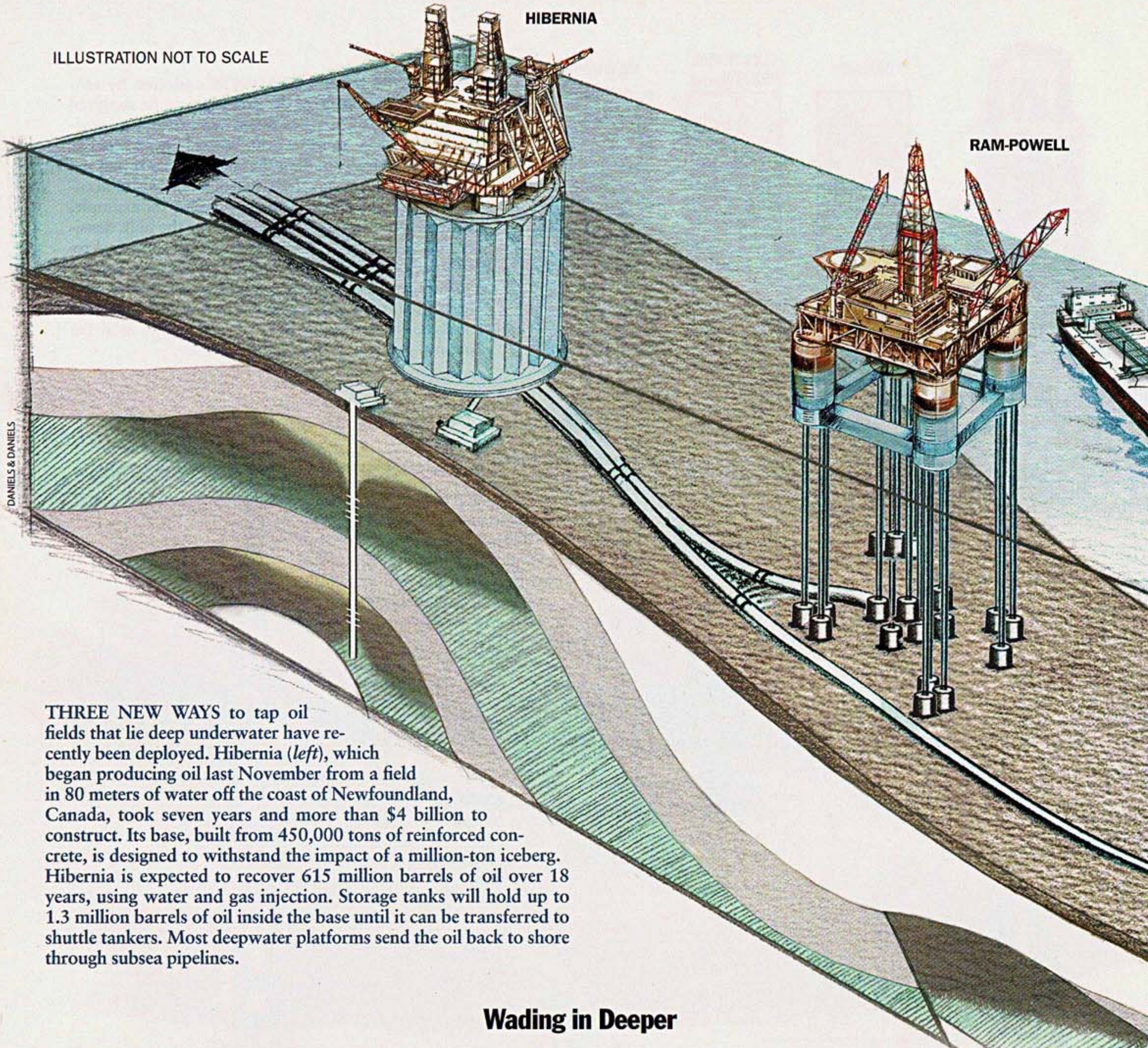


GEOLOGIC MEASUREMENTS collected by sensors near the bottom of the drill pipe can be analyzed at the wellhead or transmitted via satellite to engineers anywhere in the world. Several characteristics of the rocks surrounding the drill bit can reveal the presence of oil or gas (*left*). Petroleum tends to accumulate in relatively light, porous rocks, for example, so some geosteering systems calculate the bulk density of nearby strata. Others measure the electrical resistance of the earth around the drill; layers soaked with briny water have a much lower resistance than those rich in oil. Gas chromatographs at the surface analyze the returning flow of lubricating mud for natural gas captured during its journey.

"SMART" WELLS of the near future will use computers and water monitors near the bottom of the well to detect dilution of the oil stream by water. Hydrocyclonic separators will then shunt the water into a separate branch of the well that empties beneath the oil reservoir.

ADVANCED DRILLS use mud pumped through the inside of the string to rotate the bit, to communicate sensor measurements and to carry rock fragments out of the well. On its way down, the mud first enters a rotating valve (*a*), which converts data radioed to the tool from various sensors into surges in the mud stream. (At the surface, the pulses are translated back into a digital signal of up to 10 bits per second.) The mud next flows into a motor. A spiral driveshaft fits inside the helical motor casing in a way that creates chambers (*b*). As the cavities fill with mud, the shaft turns in order to relieve the hydraulic pressure. The mud finally exits through the rotating bit and returns to the surface, with fresh cuttings cleared from near the bit.

FORKED WELLS can extract oil from several oil-bearing layers at once. Computer-controlled chokes inserted in the well pipe maintain the optimum flow of oil to the surface.



THREE NEW WAYS to tap oil fields that lie deep underwater have recently been deployed. Hibernia (*left*), which began producing oil last November from a field in 80 meters of water off the coast of Newfoundland, Canada, took seven years and more than $4 billion to construct. Its base, built from 450,000 tons of reinforced concrete, is designed to withstand the impact of a million-ton iceberg. Hibernia is expected to recover 615 million barrels of oil over 18 years, using water and gas injection. Storage tanks will hold up to 1.3 million barrels of oil inside the base until it can be transferred to shuttle tankers. Most deepwater platforms send the oil back to shore through subsea pipelines.

Wading in Deeper

Perhaps the oil industry's last great frontier is in deep water, in fields that lie 1,000 meters or more below the surface of the sea. Petroleum at such depths used to be beyond reach, but no longer. Remotely controlled robot submarines can now install on the seafloor the complex equipment needed to guard against blowouts, to regulate the flow of oil at the prevailing high pressures and to prevent natural gas from freezing and plugging pipelines. Subsea complexes will link clusters of horizontal wells. The collected oil will then be funneled both to tankers directly above and to existing platforms in shallower waters through long underwater pipelines. In just the next three years, such seafloor facilities are scheduled for construction in the Gulf of Mexico and off the shores of Norway, Brazil and West Africa.

More than deep water alone hinders the exploitation of offshore oil and gas fields. Large horizontal sheets of salt and basalt (an igneous rock) sometimes lie just underneath the seafloor in the deep waters of the continental margins. In conventional seismic surveys they scatter nearly all the sound energy so that oil fields below are hidden from view. But recently declassified U.S. Navy technology for measuring tiny variations in the force and direction of gravity, combined with ever expanding supercomputer capabilities, now allows geophysicists to see under these blankets of salt or basalt.

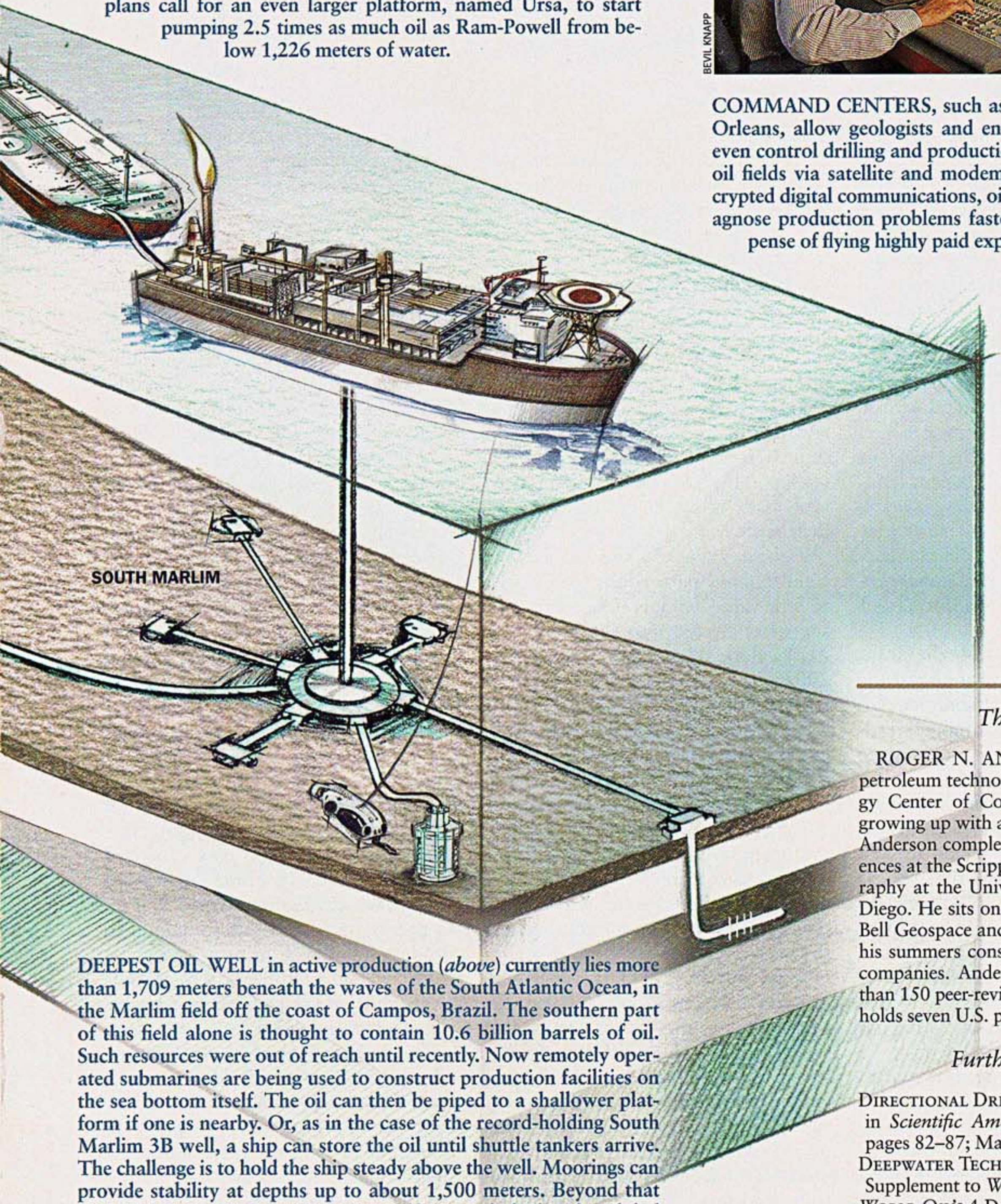
Extracting oil from beneath the deep ocean is still enormously expensive, but innovation and necessity have led to a new wave of exploration in that realm. Already the 10 largest oil companies working in deep water have discovered new fields that will add 5 percent to their combined oil reserves, an increase not yet reflected in global reserve estimates.

The technology for oil exploration and production will continue to march forward in the 21st century. Although it is unlikely that these techniques will entirely eliminate the impending shortfall in the supply of crude oil, they will buy critical time for making an orderly transition to a world fueled by other energy sources.

RAM-POWELL platform (*center*), built by Shell Oil, Amoco and Exxon, began production in the Gulf of Mexico last September. The 46-story platform is anchored to 270-ton piles driven into the seafloor 980 meters below. Twelve tendons, each 71 centimeters in diameter, provide a strong enough mooring to withstand 22-meter waves and hurricane winds up to 225 kilometers per hour. The $1-billion facility can sink wells up to six kilometers into the seabed in order to tap the 125 million barrels of recoverable oil estimated to lie in the field. A 30-centimeter pipeline will transport the oil to platforms in shallower water 40 kilometers away. Ram-Powell is the third such tension leg platform completed by Shell in three years. Next year, Shell's plans call for an even larger platform, named Ursa, to start pumping 2.5 times as much oil as Ram-Powell from below 1,226 meters of water.

BEVIL KNAPP

COMMAND CENTERS, such as the one above in New Orleans, allow geologists and engineers to monitor and even control drilling and production equipment in remote oil fields via satellite and modem connections. With encrypted digital communications, oil companies can now diagnose production problems faster and can save the expense of flying highly paid experts around the world.



DEEPEST OIL WELL in active production (*above*) currently lies more than 1,709 meters beneath the waves of the South Atlantic Ocean, in the Marlim field off the coast of Campos, Brazil. The southern part of this field alone is thought to contain 10.6 billion barrels of oil. Such resources were out of reach until recently. Now remotely operated submarines are being used to construct production facilities on the sea bottom itself. The oil can then be piped to a shallower platform if one is nearby. Or, as in the case of the record-holding South Marlim 3B well, a ship can store the oil until shuttle tankers arrive. The challenge is to hold the ship steady above the well. Moorings can provide stability at depths up to about 1,500 meters. Beyond that limit, ships may have to use automatic thrusters linked to the Global Positioning System and beacons on the seafloor to actively maintain their position. These techniques may allow the industry to exploit oil fields under more than 3,000 meters of water in the near future.

The Author

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Further Reading

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