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When the **energy source**
is **unconventional,**

so are we.

Unconventional Gas

Photograph taken in The Cave Without a Name, Boerne, Texas.

WHITE PAPER

Unconventional Gas

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Schlumberger is an oilfield services company supplying technology, project management, and information solutions to the E&P industry.

Executive summary

In an era of declining production and increasing demand, economically producing gas from unconventional sources is the next level of the fossil-fuel recovery challenge. The mammoth volume and long-term potential of coalbed methane (CBM), tight gas, and hydrate resources are driving technical progress. Attractive gas prices in North America and unprecedented interest in world markets promise to bring unconventional gas into the forefront of our energy future. Schlumberger is increasing investment to $150 million a year to help solve the technology challenges involved in gas recovery initiatives.

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Unconventional Gas

Once recognized by the industry as a hazard to be avoided at all costs (even a nuisance), natural gas is now recognized as the premier clean energy resource.

Unconventional gas will continue to grow in importance as a complement to conventional fossil fuel as world demand continues to increase. According to the U.S. Geological Survey, coal is the most abundant energy source in the world. It also plays host to plentiful natural gas resources. Resources of CBM, an environmentally more acceptable energy source than the coal itself, are reported as between 3,500 and 9,500 Tcf contained in subsurface coal seams around the world, with anywhere from 1,000 to 3,000 Tcf in North America alone. Worldwide, the amount of carbon bound in gas hydrates is conservatively estimated at twice the amount of carbon to be found in all known fossil fuels on Earth.

Once recognized by the industry as a hazard to be avoided at all costs (even a nuisance), natural gas is now recognized as the premier clean energy resource. While existing natural gas resource estimates give no cause for concern, extraction of unconventional gas resources—CBM, tight gas, and gas hydrates—is gaining increased industry attention, for both its ability to alleviate high-volume demand in markets like the United States and Europe, and also as a important longer-term source of energy.

In the United States, CBM plays are very much in the public's focus because of the strain on natural gas supplies. According to the Gas Technology Institute, the CBM resource potential represents about 12% of the total U.S. energy resource potential. As a result, Schlumberger is targeting research and development (R&D) resources to meet the technology needs of this rapidly growing marketplace.

The exploitation of CBM has been steadily progressing in the United States because of the proximity of resources and improved finding and transporting mechanisms. Medium and large independents are prime operators for plays in maturing basins and are capitalizing on the large U.S. resource base to support continued business growth. Annual production from 11 coal basins now exceeds 1.5 Tcf, 10% of the annual gas production.

Major coal resources exist in 69 countries; 35 of these countries have some CBM activity, and 17 have active CBM wells. CBM is gaining importance in Australia, China, Indonesia, and Europe.

- Alaska has the greatest potential coal resources—more than Canada and the Continental United States combined.

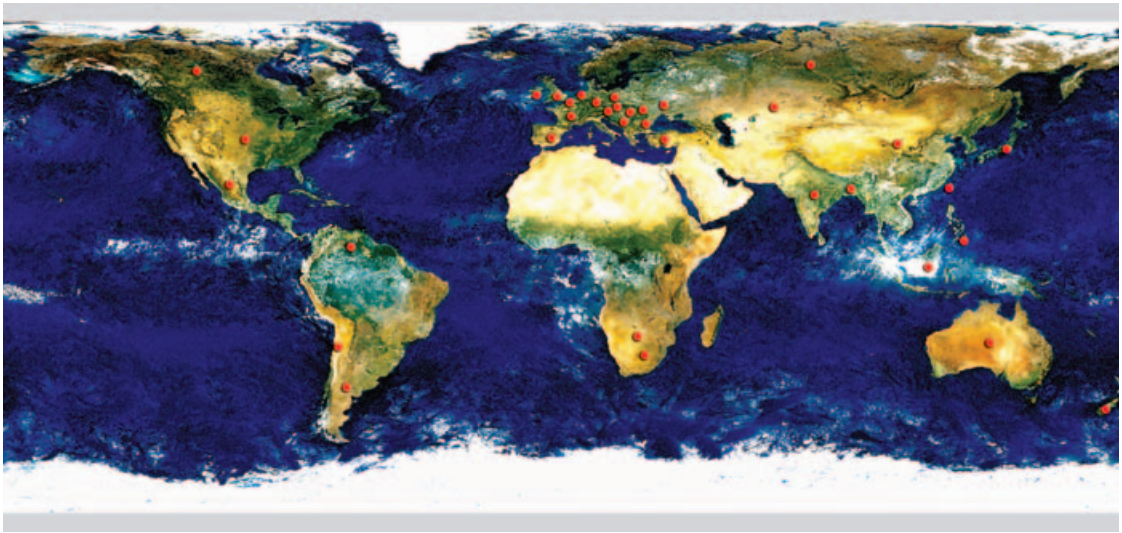

Fig. 1. Worldwide CBM activity. By 2001, 35 (red dots) of the 69 coal-bearing countries had investigated CBM development.

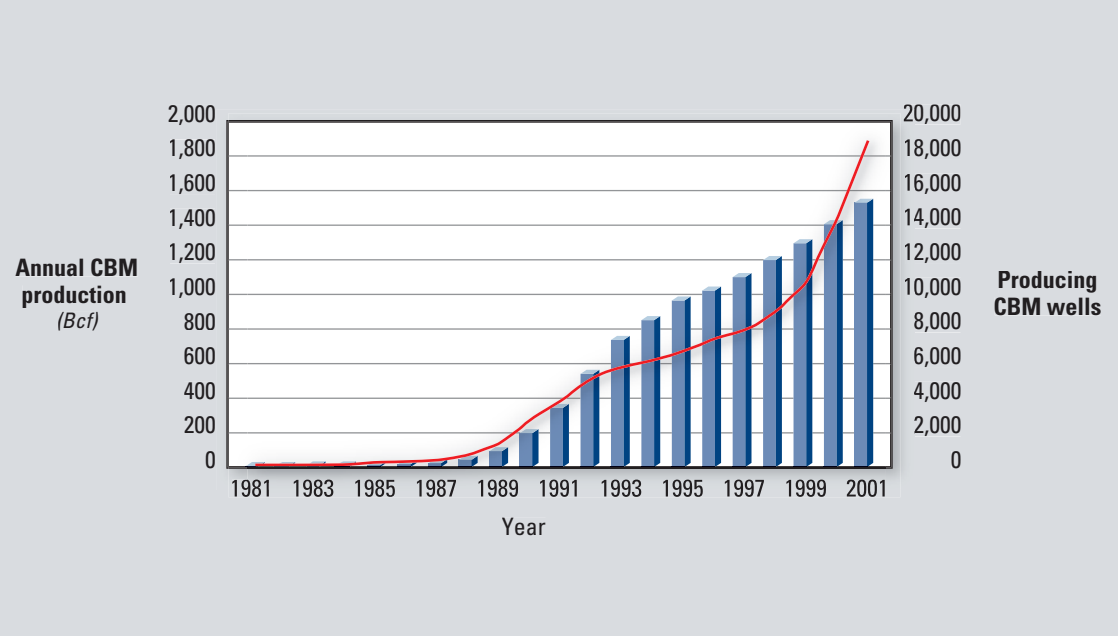

Fig. 2. U.S. CBM production (blue) and number of producing wells (red).

Schlumberger is targeting research and development resources to meet the technology needs of this rapidly growing marketplace.

- China's resource potential is greater than the United States and Australia combined.
- Canada's and Australia's vast resources are under development.

Better reservoir delineation in the arena of unconventional gas will require bold efforts in R&D to effectively address related environmental issues and implement new technology. Schlumberger has targeted R&D initiatives to meet unconventional gas technology needs and further its forward-thinking approach.

Progress is already being made in the development of these technologies, and new solutions are on the horizon that will

- assure reliable service with minimum costly downtime
- address needs of gas-abundant countries that do not have infrastructure for export
- reduce finding and development costs.

No shortage of reserves or needed technology

The three unconventional gas sources, while all are locked in some of the earth's most challenging environments, are very different in origin and characteristics.

- CBM sometimes occurs where conventional resources of oil and gas are not present. Recognized as a reservoir rock only recently, coal's large internal surface area stores six to seven times more gas than the equivalent rock volume of a conventional gas reservoir. CBM can be used as an energy source that is environmentally more acceptable than coal.
- Only a portion of stored gas can be economically recovered from coal. Recent advances in well design and production technology can significantly increase the proportion of methane that can be commercialized. Drilling activity to access gas from coalbeds has increased dramatically in the past decade; however, the percentage of methane that has been converted to actual recoverable reserves is only a fraction of the in-place resource.
- Tight gas exists in underground reservoirs with microdarcy-range permeability. It is known to exist in large quantity but does not flow easily toward existing wells for economic recovery. Estimates vary, but some studies suggest that total gas in place in the United States may exceed 15,000 Tcf, with annual production between 2 and 3 Tcf. There are approximately 40,000 producing tight gas sand

CBM can be used as an energy source that is environmentally more acceptable than coal.

wells; current average production per well is 170 Mcf per day. Often found onshore, the size, location, and quality of tight gas reservoirs varies considerably; only a small percentage are economically viable with existing technology.

- Gas hydrate, or methane hydrate, is composed of natural gas molecules trapped inside ice. In terms of carbon, gas hydrates seem twice as massive as all other fossil fuels—coal, gas, and oil—combined. The amount of methane trapped in marine sediments as a hydrate represents such an immense carbon reservoir that it must be considered a dominant factor in estimating unconventional energy resources.

Key existing and needed technologies

No single tool delineates the combination of lithologies and geometries of faults and fractures associated with commercial CBM, tight gas sand reservoirs, or hydrates. Seismic (especially multicomponent three-dimensional seismic) information, specialized wireline logs, cementing and stimulation methodology, drilling and measurement, conventional subsurface data, reservoir engineering data, and simulation are all necessary. Each domain depends on input from others, and the importance of validated, timely information to users in all areas of expertise, at any point in the process, is recognized across the industry. Schlumberger is pioneering data services and understands the need to deliver ever-earlier value from information management solutions by incorporating our clients' existing technology choices.

Fig. 3. (1) Raw data are acquired from subsurface exploration. (2) Transmission is accurate and secure, often in real time. (3) Data management systems store the data for efficient retrieval. (4) Professionals process the data and apply quality control procedures, creating information. (5) Information is interpreted and analyzed, creating knowledge. (6) Archived interpreted results provide an accessible, reliable bank of vital knowledge—a valuable asset.

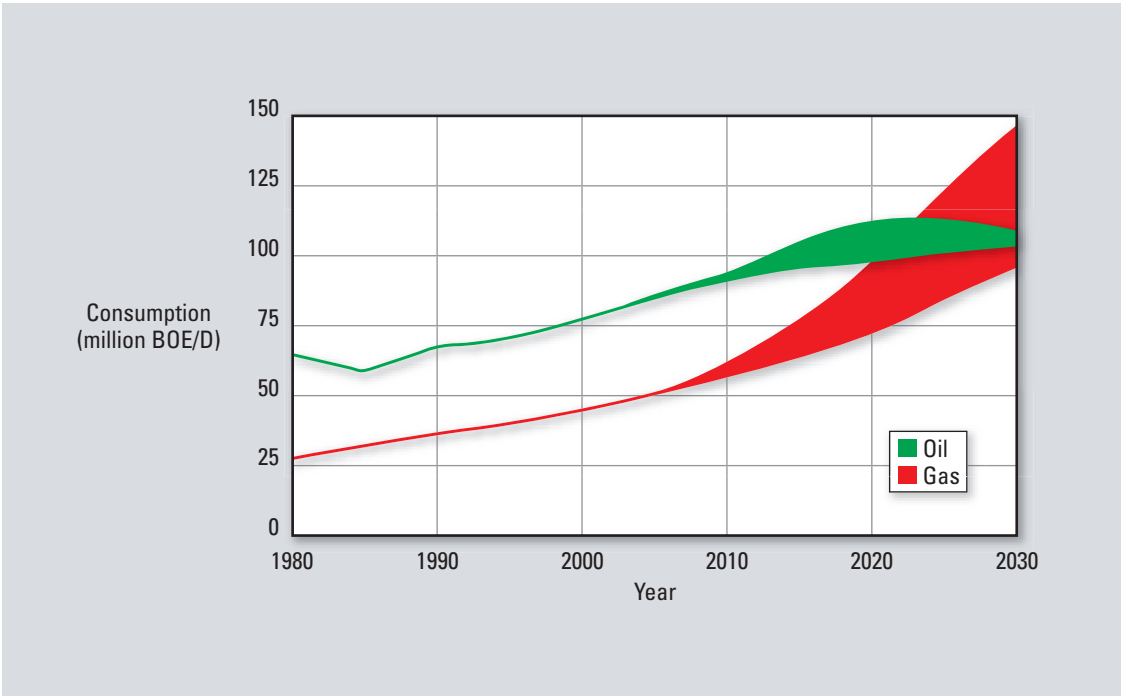

Fig. 4. Expected oil and natural gas consumption. Some experts believe gas consumption will exceed that of oil by about 2025, when put in consistent units of barrels of oil equivalent per day (BOE/D). Future estimates indicate prediction ranges. (Adapted from a presentation given at the 2003 World Gas Conference[1])

Coalbed methane—Experience and advanced technology are having a positive impact on coalbed exploitation.

- New logging measurements and sampling devices are enhancing evaluation of coal deposits.
- Light cements combined with the effective use of additives minimize damage to sensitive CBM reservoirs.
- Nondamaging fracture-stimulation fluids and innovative hydraulic fracture designs are being used to improve gas and water flow to the wellbore.
- Use of artificial lift techniques and intelligent software is promoting rapid and efficient dewatering of coals—a critical element of environmentally sensitive exploitation.

Schlumberger is actively involved in research to optimize stimulation in CBM fields. Improved cementation and stimulation practices will reduce completion cost per well and improve well success rate.

The presence of open natural fractures in the coals as well as complications with associated sandstone zones contribute to the breadth of reservoir characterization problems and the need for new technologies to solve them. It is estimated that if fracturing in coal seams could be brought up to parity with sandstone fracture stimulation, then the recoverable reserves from coal seams could be tripled over today's projections.

Tight gas—The industry goal is a fourfold increase in tight-gas production. Past tight gas sand production was fueled by both technology and gas price incentives. Future price incentives are thought to be limited; therefore, technology development must play the major role in future increases.

A concerted technology effort to better understand tight gas resource characteristics and develop solid engineering approaches is necessary for significant production increases from this low-permeability, widely dispersed resource. To meet the economic requirement of wellbore positioning close to the producing formation,

Tight gas exists in underground reservoirs with microdarcy-range permeability. It is known to exist in large quantity but does not flow easily toward existing wells for economic recovery.

[1]Watts, P.: "Building Bridges—Fulfilling the Potential for Gas in the 21st Century," speech delivered at the World Gas Conference, Tokyo, Japan, June 3, 2003, http://www.shell.com/static/media-en/downloads/speeches/PBWwgc03062003.pdf (accessed Jan. 6, 2004).

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tens of thousands of wells would need to be drilled to reach targeted production levels—a staggering economic and environmental challenge.

Key issues for exploiting tight gas sands revolve around stimulation and cementing. Advanced techniques like horizontal drilling and technologies that permit efficient fracturing of multiple zones per well allow gas to migrate a shorter distance to reach a location where it can enter a well and be produced. When these reservoirs extend vertically for several thousand feet, new fracturing techniques are required. To create better solutions adapted for gas, industry researchers will need to understand underlying flow physics in greater detail.

Gas hydrates—Naturally occurring hydrates can be found in many places, including the continental shelves near Japan, Europe, India, the Gulf of Mexico, the U.S. western seaboard, and Alaska. Rough estimates of hydrate resources exceed 60 million Tcf or almost 5,000 times the conventional gas resource. Under the ocean, hydrate estimates range from 30,000 to 49 million Tcf, and beneath permafrost, the hydrate resource estimates range from 5,000 to 12 million Tcf.

Current and anticipated development

Production of unconventional gas is growing because of a new understanding of reservoir conditions brought about by technology advancements and more efficient use of tools. Permeability, formation pressure, and reservoir fluid saturation are critical in identifying areas suitable for CBM development.

The first CBM resources exploited each contained one thick coal seam; now the potential exists to exploit multiple thin coal sections. The technology that is being used to exploit thin beds is completely different than that used to address one continuous coal seam.

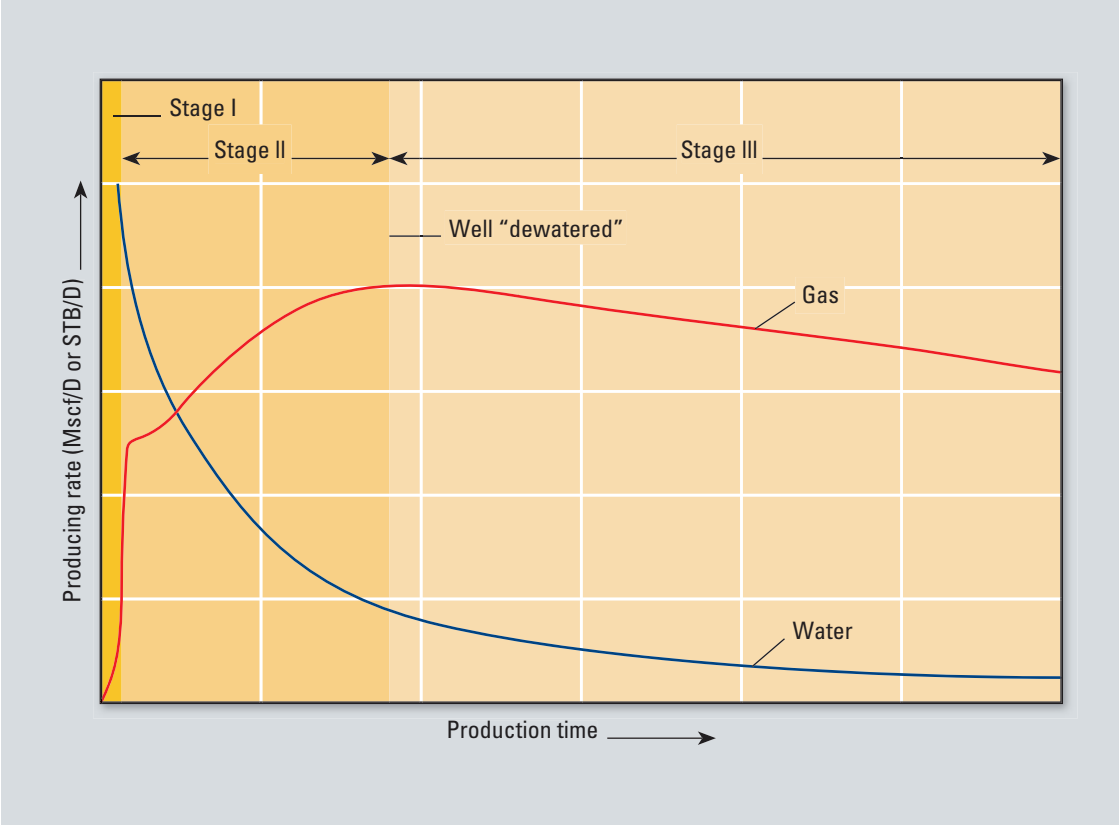

Fig. 5. Coalbed production characteristics. During Stage I, production is dominated by water. Gas production increases during Stage II, as water in the coal is produced and the relative permeability to gas increases. During Stage III, both water and gas production decline.

It is also now feasible to model and produce gas-bearing sands and coals at the same time. The productivity curve of gas from sands begins high, but plateaus and tapers off rapidly. At the point of sand production decline, the productivity curve of coal kicks in. This ability to achieve a balanced effect from the peaks and declines in sand and coal production is economically attractive.

Effective reservoir modeling is resulting in identification of sweet spots in CBM basins prior to drilling, and efforts continue to achieve cost-effective, successful gas completions. U.S. CBM production has been extended by recent completions to a depth of more than 8,400 ft.

Water-handling methods for CBM exploration now exist and continue to be developed, resulting in environmentally and socially appropriate water disposal. Regional expertise and local infrastructure serve to mitigate hazards that exist within the sensitive environments in which CBM and other unconventional gas sources are found.

Tight gas exploitation is benefiting from real-time, near-bit sensors that allow alteration of the drilling target as new information dictates. Refracturing and restimulation treatments using innovative fluids, improved proppants, and proppant flowback control are being used to access pay zones. Improved diagnostic techniques, such as short shut-in time well tests, are helping to determine the current stimulation condition of a well and verify refracturing potential. Slimhole drilling and completion technologies are aiding cost control.

As a member of a joint industry project, Schlumberger Technology Corporation will participate in development of necessary modeling, technology, and data to study gas hydrates in the deepwater Gulf of Mexico. The research could help reduce U.S. dependence on foreign sources of natural gas and provide a cheaper local supply.

Coming challenges

Water handling remains a big challenge in CBM exploitation. Pumps are intolerant to fines produced from the coal, and pump failure rates are high. Economically and environmentally feasible techniques to dispose of the water at surface or through reinjection into the formation still need to be addressed. An optimal dewatering strategy, coupled with nondamaging cementing and stimulation techniques, will help remove water from the coal's fracture permeability network, thereby increasing well productivity.

In the area of tight gas exploitation, the higher-quality tight gas sand and gas shale formations have already been developed. The impact of new technology and methodology that will lower the cost to drill, complete, and produce these formations will be great.

The pace of future development in all three areas of unconventional gas will depend on the economics of exploitation. Hence, technology will be a driver for better reservoir understanding and resulting improved economics.

Schlumberger will continue to develop high-risk, high-reward technology to harvest unconventional gas resources, stepping up impact on economic and environmental viability. Future efforts will concentrate on

- reducing operator risk and cost through the upfront provision of efficient, integrated services and field management
- providing technology, systems, and services that can operate more efficiently and consistently under environmentally strict conditions
- improving reservoir delineation through improved technology offerings (for example, drilling fewer wells with better results using a better reservoir model)
- finding appropriate water solutions (such as light water treatment).

It will continue to require the coordination and integration of input from all disciplines to succeed in the exploitation of unconventional gas. Schlumberger will continue to improve accepted practices and offer new approaches to increase production, reserves, and shareholder value for clients. The end result will be cleaner, more plentiful, and cheaper energy.

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Technology gains in CBM

CBM producers are witnessing higher production rates per well from improved stimulation as a result of better zonal isolation and reservoir understanding. Existing Schlumberger technologies that are making significant contributions in CBM extraction include the following:

- the wireline ECS* Elemental Capture Spectroscopy sonde to measure elemental concentrations such as ash content
- the DSI* Dipole Sonic Imager to calculate the orientation of earth stresses
- the FMI* Fullbore Formation Microimager for investigating tectonic fractures in very deep coal sources.

In the cementing category, developments have reversed former negative aspects of coal reservoir cementing with the LiteCRETE* CBM slurry system. Previously, establishing a good cement bond without damaging the coal and reducing production had proven difficult. The new lightweight and therefore less damaging LiteCRETE CBM slurry is mixed with fibers to facilitate sealing off coal cleat faces. This reduces damage to rock permeability, creates a good formation-to-cement bond, does not require additional cement, and offers the benefit of a bond that allows for better fracturing and stimulation.

The Schlumberger Wireline Perforating Platform (WPP) brings new efficiency to oriented wireline perforating. Perforation orientation is critical in optimizing perforation-to-fracture communication, especially for coalbed methane (CBM) fracture treatments.

The WPP can run guns in vertical and inclined wells, and its small (1.69-in.) outer diameter (OD) is compatible with through-tubing operations.

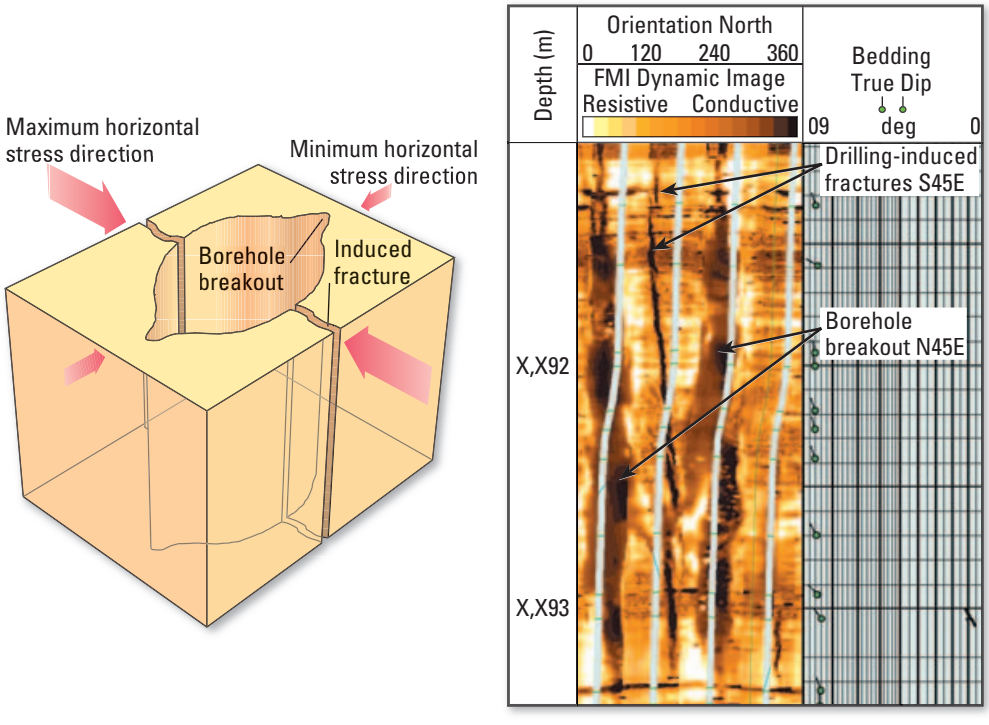

Fig. 6. In-situ stress determination from borehole images. During drilling operations, stress release around the borehole causes induced fractures and borehole breakout (left). These phenomena indicate the direction of in-situ stresses. The orientation of these features, interpreted from FMI data (right), is used in hydraulic fracture treatment and deviated well designs.

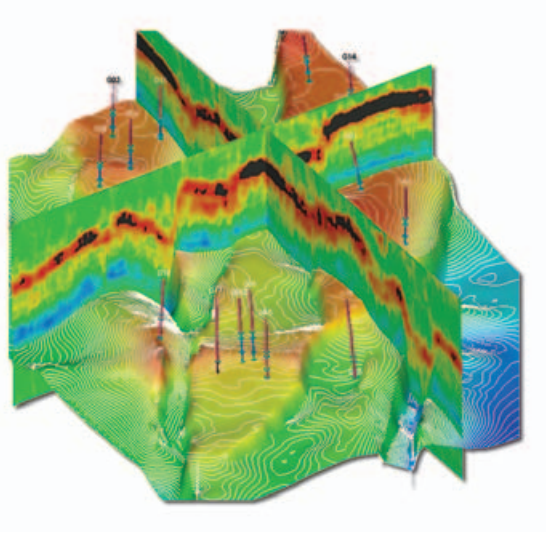

Fig. 7. ECLIPSE reservoir simulation software is a unique combination of geological modeling, simulation grid building, upscaling, and grid editing tools that can be launched and managed from the ECLIPSE Office* interface.*

Significant time is saved over previous techniques because the downhole motor system incorporated in the WPP can orient the guns to the preferred fracture plane (PFP) and shoot themin a single trip. The WPP uses the Secure* detonator system, so radio silence is not necessary and selective perforating can also be performed in one run. Integrated pressure and temperature sensors acquire the data necessary for IMPULSE* testing for the determination of reservoir pressure and permeability prior to fracture stimulation.

Because coal fracture systems must be connected to the wellbore through nondamaging stimulation methods, fracturing fluid systems and stimulation designs are increasing fracture efficiency and creating enhanced environmental compliance. New fracture-monitoring technology promises real-time images of hydraulic fracture creation. The StimMAP* hydraulic fracture stimulation diagnostics software allows real-time, onsite imaging of hydraulic fracture seismic events, resulting in improved job placement, enhanced well productivity, and a better understanding of fracture geometry for future field development decisions.

Schlumberger continually monitors artificial lift needs and technical developments to create innovative product solutions. DuraLift* progressing cavity pumps (PCP) provide the artificial lift required in many gas wells, but without previous gas-specific issues encountered by other artificial lift equipment. Comprising a drive mechanism and a downhole pump, Schlumberger PCPs are ideally suited to gas well dewatering, without suffering from gas-lock as with other pumps.

Identifying potential reservoir concerns before they turn into real production problems is an important industry challenge. Our Sensa* distributed temperature sensors generate accurate, real-time data, helping customers to optimize production on a continual basis.

When it is determined that drilling horizontally through a coal seam is preferable to fracturing and stimulation, the latest developments in drilling offer more efficient access.

Modeling CBM reservoir behavior is a challenging task needing expert attention and basin-specific answer products. Schlumberger offers this expertise through a third-party consultancy and the ECLIPSE reservoir simulation software. Through ECLIPSE Office integrated simulation manager and case builder software, reservoir simulation capabilities are expanded to allow nonexpert users to combine physics data with special templates for accurate reservoir simulation. In addition to incorporating isotherm data and handling uncertainties, the software has the capability to manage multiple gas types.

The ECLIPSE software offers multiple choices of robust numerical simulation techniques for accurate and fast solutions for all kinds of reservoirs and all degrees of complexity—structure, geology, fluids, and development scheme. This unparalleled flexibility leads to maximum productivity.

The pace of future development in all three areas of unconventional gas will depend on the economics of exploitation.

Technology is key.

New hydrocarbon sources are typically locked in the earth's most challenging environments. Yet, in an era of declining production and increasing demand, their long-term potential propels the demand for unconventional solutions.

Schlumberger Oilfield Services (OFS) brings you advanced tools and expertise to better understand the environment.

- Advanced simulation software
- Cementing technology
- Expert services
- Formation evaluation tools
- Imaging tools
- Information services
- Stimulation technology

Schlumberger leads the way.

To learn more about unconventional gas, visit www.slb.com/oilfield/uncongas.

OF_03_056
January 2004
Produced by Oilfield Marketing Communications, Houston.

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