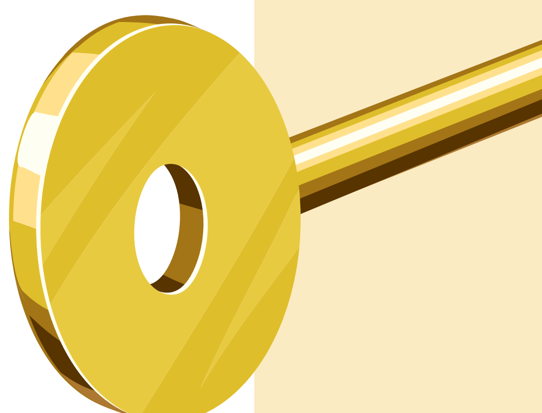
Unlocking tight gas

The world's potential reserves of unconventional natural gas are huge – but extracting them is far from easy. *Nina Morgan* learns how BP is already recovering tight gas from unconventional reservoirs, and how the company's technologists and engineers are building on that success



First the good news. Around the world there remain thousands of trillions of cubic feet of natural gas that could be produced to supplement the world's energy supplies. But there is a catch. These particular gas resources are very difficult to produce. The reason? The gas is 'unconventional'. It is held in tight reservoirs where the permeability of the reservoir rocks – that is, their capacity for transmitting fluids – is so low that the gas molecules cannot flow into production wells without help. Conventional gas reserves flow unassisted.

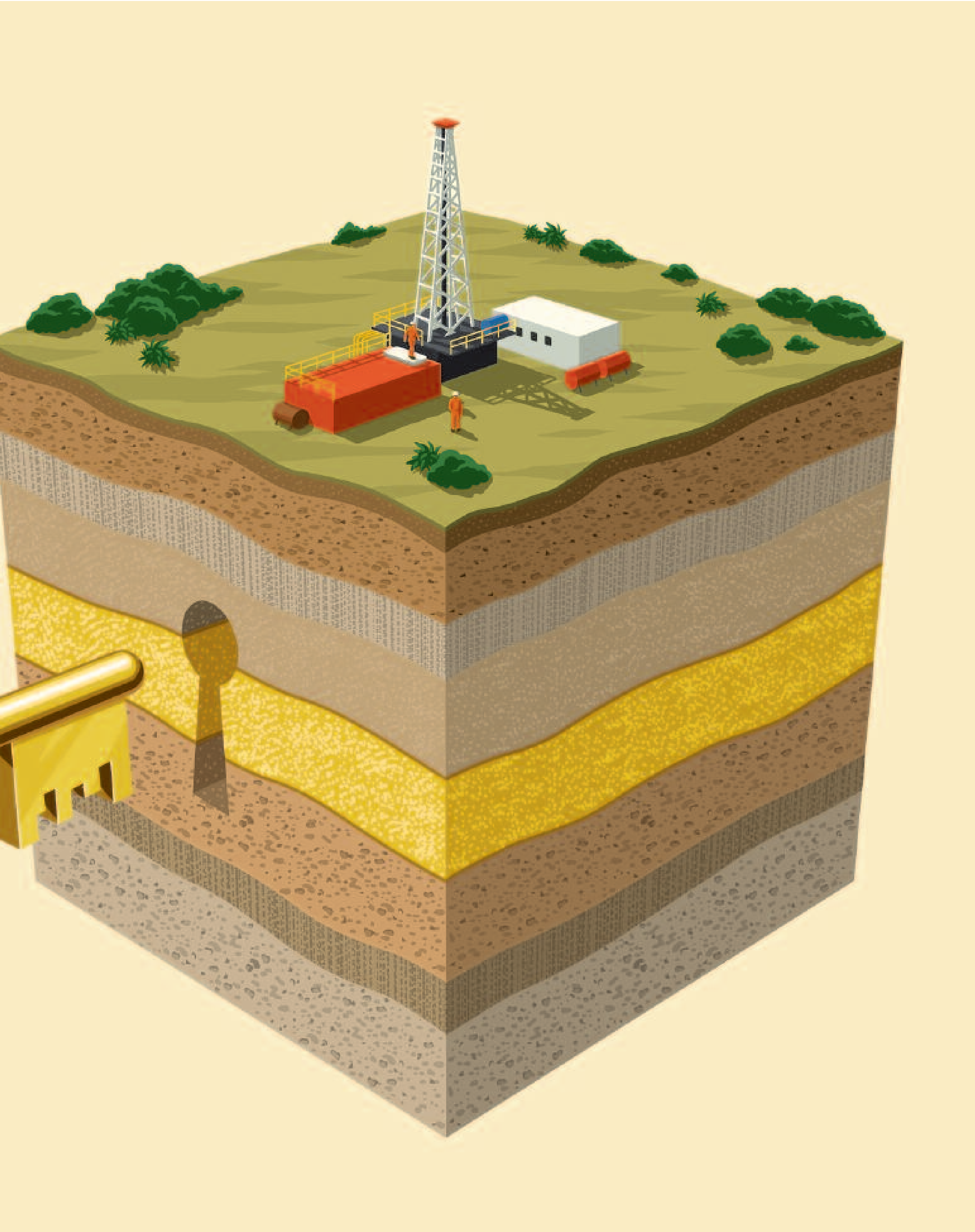
'Finding ways to drain tight gas fields is an important goal,' says Pat O'Bryan, technical director for wells in BP's North America Gas strategic performance unit, based in Houston. 'There are orders of magnitude more unconventional gas resources out there than there are conventional ones.'

BP has significant volumes of tight gas in its global portfolio. The company has already developed considerable expertise over many years in recovering tight gas, spearheaded by its North American Gas business – almost half of BP's current North American gas production of around 2.4 billion cubic feet per day is accounted for by tight gas. Now this know-how, accompanied by further technology developments, is being actively applied to BP's growing number of tight gas assets in the USA and elsewhere, for example in North Africa and the Middle East. In February this year BP began a six-year project in the huge Khazzan and Makarem gas fields in Oman to appraise conventional and deep tight gas reservoirs, bringing new technology to bear in optimising well locations to access and recover the gas.

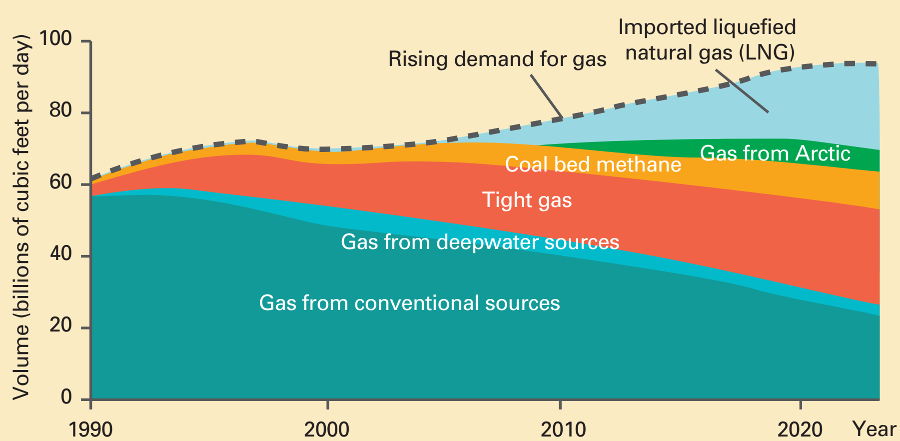
'In drilling and production terms, producing tight gas is a challenging operation,' adds O'Bryan. 'But BP is committed to achieving success across our tight gas portfolio. This is an exciting opportunity which offers potentially significant rewards.'

Upwardly mobile

Because gas is very mobile compared with crude oil, it is usually relatively easy to produce. Where the gas is held in conventional reservoirs, it naturally flows into the wells and up to the



NATURAL GAS IN NORTH AMERICA – SUPPLY AND DEMAND



Demand for natural gas in North America and sources of gas supply. Source: CRA International

surface with little effort required from production engineers. Tight gas reservoirs, however, are a different story.

The tight reservoir rocks tend to be much older – many were originally deposited during the Palaeozoic era more than 248 million years ago – and typically lack the thick layers of porous and permeable sands that characterise the reservoirs in younger Tertiary basins such as the North Sea and the Gulf of Mexico. Any porosity – spaces between the rock grains – and permeability they once had, has often been greatly reduced as a result of compaction, cementation, recrystallisation and chemical changes during their long and complex burial histories. In conventional reservoirs permeabilities typically range from 0.01 to 0.5 darcy – the darcy is the unit used to measure permeability – but in tight reservoirs permeabilities can be as low as fractions of a millidarcy, or even in the microdarcy range.

As a result many more wells are needed to drain a tight gas field because each well produces a relatively small amount of gas. In addition, the wells need to connect with as much reservoir as possible, so they often have very complex geometries. They may, for example, be drilled on a deviated path to bypass obstacles; or they can be horizontal; or multilateral, where several horizontal wells are drilled in different directions originating from a single vertical well. Some have 'fishbone' geometries, with a central 'spine' and up to 30 small boreholes drilled off at the sides.

In its operations in North America, BP uses a range of such drilling techniques to access tight gas. Now the North American group is creating a centre of expertise to share its know-how in producing tight gas throughout BP. The group is homing in on four main goals: finding the best well locations; drilling and completing to the technical limit; operating smart; and minimising BP's footprint.

'These four principles,' O'Bryan explains, 'define BP's approach to recovering tight gas around the world.'

Underground illumination

One of the main technologies BP is using – and continuously improving – for finding and understanding tight gas resources is land seismic surveying.

Land seismic is a key tool used to optimise well locations and identify the 'sweet spots' in tight gas fields – the areas of improved porosity and permeability. In conventional land seismic surveys the seismic source is generated by pounding on the surface using truck-mounted vibrators, or by setting off buried dynamite charges. The seismic signals that are reflected by geological structures in the earth's surface are detected by thousands of geophone receivers attached to cables laid out in parallel on the ground.

Basic land seismic technology has been around since the 1920s, but thanks to recent work by BP in the tight gas arena the acquisition techniques are being modified to obtain better data, drive costs down and minimise the operating footprint.

The company commands a leading position in the industry in seismic technology for the offshore sector, and is transferring that knowledge to the onshore business with very positive effect. In the offshore arena, innovative seismic acquisition methods developed by BP (*Frontiers*, April 2007) such as nodes – essentially autonomous recording units – and wide azimuth towed streamer marine surveys, combined with new computer processing techniques, are enhancing the efficiency of appraisal and development of offshore fields. One benefit of these advances is that it is now possible to obtain clear images of reservoirs buried beneath salt – the presence of salt formations distorts seismic signals. Now BP is adapting this leading-edge seismic capability to help in the development of tight gas fields, most of which are located on land, explains Mike Mueller, technology manager for BP North America Gas.

> BP's tight gas expertise in North America is being applied to gas fields in North Africa and the Middle East

'You could say that the land imaging effort is now stealing shamelessly from the offshore sector and redeveloping the technologies that are used to produce detailed subsalt images in places like the Gulf of Mexico and offshore Angola,' observes Mueller.

But it's all in a good cause. For example, cableless seismic receiver technology is an onshore adaptation of nodes, combining GPS (global positioning system) with wireless communication technology to eliminate the need for positioning heavy, awkward cables on land – this not only speeds up acquisition, but also allows more sophisticated data transfer. And because the cableless systems can be deployed by men with backpacks, they eliminate much of the ground disturbance associated with conventional land seismic, thus reducing BP's operating footprint.

The first large scale cableless seismic survey was carried out by BP at the end of 2006 in the vast Wamsutter gas field in Wyoming, USA, which, says Mueller, 'has pushed back the frontiers of land seismic technology.'

The Wamsutter field covers an area of around $4000km^2$ – BP is the largest operator in the field, currently with some 1100 wells. The reservoir section is of the order of 600m thick and made up of thousands of tiny gas pay zones, some conventional and already being produced, but many tight, which BP aims to develop.

'To do this, we aim to triple the number of wells, and do it without causing environmental damage,' explains O'Bryan. 'The new seismic technology is helping us to identify the best well locations. It also helps us to design deviated wells in order to minimise the number required.'

In 2005, BP announced a $2.2 billion investment programme for Wamsutter, involving drilling 2000 new wells over a 15 year period, targeted at tapping into more tight gas (*Frontiers*, December 2005).

Sweet spot search

Because seismic waves travel faster through rock than through pore spaces, identifying areas where seismic velocity is reduced can indicate areas of higher porosity. Variations in seismic velocity with direction can also be related to fractures in the rocks, and fractures mean better permeability.

Applying advanced seismic techniques to detect changes in porosity and permeability is playing an important role in Algeria where BP and its joint venture partners Statoil and Sonatrach are developing two major gas fields, In Amenas and In Salah (*Frontiers*, April 2004). The fields contain a mixture of conventional and tight gas. Production of conventional gas is already under way in both fields, and the partners are now assessing how best to produce the tight gas, reports Miles Cudmore, technical director for BP's North Africa strategic performance unit.

'The new wide azimuth seismic acquisition and processing techniques,' explains Cudmore, 'are helping us to identify the reservoirs and choose the best drilling locations by allowing us to "see" the reservoirs more clearly and detect fractures in them. Using innovative data processing techniques, the fractures appear as wavy – or sinusoidal – reflectors on the seismic data. We are confident that these effects are due to fractures because we can correlate them with what we see in wells.' (See diagram on page 12.)

A pilot wide azimuth survey, carried out in 2004 over part of the In Amenas field, was so successful at improving the reservoir image and highlighting areas of fractures that a full wide azimuth survey began in July this year. Meanwhile, the results so far have enabled the partners to home in on new well locations to be drilled in 2007. 'By doing this,' says Cudmore, 'we can test whether the model of the reservoir we've developed, with the aid of the seismic, actually works.'

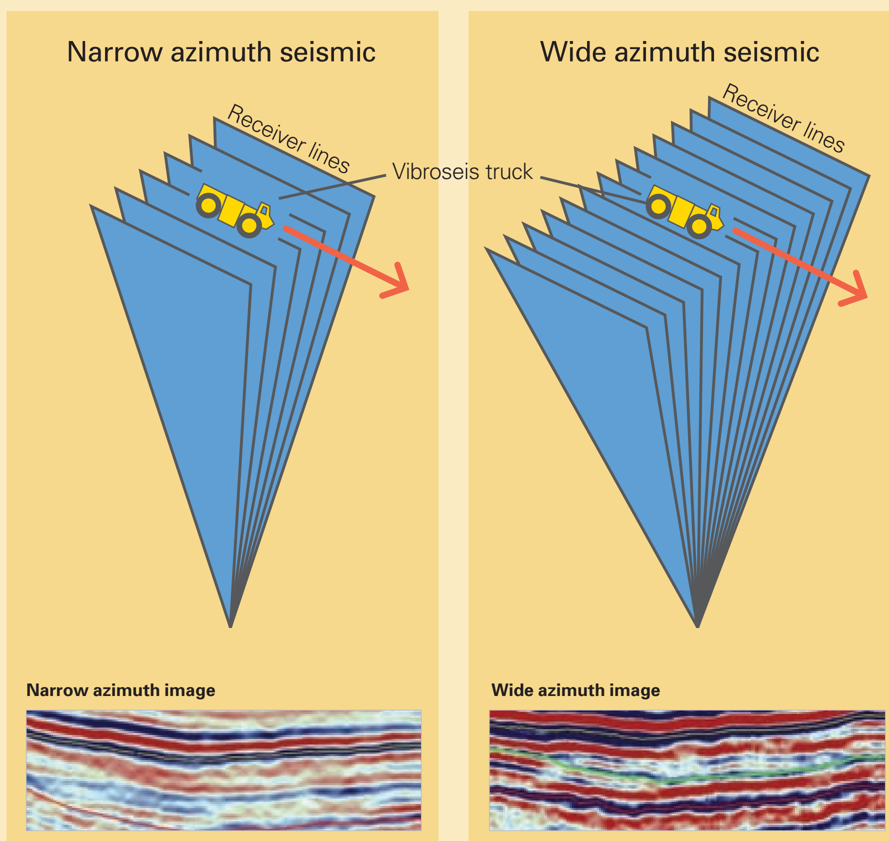
In the Khazzan and Makarem gas fields in Oman, the new seismic technology will be also used to optimise well locations. 'The main goal for the seismic in Oman,' says John Pooler, subsurface and wells director for BP Oman, based in Muscat, 'will be to provide a better picture of the patterns of porosity and permeability.'

Fracs and water

Once the best well locations are identified and the wells drilled, the next challenge is to connect with as much of the reservoir as possible. This is where BP's expertise in another technology – well stimulation involving fracturing, or 'fracing' – comes into play.

In simple terms, fracing technology involves pumping fluids down wells and into the reservoir under pressure in order to create

APPLYING WIDE AZIMUTH SEISMIC TO TIGHT GAS



In conventional narrow azimuth land seismic surveys the sound source is typically provided by a 'vibroseis truck' on the surface. The reflected seismic waves are recorded by a series of surface receivers mounted on cables, placed in a relatively narrow parallel pattern on the ground.

In wide azimuth surveys, many more parallel receiver cables are used, incorporating thousands of individual sources and receivers. The additional data can be processed using advanced imaging algorithms to provide clearer images with sharper resolution than those obtained by narrow azimuth surveys. The technique is particularly useful in locations where good seismic images are difficult to obtain.

Truck-mounted vibrators are used to create seismic signals on land

Deployment of cableless seismic receivers for a large scale survey in the Wamsutter gas field in Wyoming

cracks in the rocks to improve permeability. This involves two types of materials: the fluids themselves, and materials known as proppants – very small beads of sand or man-made ceramics – which are used to hold the cracks open.

'Development of fracing technology is being taken further by BP's North America Gas team,' says O'Bryan. 'Stimulation of wells requires a major effort, particularly in tight gas fields where many wells have very complex geometries.'

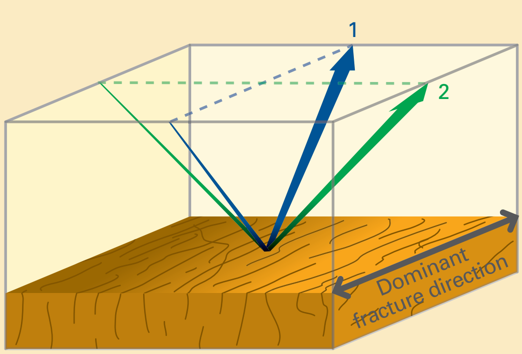
Developing fluids and proppants having the right physical and chemical properties to stimulate different types of reservoir rock is no easy task. As part of its technology plan, BP is working with a number of university researchers and service companies on new chemistry to create fracing fluids with 'perfect' viscosity and flow behaviour properties, and new proppant materials with 'perfect' strength properties. In this context, 'perfect' will mean right for each job, because reservoir properties vary considerably in different locations.

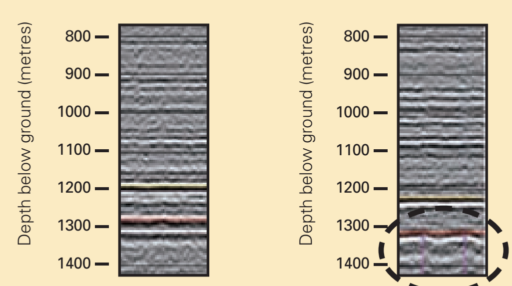
'The key is to understand which fracing technique works best in which reservoir,' adds Pooler.

Another issue associated with tight gas wells is deliquification, which introduces different challenges. Many of BP's existing tight gas reservoirs also produce low volumes of water. Typically there isn't enough reservoir energy to lift the produced water out of the well and, if left in the well, the water can significantly reduce the production rate over time and even kill the well. Artificial lift equipment, such as rod pumps and plunger lift, can be installed to remove the water from the wellbore. While these technologies are used extensively on vertical or slightly deviated wells, they have very limited applicability in highly deviated, horizontal, or multilateral wells, such as those used in tight gas fields.

'Finding an effective low-power solution to deliquifying these wells will be another step

DETECTING RESERVOIR FRACTURES WITH SEISMIC





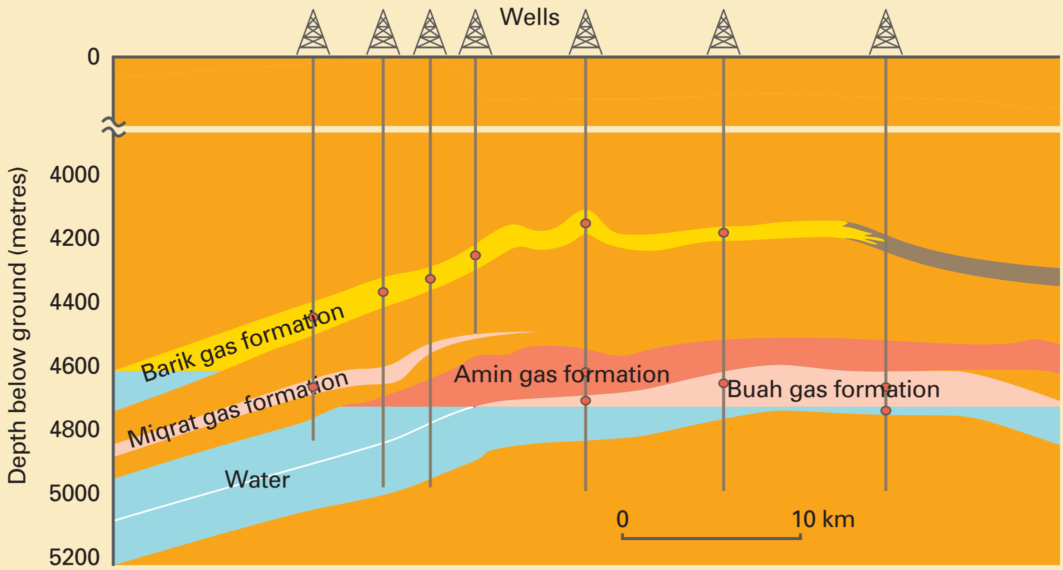
No fractures **Fractures present**

Seismic is proving to be a useful tool for detecting the presence of natural fractures in subsurface rock formations. Fractures can indicate better rock permeability, which makes it easier for gas to flow into wells.

Fractures affect the velocity of reflected seismic waves to different degrees, depending on the waves' orientation in relation to the fractures. When the ray paths are parallel to the fractures (like path 1 in the graphic above), the reflector velocity is little affected. But when the ray paths are at an angle to the fractures, the reflector velocity is slowed down. The greatest effect is seen when the source and reflector ray paths are perpendicular to the fracture direction (like path 2).

These changes in velocity due to fractures appear as sinusoidal – or wavy – reflectors in seismic images. In the left-hand seismic image above, the reflectors at the reservoir depth of 1300-1400m are straight. But in the right-hand scan of a different area of the reservoir, the reflectors at this depth are wavy – revealing the presence of fractures.

GAS IN OMAN – THE KHAZZAN AND MAKAREM GAS FIELDS



Cross-section through the Khazzan and Makarem gas fields in Oman, where BP is appraising conventional and deep tight gas reservoirs

forward in successfully operating tight gas reservoirs,' says O'Bryan. 'To minimise our footprint, we are evaluating pumps that can do the job effectively, along with the ideal motor to run the pumps, powered by solar panels.'

BP believes it is leading the way in introducing, scaling up and implementing the new seismic, well stimulation and production technologies for tight gas, on the global stage. Support between the company's business units in different regions is an important component in this drive forward, exemplified by BP's Tight Gas Symposium, held in May this year, to help BP technologists and engineers from around the world to share experiences on the challenges of implementing different technology applications in a number of tight gas fields.

'In Oman,' notes Pooler, 'we are benefiting greatly from the experience of others in BP in selecting the technologies to apply in the Oman gas fields.'

Technologists from BP are actively sharing the tight gas expertise developed in the USA with groups around the word. For example, experts from North America Gas are now working with the North Africa business unit.

'This is putting us in touch with fracturing contacts across North America,' reports Cudmore. 'And we've been sharing our seismic expertise in fracture detection with our colleagues in Oman. It's a great example of how we work in a joint way.'

Going from winning technologies in one region to implementing them across BP's business elsewhere is no small undertaking, notes O'Bryan.

'We're working all out on this with contractors and service providers,' he concludes. 'BP is committed to growing our successful technologies to make the production of tight gas easier and more cost effective around the world.' ■

Drilling in Algeria: BP is assessing tight gas production in the In Amenas and In Salah gas fields

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