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# GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

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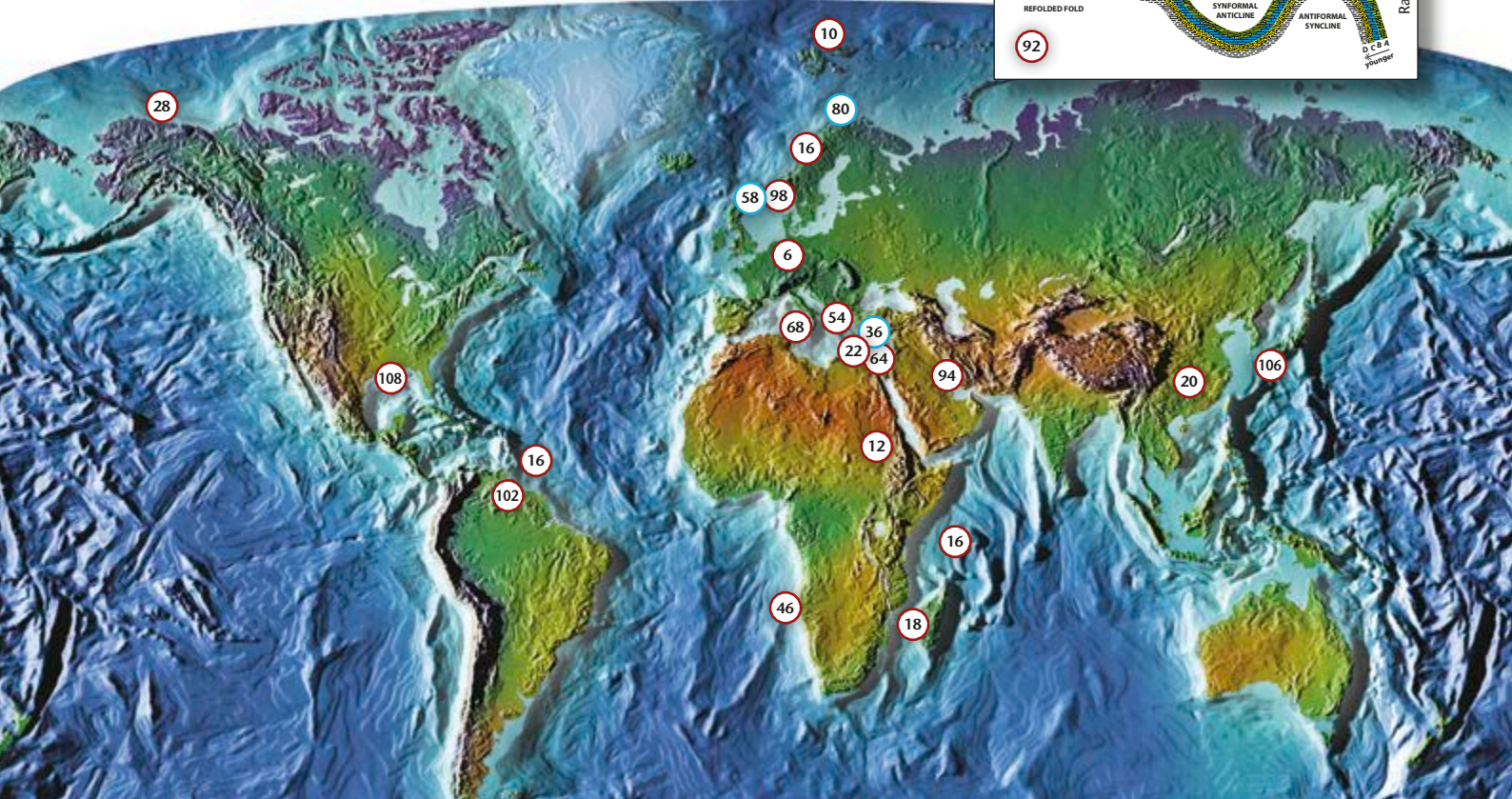
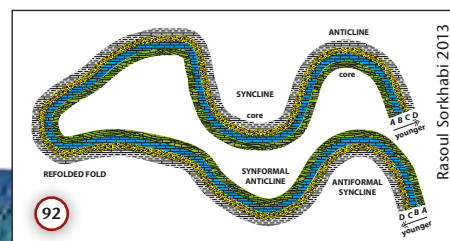
Broadband seismic technology and beyond: the interaction between ocean waves and recorded seismic data is important.



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## Publish What You Pay

The petroleum industry works in countries throughout the world, including those with political and economic instability and low levels of development. This can bring it into difficult or ambiguous moral territory. It is important for both global supply and for resource-rich, economically poor countries that their resources are accessed, but everyone wants to avoid the much discussed 'resource curse' of extreme and endemic corruption coupled with continuing poverty, with Nigeria being the most frequently cited example.

In April the European Union agreed ground-breaking new rules forcing oil, gas, mining and logging companies to publish details of the payments that they make to governments around the world for access to natural resources. This is a landmark action against corruption, providing citizens of resource-rich countries with detailed information about the money generated by their natural wealth. The law includes publicising the amounts paid for each individual resource project companies invest in, thereby allowing local communities to monitor payments from developments in their local areas. It also brings Europe in line with the Dodd Frank Act, which was introduced in the US in 2012.

The introduction of these laws was driven partly by the 'Publish What You Pay' campaign, which seeks transparency in the extractive industries, believing that secrecy in the energy and mining sectors hinders development in resource-rich countries. Initially, oil companies reacted quite positively to this campaign, more so than mining organisations, with a number of majors responding cautiously but favourably to the idea of revenue transparency.

It is surely true that nobody in the industry is keen to actively support corruptive practices. However, it is interesting to note that several companies which had publicly backed anti-corruption and transparency measures in the past have been under pressure recently to support a lawsuit being brought by a consortium led by the Independent Petroleum Association of America to overturn the payment disclosure provision in the Dodd Frank Act. Do they represent the industry as a whole?

Have we got that much to hide?

**JANE WHALEY**  
Editor in Chief



## INSIGHTS FROM SPACE

The East Mediterranean as seen from space – one of the methodologies which can be used to assess this up and coming region for hydrocarbon potential. Enhanced SRTM elevation data for the Mediterranean region reveals onshore structural features and regional gravity data is shown offshore. SRTM from the Global Land Cover Facility, University of Maryland, gravity data from Sandwell and Smith (2009).

Inset: Following a rock properties based workflow for shale plays makes it possible to gather intelligence which not only defines where to drill and how to frac, but also better predicts the economic outcome.



*Will the citizens of Tanzania enjoy the benefits of the recent discovery of hydrocarbons?*



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# Something Worth Arguing About

The newly launched European Shale Gas Argument Map aims to provide information both for and against the extraction of shale gas

Commissioned by TNO, a Dutch independent research company who strive to 'connect people with knowledge', the European Shale Gas Argument 'map' is essentially a diagram which details arguments both for and against the introduction of shale gas extraction within Europe. The analysis was launched at the European Parliament in February 2013 with the aim of bringing about judicious discussion on the subject, as explained by Member of European Parliament (MEP) Lambert van Nistelrooij: "What we did today is decide to ask the European Commission to come up with a broader debate. We should have a reliable, transparent, sustainable way of approaching the shale gas questions in the next year."

The 'map' functions by providing the reader with information both for and against the extraction of shale gas. For example, within the economy section of the diagram one of the pro arguments is that 'shale gas production increases regional employment', while one argument against it is that 'it is unclear how much gas can be profitably produced and whether public investments are worth making'.

## Rational Debate?

Rene Peters, the Director of Oil and Gas for TNO, said that "the first use we hope that this 'argument' will get is that the discussion will go more into a rational debate, rather than an emotional debate." He continued by saying "We have already identified a number of areas where good scientific evidence or research-based facts are not yet available to make this a balanced discussion. And that's why we have decided to take the initiative, together with the European Energy Research Alliance, to come up with a European research programme on shale gas – to actually deliver unbiased and factual information to get the discussion on shale gas rationalised."

The European Shale Gas Argument Map has been developed to encourage a "European initiative to do research on shale gas, because knowing more about it is of great importance," said Mart J. van Bracht, Director of TNO Energy. Van Bracht went

on to say that "natural gas is one fuel which at this moment is really important for the European economy, but will also be very important in the future." A mention of the economy will surely have many ears pricked, supporter of shale gas or not.

Shale gas extraction through fracking has widely been ill received within the public domain. As acknowledged in 'Golden

Rules for a Golden Age of Gas', a report by the International Energy Agency, a key constraint is that 'unconventional gas does not yet enjoy, in most places, the degree of societal acceptance that it will require in order to flourish'. And, with the imminent release of the fracking-themed, high-budget movie *Promised Land*, starring Hollywood legend Matt Damon, the debate will roll on.

Media on fracking, such as the film *Gasland* by Josh Fox, have acted even further to restrict an informed and open debate on the topic. On a recent blog post Fox wrote, "Politicians and publications have conditionally endorsed so-called 'safe fracking' as a part of the nation's energy mix. But safe fracking is an impossibility, and the industry's claims for it are knowingly based on false premises." This is a view that is widely received and supported, and the negative perception is particularly strong within the European Union. But, as Rene Peters points out, "The European shale gas industry

is capable of working responsibly, and the restrictions are much tighter here than in the US."

## Pros and Cons

The European Shale Gas Argument Map will allow for a timely and important debate to find a voice within a wider audience – highlighting the pros as well as the cons. By producing this report TNO have visualised a subject which is being lost in the passion of a minority. It should work to bring about a view and an understanding which has widely been ignored up to this point, and will allow for proper research and facts to decide on the future of shale gas and fracking within Europe. ■

KATHERINE COOK

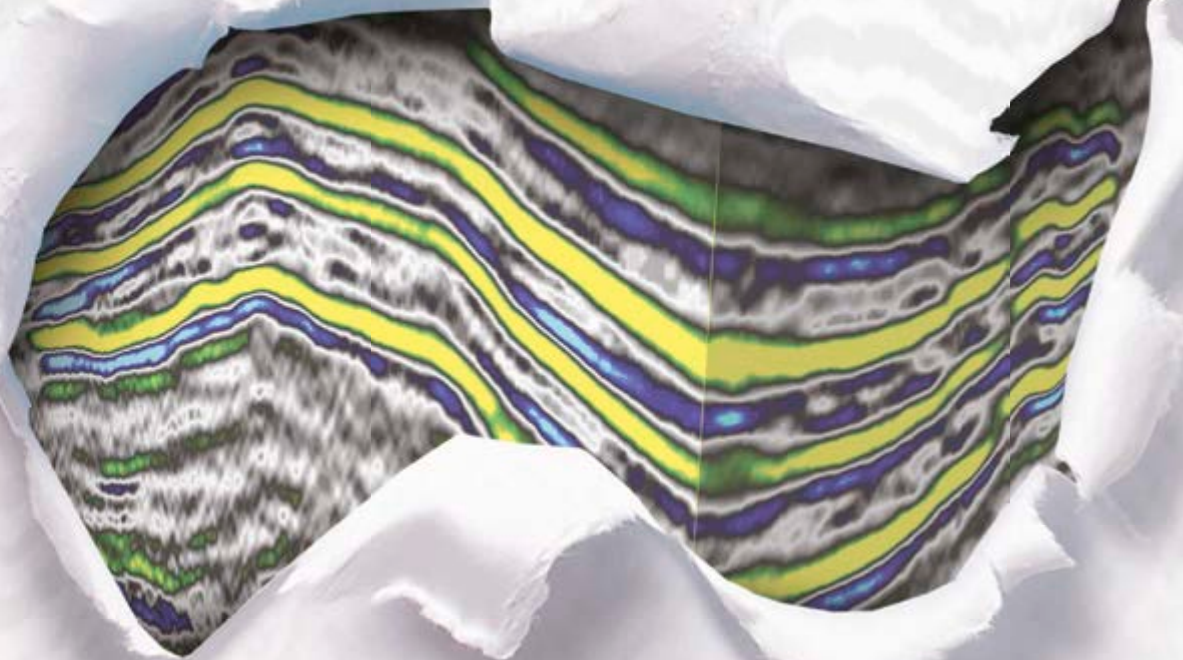


MEP Lambert van Nistelrooij presents the European Shale Gas Argument Map to the European Parliament.



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# The Transparent Imperative

## Why oil and gas companies must master social media

The oil and gas industry is seen by and large with great scepticism by the American and European public, and are often painted as a bunch of fat cats who look for every opportunity to ruin the environment and oppress the poor.

We all know how absolutely ludicrous this perception is. Oil and gas companies not only contribute billions of dollars to the economy in the form of jobs and tax revenue, but we also care for our communities. Cabot Oil and Gas, for example, bend over backwards to give back to the small towns of the north-east US where it operates. Exxon gives away millions for college scholarships. In my own hometown of Fort Worth, Texas, Chesapeake and XTO are permanent fixtures of the philanthropic landscape.

So why does the industry continue to battle uphill against negative public sentiment?

Many within the oil and gas community quickly point to Hollywood celebrities and hopelessly ignorant politicians as the main source of our problems. You cannot completely discount the sway these people have over the public, but I think it is time to take a good look in the mirror and see how we as an industry are contributing to the problem.

### The Brave New World

The past five years have brought about revolutionary changes in oil and gas. Horizontal drilling, zipper fracs and multi-well pads have become the norm overnight. In the same way new drilling technology is shaping the industry, new social media technology is shaping the world. As social media expert Jay Baer points out, once upon a time the only way to complain to a company about a defective product was to go back to their booth at the town bazaar. Then they invented the postal service and we could write letters. Next came the telephone and customer service representatives to man the phones. Email followed and consumers were given yet another way to engage with vendors and brands. Social media is the next natural step in customer engagement.

Unfortunately, many in the industry are still living somewhere between the town bazaar and the telephone. When a frightened public is faced with perpetual scare tactics from oil and gas opponents and ominous headlines from journalists who glory in fanning the flames, it takes much more than parades and

community picnics to turn the tide.

The world has changed – drastically. Look at Facebook's one billion users – there are nearly as many Facebook users as there are Catholics in the world. If Facebook was a country, it would be larger than China in three years. The amount of time people are spending on social media is staggering, and this has trained them to expect certain things. Today, if someone wants to learn more about your company, they often go to your Facebook page or Twitter account before your website. People have become accustomed to interacting with brands and forming their opinions about them based largely on how they interact with their audience. The same could be said about entire industries.

However, if you search social media platforms to find valuable insights about oil and gas, you would not walk away with a favourable image of our industry. Instead, you will get an earful from Josh Fox and his anti-fracking *Gasland* minions. You will be told,

inaccurately, that companies refuse to disclose the ingredients of their frac fluids, and shown endless pictures of flaming water faucets, all of which have been proven to be caused by naturally occurring biogenic methane. And we as an industry remain conspicuously absent in all of this.

I recently checked Facebook to see how many of the largest oil and gas companies on earth were active on the network – less than a dozen. Here we are with the greatest American energy revolution happening right before our eyes, which has already poured untold billions of dollars into the US economy, and we are letting our adversaries dictate the conversation and shape public perception. And the best answer we can come up with is to kick the can and grumble about how bad we have got it.

### Be In It to Win It

It is time to face facts. These conversations are taking place, whether we like it or not. The only question that remains is will we come to the table to present the facts? Will we be open and transparent, building trust and gaining the admiration we so richly deserve? Or will we continue to bury our heads in the sand hoping the problem will go away?

If it were not for oil and gas, we would still be driving horse carts, dying of dysentery, heating our homes with wood from disappearing forests and fumbling around in dark rooms the moment the sun went down. Truth be told, the oil and gas industry is responsible for lifting the world out of poverty. As John D. Rockefeller said, "Let the good work go on. We must ever remember we are refining oil for the poor man and he must have it cheap and good."

The world needs to know our story. If we do it right and are willing to meet people where they are on Facebook, Twitter, LinkedIn, etc., they will not only gain an appreciation of our achievements of yesterday, but will eagerly partner with us as we build the bright future of tomorrow. ■

**JAMES HAHN II, DRILLINGINFO**

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# Ready to Explore the Offshore Arctic?

To unlock the vast, technically recoverable oil and gas resources that are attracting international oil companies to the Arctic will take Herculean effort. For example, Shell has spent billions of dollars preparing to drill in the Beaufort and Chukchi Seas off northern Alaska, only to have plans cut short in 2012. In addition, Shell was barred from drilling into oil-bearing formations that year by Federal regulators because additional spill prevention and clean-up equipment were not available. Now they have delayed future drilling another year to, as their president, Marvin E. Odum puts it, "give us time to ensure the readiness of all our equipment and people."

Fortunately for Shell and other companies planning to operate in the Arctic, these are long-term projects and they are now not alone in these endeavours. The Arctic environment can be most unforgiving and a significant proportion of the reserves targeted by the oil companies are believed to lie offshore, in the Arctic's environmentally sensitive and productive shelf areas. The protection of this fragile environment is a top priority for any company operating in the Arctic. To ensure this end, a new consortium of nine international oil and gas companies has pooled their resources and launched a collaborative effort to enhance Arctic oil spill capabilities.

In January 2012, the Arctic Oil Spill Response Technology Joint Industry Program (JIP) was launched. The purpose of the programme would be to undertake specifically targeted research projects identified to improve industry capabilities and the coordination in the area of Arctic oil spill response. International research programmes under the JIP would be created to enhance industry knowledge and capabilities in the area of Arctic oil spill response and to raise the awareness of existing industry oil spill response capabilities in the Arctic.



## Key Areas of Research

Nine international oil and gas companies (BP, Chevron, ConocoPhillips, Eni, ExxonMobil, North Caspian Operating Company (NCOC), Shell, Statoil and Total) support the JIP. The International Association of Oil and Gas Producers (OGP) are providing expertise to the JIP. Leading industry experts and scientific institutions will perform the technical work and scientific studies.

The JIP will manage ten research projects that will cover six different areas: namely 1) dispersants, 2) environmental effects, 3) trajectory modelling, 4) remote sensing, 5) mechanical recovery, and 6) in-situ burning. Each of the individual research projects will have information which can be downloaded from the JIP website. This research is designed to advance the response capabilities relating to an oil spill as well as understanding the environmental effects of a spill and the response activities that follow.

The research will also address the unique Arctic operating conditions that include prolonged periods of darkness, extreme cold, distant infrastructure, sea ice, and a high cost of operation. This collaboration among companies, academic, government and non-government institutions assures the most efficient use of resources, funding, and the expertise to improve the technologies and methodologies for Arctic oil spill response. The JIP's research project findings will be available either in peer reviewed journals or within its website and general dispensed materials.

For more information visit [www.arcticresponsetechnology.org](http://www.arcticresponsetechnology.org). ■

THOMAS SMITH

## ABBREVIATIONS

### Numbers

(US and scientific community)

M: thousand	= $1 \times 10^3$
MM: million	= $1 \times 10^6$
B: billion	= $1 \times 10^9$
T: trillion	= $1 \times 10^{12}$

### Liquids

barrel = bbl = 159 litre

boe: barrels of oil equivalent

bopd: barrels (bbls) of oil per day

bcpd: bbls of condensate per day

bwpd: bbls of water per day

### Gas

MMscfg: million ft<sup>3</sup> gas

MMscmg: million m<sup>3</sup> gas

Tcfg: trillion cubic feet of gas

Ma: Million years ago

### LNG

Liquified Natural Gas (LNG) is natural gas (primarily methane) cooled to a temperature of approximately -260 °C.

### NGL

Natural gas liquids (NGL) include propane, butane, pentane, hexane and heptane, but not methane and ethane.

## Reserves and resources

### P1 reserves:

Quantity of hydrocarbons believed recoverable with a 90% probability

### P2 reserves:

Quantity of hydrocarbons believed recoverable with a 50% probability

### P3 reserves:

Quantity of hydrocarbons believed recoverable with a 10% probability

### Oilfield glossary:

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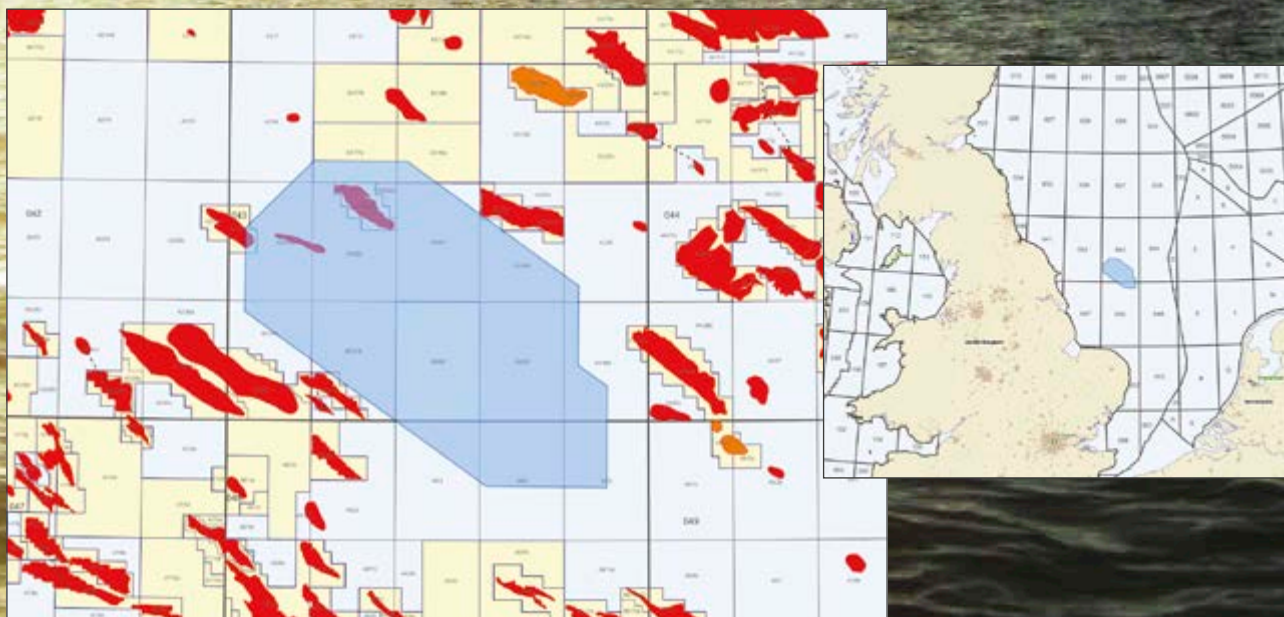
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# South Sudan: "The Oil is Now Flowing"

South Sudan is to resume oil production – a positive move for the new country, but uncertainty remains

After a 15-month stalemate, South Sudan has announced it is to resume oil production, ending a bitter row with former civil war foe and neighbour Sudan and marking a major political and economic breakthrough for the world's newest nation. The Republic of South Sudan officially came into being on 9 July 2011, when over 98% of the population voted for independence from Sudan in the historic referendum of January that year, set up under the 2005 Comprehensive Peace Agreement (CPA). The civil wars between North and South Sudan have spanned the last five decades, the most recent one claiming nearly two million lives and leaving four million others homeless.

South Sudan won control of approximately 75% of the 470 Mbpd of low sulphur crude produced by the formerly unified country. The oil exports went almost exclusively to Asian markets, particularly China, the biggest buyer of South Sudanese oil before the shutdown. However, CPA negotiators were not able to reach an arrangement on how to divide the revenue from the southern oilfields and collaboration between the two countries broke down in January 2012 when they failed to agree over oil transportation fees. President Salva Kiir of South Sudan accused the Sudan government of illegally siphoning off \$815m of its crude oil, which the government in Khartoum said provided compensation for unpaid transit fees.

"The oil is now flowing," said South Sudan oil minister Stephen Dhieu Dau on 20 April this year, as he flicked a switch to restart production at a ceremony in the Thar Jath field in Unity State, an oil-producing region of South Sudan on the contested border with Sudan. He was received by crowds dancing in celebration as he declared, "This is a sign of peace."

During the oil shutdown, Information Minister Barnaba Marial Benjamin said South Sudan was exploring the feasibility of building a new 2,000 km pipeline, either south to the Indian Ocean through Lamu, Kenya or east to the Gulf of Aden through Ethiopia and Djibouti. It remains unclear if this was a negotiation tactic by the landlocked country, or whether this development remains a possibility.

## Economy and Development

Combined, the two countries account for only 0.6% of global oil production, but oil is integral to the economy of them both, accounting for 98% of South Sudan's government revenues and 82% of its GDP, which is a high degree of dependency even compared to most OPEC countries. The closure has devastated both economies, costing billions of dollars and sending people onto the streets in protest at the inflation incurred. President Kiir said he will run the country on an austerity budget at least for the next fiscal year beginning in June, despite the resumption of crucial oil flow.

Development experts have urged the government to use oil proceeds to begin investing in the country and its people, ensuring sustainable economic growth. According to the World

Bank, South Sudan may have received slightly more than \$10bn in oil revenue from 2005 to January 2012, when production shut down. However, basic social services remain scarce as these revenues are not yet being poured into schools, hospitals, roads and agriculture, possibly because they prefer to spend the money on security. Dr Leben Nelson Moro of Juba University's Faculty of Peace and Development Studies said, "The oil money must be used in a manner that will be beneficial to the whole country and not the few people who are close to the treasury."

South Sudan has some of the worst health and education indicators globally. In 2011, the adult literacy rate was 27% and according to the UNDP the maternal mortality rate is 2,054 per 100,000 live births, the highest rate in the world, giving a woman a 1 in 7 chance of dying during her lifetime from pregnancy-related causes.

## Investment Needed

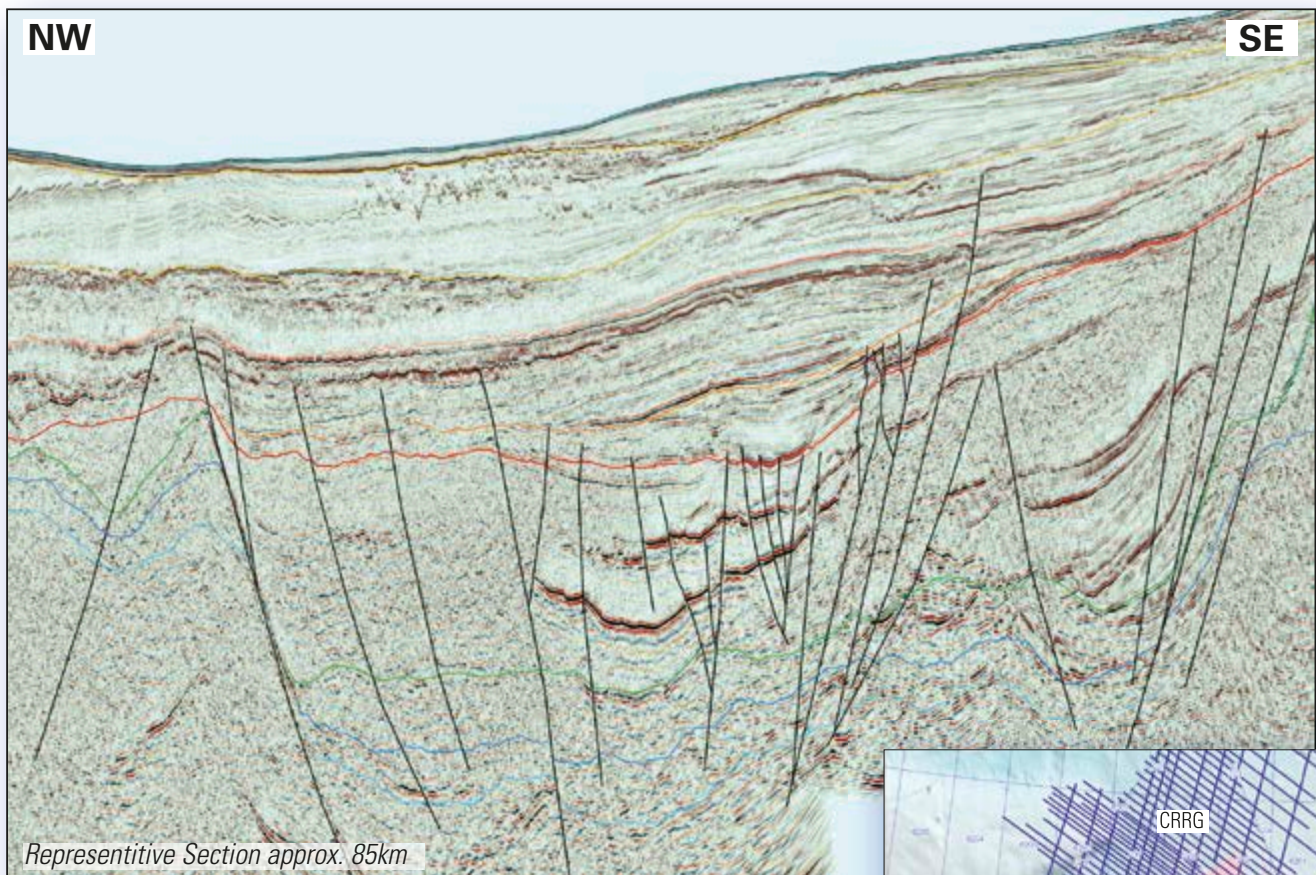
According to most analyses, South Sudan has just 10 years of extraction remaining, a limited amount of time for the world's youngest country to become self-reliant. South Sudan cultivates just 5% of its arable land, constituting less than 1% of its GDP from agricultural exports, which illustrates the economic potential the country can harvest from farming. Before this potential can be garnered there is a large need for capital investments, especially roads, as the country, the size of France, has just 100 km of tarmac roads – low even by African standards.

It took less than a month to shut down extraction but analysts at PFC Energy said it may take a year to reach pre-shutdown production levels due to damaged equipment. This resumption offers the impoverished nation a chance to rebuild, but as the oil flows again, strict accountability will be needed to prevent potential corruption. Despite the projected positive images, uncertainty still remains about this period of respite. ■

SCARLETT BARCLAY

*South Sudan is landlocked and consequently reliant on the infrastructure of its neighbour Sudan to sell the oil on international markets.*

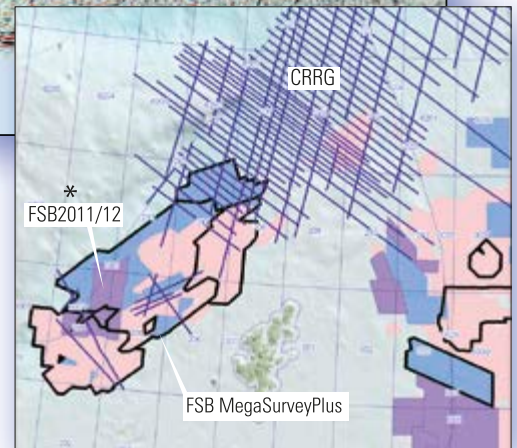




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# Oil Prices Under Pressure

They should rise with accelerated growth in the second half of the year

Oil prices came under heavy pressure in the first weeks of April. Weaker-than-expected macroeconomic data from the US and somewhat disappointing growth figures from China in the first quarter contributed to this. But we are in a period of the year when the oil market is usually somewhat slacker, when demand for oil products is typically low. This year, the seasonal effect was especially noticeable because more refineries than usual shut down production for maintenance work. By the beginning of May, oil refineries are normally out of the maintenance season, leading to a sharp increase in refinery runs and thus a boost in the demand for crude.

The rate of growth in the world economy is expected to bottom out in the second quarter of this year, only to increase slightly as we move into the second half of the year. US budget constraints are expected to dampen economic growth in the current quarter. Growth in China and the US is expected to pick up somewhat in the latter part of the year and recession in the Euro zone should be over by then.

Downward pressure on prices based on the situation in the physical oil market has meant that the scope of bets in the financial section has fallen, approaching the level we saw last year when the crisis in Europe was at its highest. Increased uncertainty contributes to the financial speculators' wishes to sell out of the oil market, leading to exaggerated downward reactions in prices.

Downward pressure is less now than last spring, when Euro-related turmoil raged, investors shunned risk-related investment classes, and Saudi Arabia flooded the market with oil. Prices bottomed in June at \$89/barrel and many fear a similar dive this year. Sustained oil prices around \$80 per barrel could, for example, dampen investment activity on the Norwegian Shelf. In my opinion, however, it would take even more unfortunate circumstances before this might happen.

## Growth Uncertain

There is uncertainty linked to the growth outlook in the world and thus to the demand for oil. Growth in China is only slowly picking up again, as it struggles with unsettling financial imbalances and structural problems. A significantly lower growth in the Chinese economy than the assumed 8% would contribute to a lower oil price of a longer-lasting character.

Much attention has been paid to the rise in potential oil production, which appears to be higher than the growth in demand. The rapid production recovery in the US and Canada is, however, offset by production disruptions in other key producing areas. The security situation in Libya is worrisome and the growth in oil production there has stopped. In Nigeria, militant attacks on oil installations in the oil-rich Niger Delta are increasing. Furthermore, the continuing war in Syria represents a threat to stability in the entire Middle East, including in the major oil-producing countries of Iraq, Iran and Saudi Arabia. The conflict over Iran's nuclear programme is also equally entrenched and unrest has flared up after the presidential elections in Venezuela. There is therefore considerable uncertainty related to the supply side of the oil market.

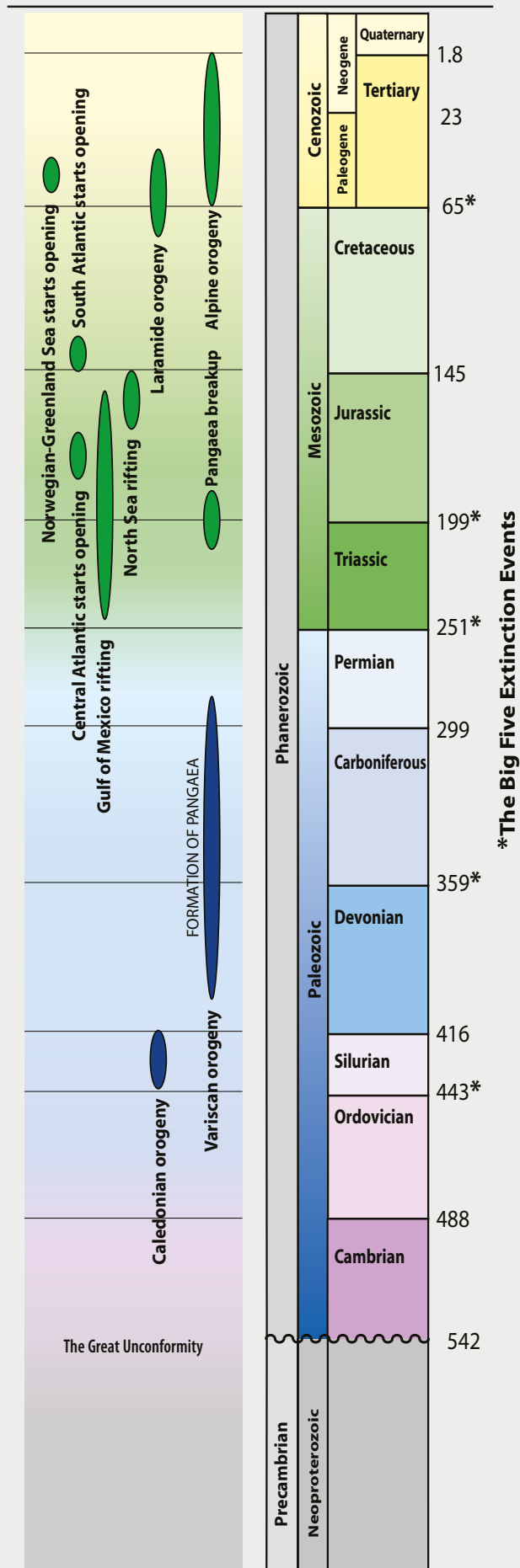
I therefore believe that the large correction downward in the price of oil is behind us, and expect prices to rise again as the world economy gains momentum in the second half of the year. ■

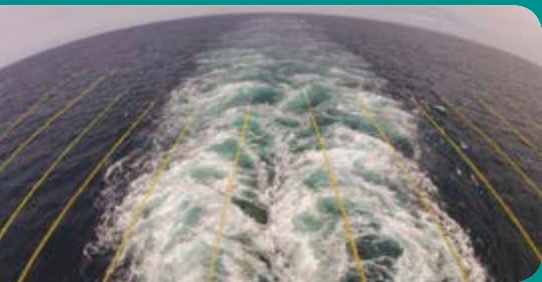


THINA MARGARETHE  
SALTVELT, PH.D

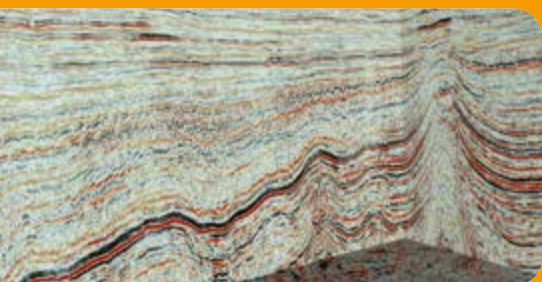
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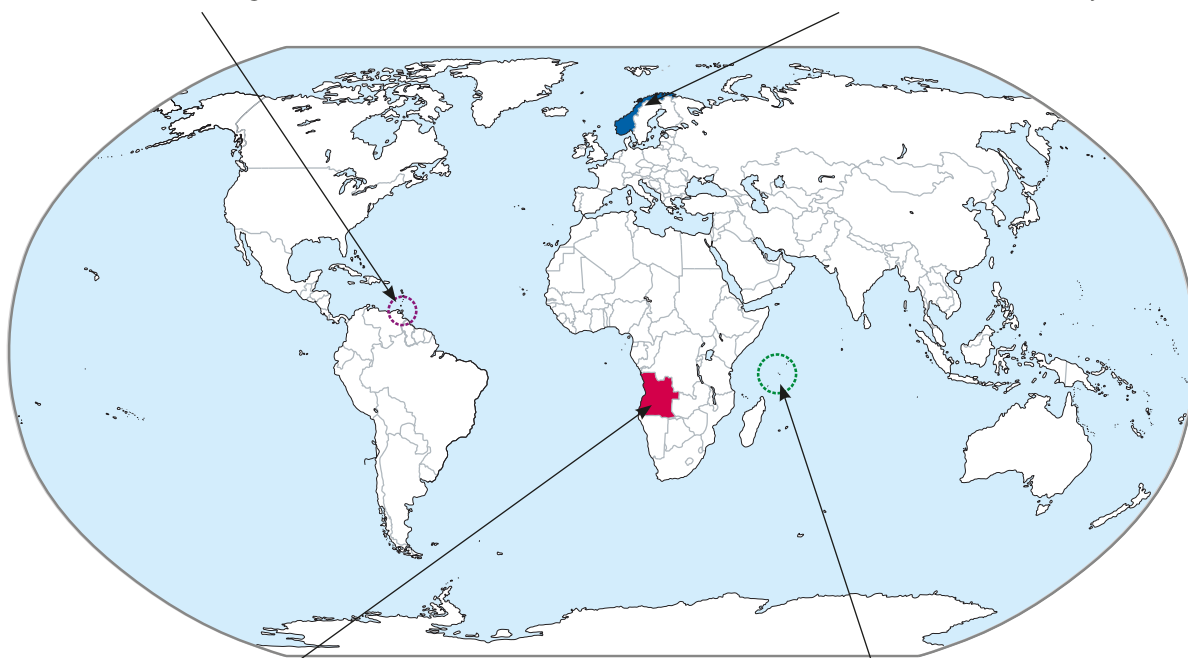
# Established Plays and Frontier Acreage

## Trinidad & Tobago

Following a block nomination period that closed in February 2013, the Ministry of Energy and Energy Affairs has signalled its intent to offer acreage in shallow, medium and deepwater via a round of competitive bidding. At least six blocks will be offered and a timetable will be announced shortly. A positive outcome is seen as essential for the industry, as both oil and gas production is forecast to decline steadily, while gas production will only begin to pick up again in 2015. The government expects an upturn in drilling activity and, with several new smaller international oil companies participating in the sector, there is scope to slow the rate of decline in oil production. Located close to the lucrative US markets and offering relative economic and legal stability, there should be a strong draw for new investments, particularly in gas to support the Atlantic LNG project. Fiscal and contract changes announced in 2010 have helped stimulate the sector and further incentives were introduced in the 2013 budget.

## Norway

The Ministry of Petroleum and Energy (MPE) has opened the Awards in Predefined Areas 2013, with six additional blocks available around the Aasta Hansen discovery. The MPE seeks to ensure that any further resources in this area are identified and can be exploited in a timely and optimal manner now that Aasta Hansen is progressing. The deadline is 11 September 2013. Oil production in Norway may be in decline, but the country retains considerable upside gas potential and should continue to be a major force in European energy supply for decades to come. Large discoveries are clearly still possible in mature areas, as demonstrated by the recent giant Johan Sverdrup and surrounding oil finds. This should stimulate new investment from domestic and foreign operators, slow a decline in oil output and spur on gas production. The government has also presented its proposal to open the south-eastern Barents Sea for petroleum activity, the first new region for nearly 20 years. This process began in spring 2011 after Norway and Russia concluded 40 years of negotiations on the delimitation line in the Barents Sea. The areas included in the present recommendation, the southernmost part of the new region, are expected to hold 1.9 Bboe, increasing the amount of undiscovered resources in the Barents Sea by more than 30%.



## Angola

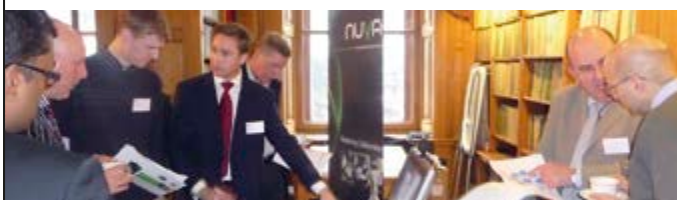
Angola's government has approved a plan to hold a bidding round for licences to explore for oil onshore in the Kwanza and Lower Congo Basins. According to State oil firm Sonangol, the authorities are proposing to offer 11 blocks in the Kwanza Basin and four in the Lower Congo Basin. Angola is the second-largest oil producer in sub-Saharan Africa behind Nigeria and has announced plans to ramp up crude output to 2 MMbpd in 2015, from around 1.75 MMbpd last year. Recent exploration suggests that Angola's reserves, estimated at 9.5 Bbo, may be larger than initially estimated. The country's rapid rise as an energy producer over the past two decades came despite a civil war that lasted until 2002 and which left the country lacking the infrastructure and regulatory oversight necessary to operate a modern energy sector. Steady investment since 2002 has ensured a more stable operating environment but challenges remain. An OPEC member since 1997, Angola has not always acceded to the group's demands, and the current leadership is pressing ahead with plans to boost production of oil and natural gas over the coming decade to help increase government revenue.

## Seychelles

The Seychelles government has pledged to revamp its model petroleum production sharing agreements and adjust its fiscal regime ahead of inviting oil and gas companies to bid for exploration licences from May 2013, in response to increased industry interest following a succession of discoveries off the east coast of Africa. Currently, there are no plans to hold a licence round; companies can submit an application for an area at any time, after which there will be a 90-day period for other companies to submit a competing bid. Only Afren and WHL Energy hold Seychelles acreage. The latter claims its assets represent a world class opportunity, and an independent assessment of the exploration portfolio allocated a total unrisks mean prospective resource of 3.45 Bbo for the 21 best leads. The last well to be drilled offshore was Constant Banks 1, which was abandoned with gas shows by Enterprise Oil in 1995 before reaching its target, after encountering an unexpectedly thick sequence of carbonates.

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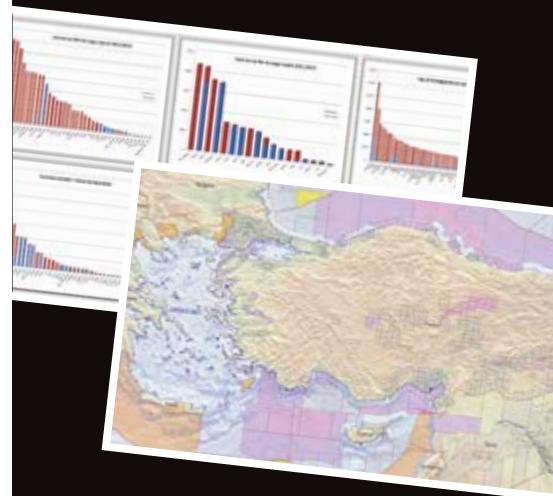
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# 100 Years and Beyond

One hundred years ago this year, the first degree in oil technology – one of the first in the world – started at **Imperial College**. To celebrate this landmark achievement, there will be a two-day centenary conference at the college on 23–24 September 2013, to which all past and present Department of Earth Science and Engineering staff and students are invited. The meeting will celebrate 100 years of petroleum-related science and engineering education at Imperial College while looking forward to the next 100 years, with presentations covering global energy trends, future geoscience and engineering technologies, unconventional hydrocarbon resources, carbon sequestration and climate change. There will also be a 'nostalgia' field trip to Dorset and a dinner in the Natural History Museum. ■



Imperial College London's South Kensington Campus

## Export Achievement Recognised

An Aberdeen-based company offering specialist operational geology software and services has won a Queen's Award for Enterprise in International Trade as it celebrates the landmark of reaching 100 employees. HRH Geology is one of only ten Scottish companies to receive this prestigious business award for outstanding growth in overseas markets in 2013. Formed in 1989, HRH Geology has grown steadily from its beginnings as a developer of the world's first geological log drawing software product and has diversified into new markets in North America, the Middle East, Africa and South East Asia. The company has delivered training and services in every continent, placed geologists in oil and gas provinces around the world and has regional offices in Houston, Abu Dhabi and Jakarta.

Founder and managing director, David Harrison, said: "It is a real honour to receive a Queen's Award for our considerable achievement in international trade and a testament to the hard work of our people in developing and successfully implementing our internationalisation strategy." ■

*David Harrison, MD of HRH Geology, with fossils found on geological field trips*



## Conference on African E&P

The first **Petroleum Society of Great Britain (PESGB)** Special Interest Group meeting, in 1998, was a one-day meeting on West Africa, but it was not until 2002 that a two-day conference devoted solely to oil exploration throughout Africa was initiated. Delegate numbers soon increased from about 250 to almost 500 in 2011. The importance of this Conference lies in its ability to attract excellent quality presentations for a modest delegate fee, as well as an increasing number of sponsors and industrial exhibitors, who find the format with its mixture of exhibitor booths, poster presentations and conference refreshment areas particularly rewarding. The Conference takes place on alternate years in London and Houston, where it is sponsored by the **Houston Geological Society**.

This year the **12th Africa Conference** will be held at the Wembley Convention Centre on 11–12 September. The technical programme will discuss North African intracratonic sag basins; West African deepwater turbidite plays; West African rifts and the pre-salt and finally East African rifts and passive margins. Several guided tours of the stadium and its sporting facilities will be provided, and an International Booth section will be introduced. ■



## China's Gas Potential

China is the world's most populous country and the largest energy consumer in the world, so the search for continuing resources is imperative. Although its **unconventional gas** industry is only in its very early stages, **China** is believed to have more than 1,275 Tcf of technically recoverable shale gas, most of which is in the Sichuan and Tarim Basins in the southern and western regions and in the Northern and North East Basins. There is no production yet, but the country aims to produce 230 Bcfpy of shale gas by 2015. To this end, **Shell** recently announced that it will spend \$1 billion a year to help China unlock its shale gas reserves, starting by exploring in the Fushun-Yongchuan block in the Sichuan Basin, where CNPC and Shell signed the first PSC for a block of shale gas in March 2012. ■

## MC Survey Offshore Mozambique

**WesternGeco** recently commenced acquisition of a major multiclient seismic survey offshore **Mozambique** using the **ObliQ** sliding-notch broadband acquisition and imaging technique, which optimises the recorded bandwidth of the seismic signal, enabling more detailed imaging of the subsurface and more reliable extraction of rock properties. This technique will provide valuable high-resolution broadband imaging in this geologically complex area, where recent discoveries and regional appraisals indicate significant frontier exploration potential.

The survey is being acquired in collaboration with the National Petroleum Institute of Mozambique (INP) and is fully supported by industry prefunding. It consists of more than 31,000 km of long-offset 2D data to help oil and gas companies evaluate the play potential of open blocks offshore Mozambique ahead of future licensing rounds. ■



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## Consultancy Services Recognised

Another UK company to be awarded the Queen's Award for Enterprise in International Trade 2013 was the **EPI Group**, a global leader in the provision of specialised seismic quality control, processing, health, safety, security and environmental technical consultancy services to the oil and gas industry worldwide. Incorporated in 1988, the EPI Group's head offices are in Cobham, UK, with regional offices in Houston, USA and Oman.

The Queen's Awards for Enterprise in International Trade are the UK's highest accolade for excellence in business and are awarded annually to companies which have achieved substantial growth in overseas earnings and commercial success for their business size and sector. Recipients are presented with the award at a reception at Buckingham Palace, and can use the Queen's Award emblem in their advertising and marketing. ■

## Argentina's Unconventional Resources

The **2nd Shale Gas World Argentina Conference**, which will be held in **Buenos Aires** in August, is an opportunity for operators, government and regulators to discuss the issues at stake in order to successfully develop Argentina's unconventional resources. Ali Moshiri, President of Chevron Africa and Latin America E&P, will open the event and highlight why Argentina is well placed to bring the North American energy renaissance to South America. As the region's second largest economy, it boasts a highly educated workforce and the technology, resources, and infrastructure to support a robust oil and gas industry.

Shale gas recovery must address three major challenges: reducing water use, managing pollution risks and limiting visual and noise intrusions at and around production sites. There will be a pre-conference workshop discussing the practical tools needed to ensure shale operations are conducted in a sustainable, environmental and socially responsible manner. ■

*Shale gas basins of southern South America*



## PRM in the North Sea

**Statoil** has initiated an extensive **Permanent Reservoir Monitoring (PRM)** programme over the Snorre and Grane fields in the Norwegian sector of the North Sea and has contracted marine geophysical services company **WGP** to build and operate a bespoke Dual Portable Modular Source System (D-PMSS™). The acquisition contract, which comprises performing surveys over each field twice a year, is for an initial fixed term until the end of 2017, with Statoil's option to extend by two further two-year terms; the first survey is scheduled to commence in October 2013.

As 'easy oil' diminishes, the demand for increasing the output from known hydrocarbon reserves increases. Reservoir monitoring techniques have been engaged by energy companies opting to invest in the installation of trenching or semi-permanent ocean bottom cable

arrays over active oil and gas fields to provide time lapse 3D (4D) data sets. The utilisation of PMSS for PRM is now a proven technique, and WGP has continuing contracts with BP in the North Sea (Valhall) and Caspian Sea. "Containerised

source systems have been in use as an exploration tool since the early 1990s, and 2013 marks WGP's 10th anniversary of providing containerised source systems for the evolving PRM sector," commented **Mark Burnett**, WGP's CEO. ■

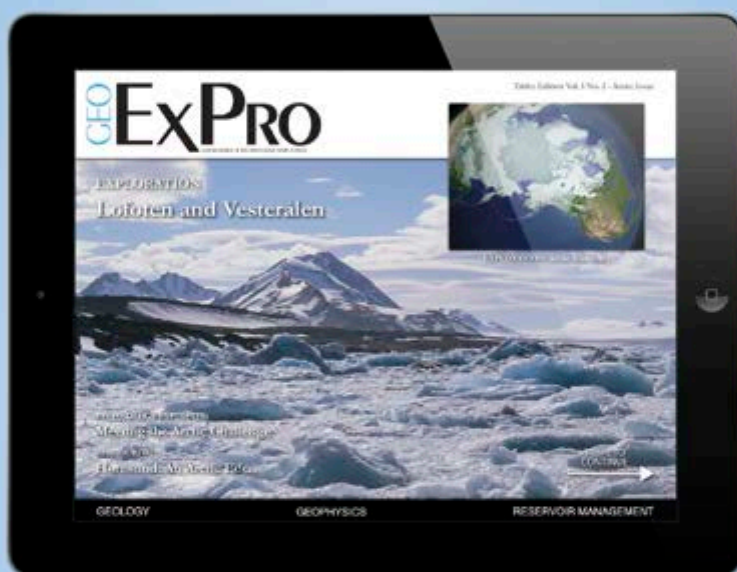
*WGP's PMS system in operation on the Valhall oil field in the North Sea*



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# Insights from Space!



**MICHAEL HALL,**  
Astrium Services,  
GEO-Information

With recent offshore gas discoveries reviving interest in the Eastern Mediterranean region, a variety of methodologies can be used to assess potential, including using data from satellites orbiting the earth. Could these reveal the presence of the elusive deeper oil?



Recent offshore gas discoveries have renewed interest in the Eastern Mediterranean region and its reassessment for hydrocarbon potential. In order to develop a detailed geological understanding of a region, and efficiently target exploration efforts, it is important to bring together modern technologies from a range of disciplines. Increasingly, data acquired from orbiting satellites are supporting upstream activity, providing unique information for areas that are often remote or inaccessible.

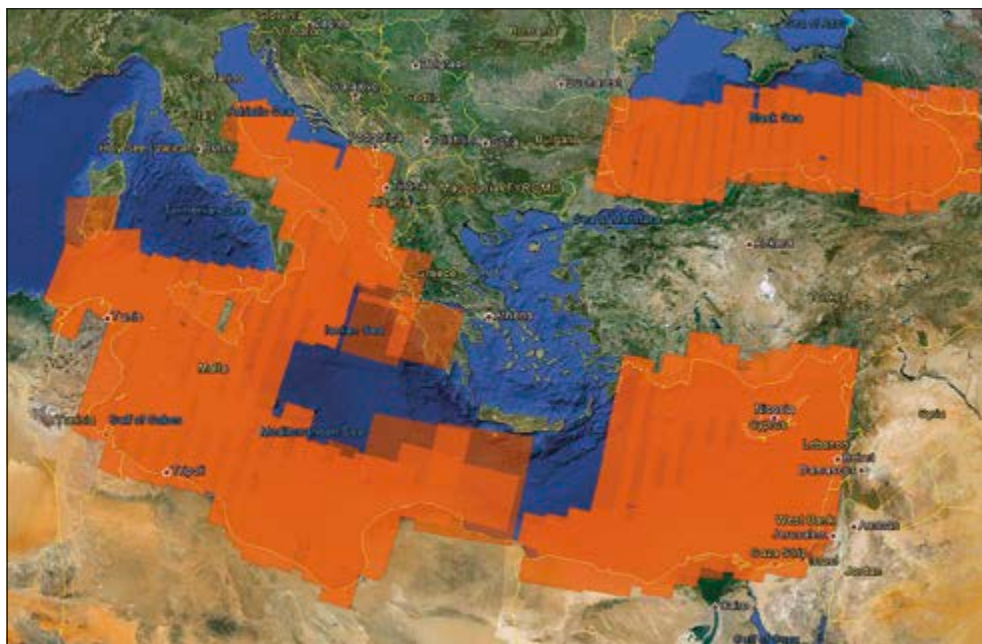
During the exploration stage of a project, satellite data can contribute in two main ways. Firstly, radar sensors can identify oil on the sea surface sourced from natural seeps, while optical data and elevation models can also be used to assess surface geology, including structure and stratigraphy. Together this represents a proven approach that has been used by oil exploration companies worldwide.

To support exploration in the Eastern Mediterranean region, Astrium Services therefore recently reassessed the area in order to produce a non-exclusive study that combines the location of offshore oil seeps with a regional evaluation of onshore geology at 1:100,000–1:500,000 scale.

## Offshore Oil Seeps

Astrum Services has interpreted over 13,000 satellite scenes for the purpose of mapping natural oil slicks for its Global Seeps database, which is a non-exclusive database of offshore oil slicks, constructed by systematically screening the world's offshore basins using a wide range of archive and newly programmed satellite data. The database now contains over 14,000 identified potential seepage slicks, including slick source points, slick vectors, probable slick type and confidence levels.

Finding slicks on the sea surface is an indicator of a working petroleum system within a basin. The methodology is based on the dampening effect oil has on wave amplitude, which directly influences the backscatter returned to the radar sensor on the satellite. What we are effectively



Coverage of radar scenes (orange) for the East and Central Mediterranean region used for identifying natural oil seeps on the sea surface. Reduced transparency indicates greater repeat coverage.

observing is the influence that oil is having on wave conditions, rather than the oil itself.

So how can we make sure that we are not confusing a natural seep with an external factor such as pollution from shipping? Critical to this distinction is the use of repeat satellite coverage with a time separation of months or even years. Persistent seeps seen repeatedly over the same area would indicate a natural source as opposed to a pollution incident. This enables slick features to be assigned a confidence level based on specific criteria.

## An Indication of Deep Oil?

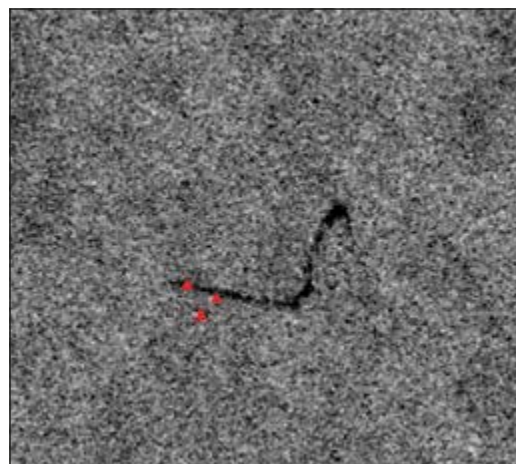
Discoveries in the southern Levantine Basin by Noble have largely consisted of biogenic gas with reservoirs located in Lower Miocene/Oligocene sands lying beneath the Messinian Salt. But a Mesozoic source of thermogenic oil and gas is also a possibility. A study by the USGS has estimated a mean of 1.7 Bb of recoverable oil in the Levant Basin Province.

Based on the interpretation of the radar data, a number of oil slicks have been identified in the Levantine Basin, with particular concentrations adjacent to the Lebanon and Israel coasts, and directly south of Cyprus. Results indicate the offshore Nile Delta

is also particularly prolific in terms of oil seeps, with a number of high confidence features. Further investigation is needed as to whether these oil slicks could be originating from this deeper oil source, where a suitable migration pathway exists.

Information on oil slicks is especially valuable when integrated with other datasets, particularly seismic data. Other studies in the region (Roberts and Peace, 2007; Peace and Johnson, 2001) have made comparisons between seismic and seep locations. Correlations have been observed with Direct Hydrocarbon Indicators, bright spots, flat spots and gas chimneys. In addition seeps were also associated

Example of a radar image showing a hydrocarbon seep located in the Levantine Basin. Multiple source points are shown (red triangles) based on multi-date imagery.





with clear migration pathways through deep-seated major faults.

### Creating a Regional Geological Context

Geological mapping from satellite imagery is an established technique, with medium 15m resolution earth observation data such as Landsat providing a rich information source for efficiently undertaking geological interpretation over extensive onshore areas. Primary data collection includes structural information such as relative bedding dip and orientation and fault identification and classification, which together with spectral and textural information allows for the assessment of surface stratigraphy.

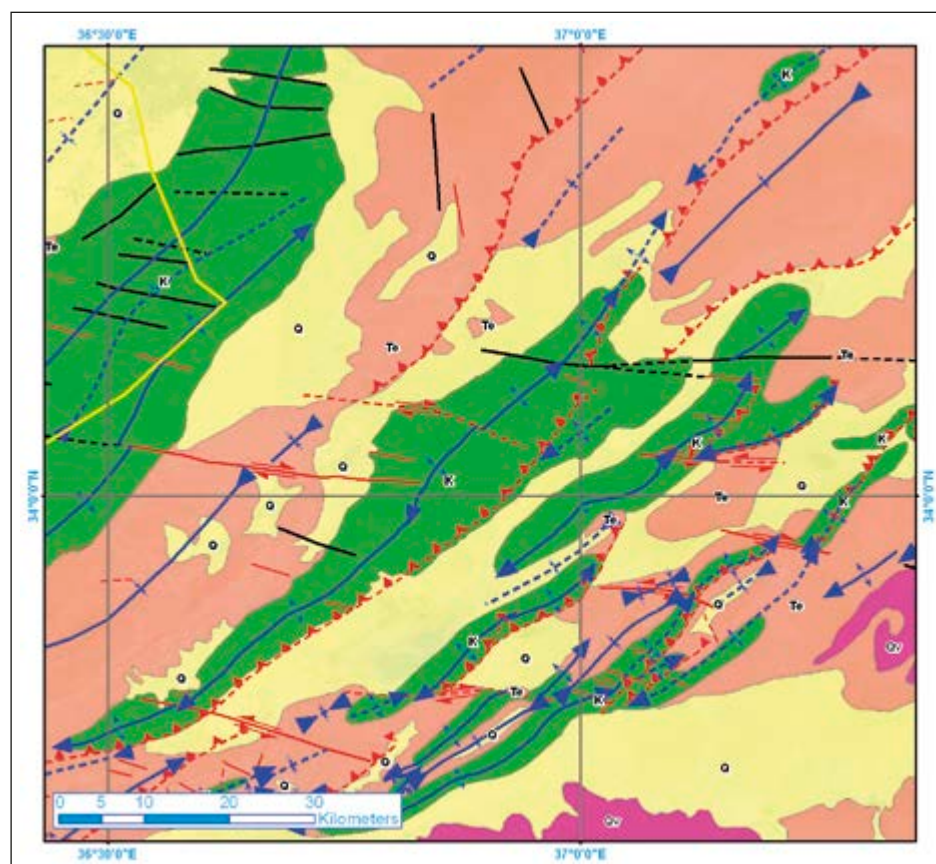
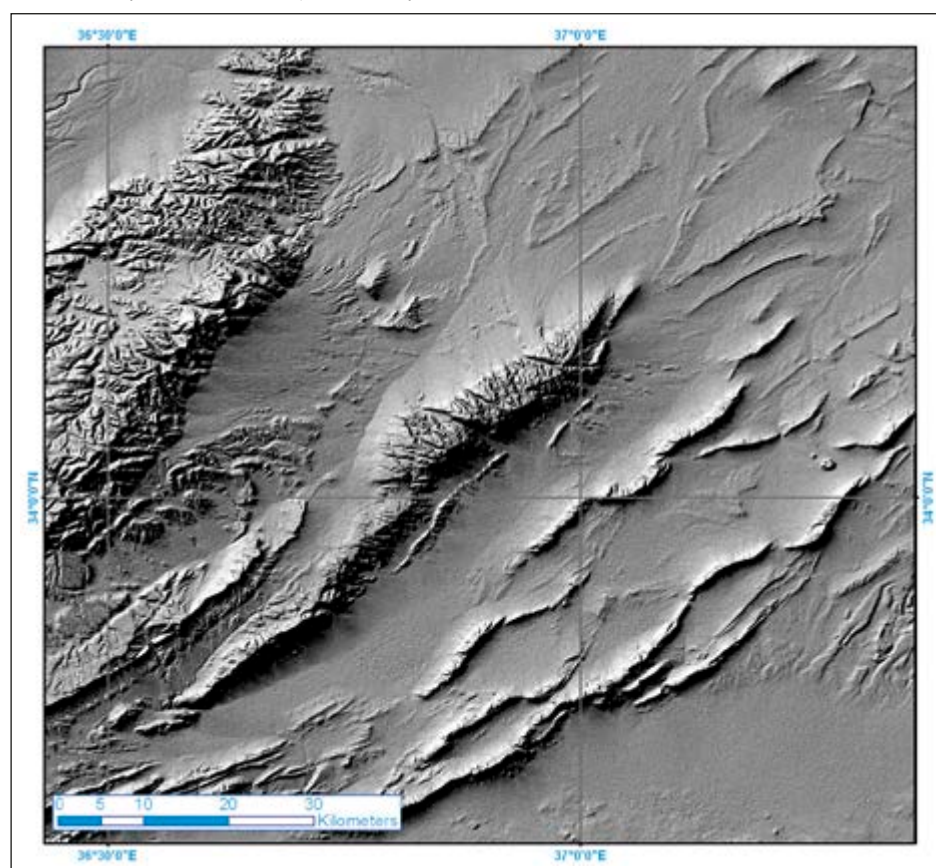
An understanding of the regional setting provided by satellite data delivers important context that simply is not achievable from ground-based observations alone. Onshore interpretation was undertaken from Tunisia to Turkey, covering Libya, Egypt, Israel, Lebanon and Syria, and leading to the creation of a seamless digital GIS dataset. The study has revealed a number of previously unmapped structures as well as providing geological context to the offshore study. For example, developing a better understanding of the nature and orientation of folding within the Syrian Arc may lead to a greater understanding of offshore structures.

Follow-up work using higher resolution data from the constellation of satellites such as SPOT 6 (1.5m resolution) and Pleiades (0.5m resolution) has also been conducted over specific areas. Through this it is possible to derive more detailed geological mapping, of great importance as regional screening progresses to individual licence block evaluation.

### Exciting Potential

The Eastern Mediterranean presents an exciting area for oil and gas exploration, with great potential, as indicated by discoveries over recent years. Remote sensing technologies have an important contribution to make in terms of regional screening

*Landsat imagery and SRTM data are used to produce a regional geological interpretation (as shown below and at top of page 26) for the Palmyride mountain belt in Syria. Using satellite imagery in this way helps develop a better understanding of the nature and orientation of folding within the Syrian Arc which has implications for the hydrocarbon potential of structures offshore.*





## Are you missing pieces to your unconventional exploration puzzle?

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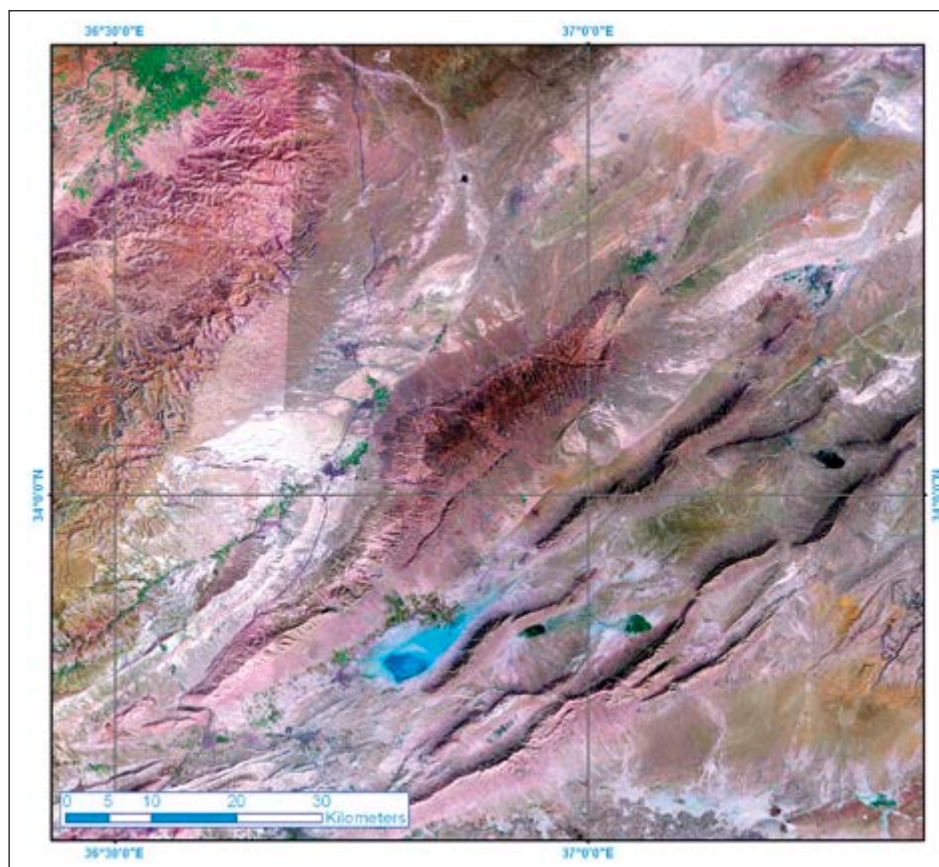


Right: Landsat imagery of the same area in the Palmyrides as shown on page 24, this time in a 742 (RGB) pseudo-colour band combination. This band combination, incorporating the short wave infra-red, enhances surface lithological variation.

and targeting, both onshore and offshore. With further drilling planned, and the presence of potential oil seeps across the region, is the occurrence of deep oil a possibility?

**Michael Hall** works as a Remote Sensing Geologist for Astrium Services, GEO-Information, with a particular focus on providing consultancy to the Oil & Gas sector. Before joining Astrium in 2008, Michael worked for the British Geological Survey – spending seven years as a remote sensing scientist and a geological field surveyor. Michael holds an MSc in Remote Sensing from University College London, and a BSc in Geological and Earth Sciences from the University of Exeter. ■

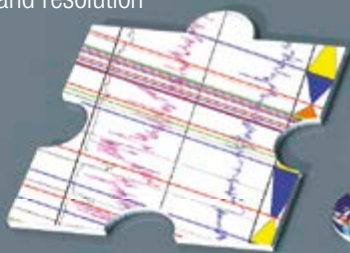
Below: Imagery for Tunisia from the recently launched SPOT 6 satellite offering imagery at 1.5m resolution can be used to produce a detailed interpretation of surface geology for key areas





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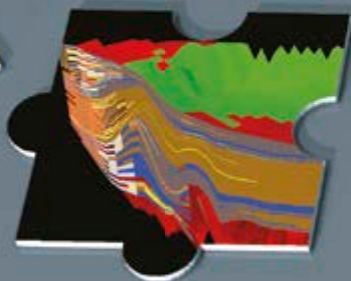
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# Alaska North Slope: Source Rocks Hold Promise

THOMAS SMITH

The US Geological Survey's recently completed assessment of three North Slope shale plays indicates a potential of two billion barrels of recoverable oil and eighty trillion feet of gas.

In Alaska's October 2010 lease sale, Great Bear Petroleum surprised just about everyone by winning 105 tracts covering over 2,000 km<sup>2</sup> directly south of the Prudhoe Bay Complex (see *GEO ExPro*, Vol. 8, No. 2). Since that time, they have set out to evaluate their acreage. Great Bear's initial 2-well drilling programme was completed in late November 2012, where they recovered over 183m of whole core from the Alcor #1 and Merak #1 wells and sampled oil from the conventional Kuparuk sand. Great Bear is currently evaluating the core samples, well logs, oil samples and other tests to assess and calibrate the play fairway. Great Bear has also just finished acquiring an additional 3D seismic programme covering approximately 596 km<sup>2</sup> of proprietary 3D seismic adjoining its existing 154 km<sup>2</sup> of proprietary 3D. These operations were fully funded by Halliburton Energy Services, Inc. satisfying the earning provisions for a 25% working interest in

510 km<sup>2</sup> and an option to provide services in just that area.

Great Bear is targeting primarily the unconventional oil and natural gas liquids (NGL) fairway in its acreage, which is adjacent to the Trans-Alaska Pipeline System (TAPS) south of the Prudhoe and Kuparuk oil fields. According to Great Bear's president, Ed Duncan, "Our initial plans were to drill a couple of horizontal sidetrack wells from the original vertical wells to test oil production from the unconventional play. However, operations and lab analysis took much longer than expected so we had to suspend drilling operations due to expiration of our rig contract."

## Multiple Targets

The US Geological Survey (USGS) 2012 assessment looked at three North Slope source rocks. These were (1) the Triassic Shublik Formation, (2) the lower part of the Jurassic-Lower Cretaceous Kingak

Shale, and (3) the Cretaceous pebble shale unit and Hue Shale, which together are referred to as the Brookian shale. These three shales generated most of the oil and gas that migrated into Prudhoe Bay and other large conventional fields found on the North Slope. Great Bear is the first to target them directly.

The Shublik Formation has sourced 23° to 39° API gravity and high sulphur (greater than 1.5%) oil from a mixture of Type I and IIS kerogen. This transgressive facies reaches a thickness that exceeds 61m in western National Petroleum Reserve A (NPRA) and thins depositionally east to Prudhoe Bay where it is truncated by the Lower Cretaceous unconformity. Both the total organic content (TOC) and the original hydrogen index (HI) are highest from northeastern NPRA to where the formation is truncated at Prudhoe Bay. The Shublik is considered a good reservoir candidate, containing brittle rock types (limestone,

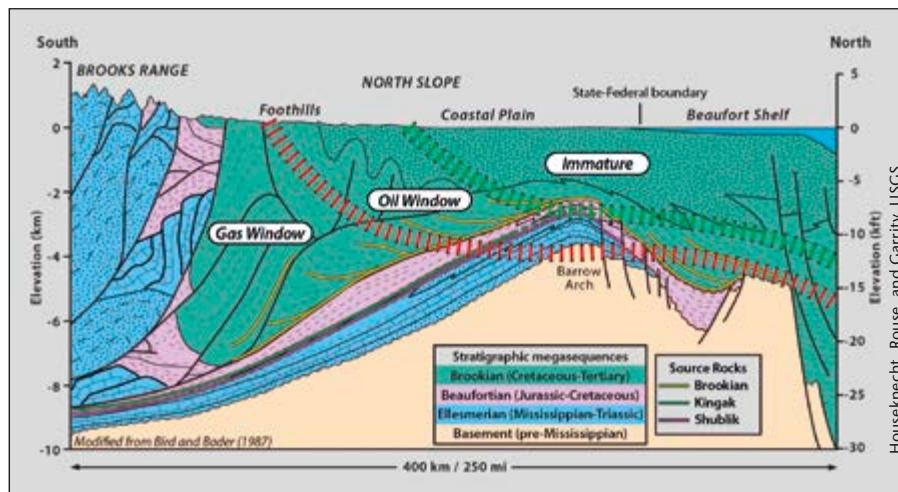
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*One of the two wells drilled by Great Bear Petroleum to evaluate shale-oil reservoirs on Alaska's North Slope, the Alcor No. 1, was drilled to 3,295m. The wells were located approximately 27 km south of Deadhorse in Alaska, adjacent to the Sagavanirktok (Sag) River. The dirt strip adjacent to the rig is the Trans-Alaska Pipeline System (TAPS), one of the few places it is buried on the North Slope.*



sandstone, siltstone and chert) in which natural fractures are common. Dr. David Houseknecht of the USGS concluded that the best oil potential for the Shublik occurs in the shale-oil assessment unit (AU) as determined by thermal maturity (the area where Great Bear is exploring). The Shublik has good gas potential for much of the North Slope.

The Kingak and the Brookian shale contrast with the Shublik in that these formations have sourced higher gravity (35-42° API) and much lower sulphur (less than 0.3%) oils from predominately Type II and III kerogen. In eastern NPRA and further east, the lower Kingak contains a condensed shale section that has high TOC and HI values. USGS researchers inferred that this area has the best oil and gas potential; however, the Kingak consists of mostly clay shale that deforms plastically and may not be a good reservoir. With similar kerogen as the Kingak, the Brookian shale does have brittle lithologies such as very-fine grained sandstone, siltstone, concretionary carbonate, and silicified tuff that could render it a much better reservoir. These brittle facies, along with high TOC and HI, occur east of NPRA across the central North Slope and have been encountered in both Great Bear wells. The area of highest oil and gas potential is located on State lands between NPRA and the Arctic National Wildlife Refuge (ANWR,) where the



Generalised geologic cross section from the Brooks Range to the Beaufort Sea shelf across the central North Slope of Alaska. Stratigraphic positions for the three source rocks (Shublik, Kingak, and Brookian) are shown schematically along with the maturities of these source rocks (gas window, oil window, and immature). The two Great Bear wells penetrated the source rocks in the oil window down dip from the Barrow Arch.

thickness exceeds 150m.

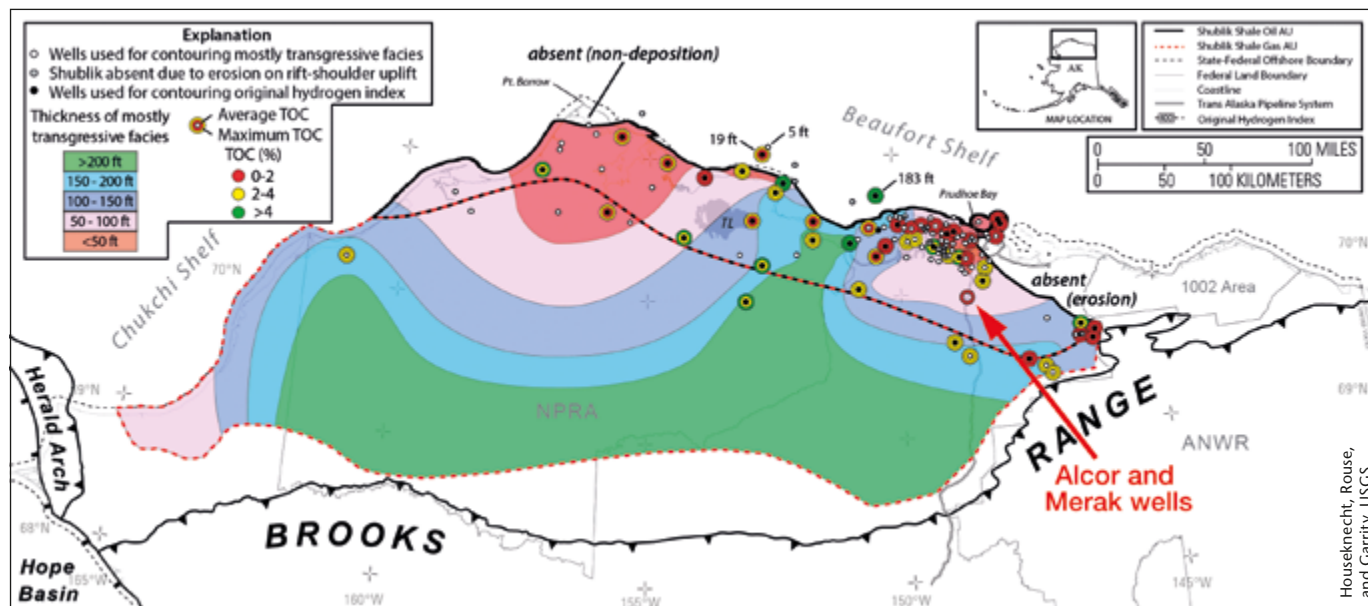
All three of these source rocks occur over much of Alaska's North Slope and range in depths from less than 900m along the Barrow Arch to over 6,000m along the Brooks Range front. Thermal maturity varies from immature near the coast, through the oil window and into dry gas to the south near the Brooks Range. The USGS has assigned the Shublik with a 95% probability that technically recoverable oil and gas will be possible, 90% for the Brookian shale, and 40% for the Kingak. With no production data to date, the USGS estimates 0 to 928

MMbo and 0 to 72 Tcfg for the Shublik, 0 to 955 MMbo for the Brookian, and 0 to 117 MMbo for the Kingak (gas was not assessed for the Kingak). They concluded that "the Shublik is estimated to contain the greatest oil and gas resource potential per unit area, with values that rank among the top few source-rock systems in the United States."

### Great Bear's Programme

The 2012 drilling programme confirmed that all three source rocks which the USGS evaluated are present and in the 'oil window'. The shallowest unconventional

Map of the most promising oil-prone shale unit, the Shublik Formation, showing thickness and TOC across the North Slope of Alaska. The location of Great Bear Petroleum's wells is the red circle on the Trans-Alaska Pipeline.







Rig on location at the Merak well.

zone, the lower Hue/HRZ shale (Brookian), was encountered with good oil shows over an interval in excess of 180m. Cores over this interval are very organically rich with TOC values up to 8%. They also recovered 30m of lower Kingak core (possibly one of the most complete ever taken). Finally, their primary target, the Shublik Formation, was cored through the entire formation. Both the Kingak and Shublik were at the thermal maturity that would support light oil and condensate generation, confirming Great Bear's regional thermal maturity fairway mapping.

In addition to these unconventional plays, the wells penetrated three conventional plays. The Brookian turbidite fan play is productive at the ConocoPhillips-operated Meltwater Field, located west of Great Bear's acreage. The next conventional play these wells encountered was the Kuparuk sandstone that is regionally productive to the north, centred at the Kuparuk Field. Finally, they encountered the Ivishak, which is the primary reservoir at the Prudhoe Bay Field.

In early 2013, Great Bear acquired 596 km<sup>2</sup> of proprietary 3D seismic, which is now being processed and expected to be completed by late summer. This data will be combined with their existing 3D to give them over 750 km<sup>2</sup> of 3D coverage across the core of their lease holdings. They will use this data to codify a dual conventional/unconventional exploration programme that covers 175,000 acres (708 km<sup>2</sup>) positioned along and west of the TAPS and Dalton Highway.

### Right Place – Right Time

In spite of the Arctic conditions, Great Bear is operating in an area that has seen decades of exploration and development activity with no urbanisation or agricultural activity across their lease position. This is often not the case in the lower 48 states, where shale development can be hampered and operationally challenging in populated or agriculturally intensive areas. There is also a lack of potable water aquifers in the central North Slope area, mitigating the possibility of municipal ground water contamination. In addition, a thick layer of permafrost is present across the area, which provides a 'barrier' between the frac depths and the surface. There are, however, ample surface and brackish sub-surface water supplies for drilling and stimulation programmes. The Dalton Highway, as well as the TAPS (currently operating at 40% of design capacity), bisects Great Bear's acreage, providing the necessary low-cost access to markets. ■

## Alaska Seeks to Reinvigorate Exploration Activity

The last five years have witnessed oil production in the lower 48 states dramatically increasing from about 4.3 to 5.8 MMBopd, marking a reverse of a multi-decade decline in domestic oil production. By most estimates, the US could become the world's largest oil producer and a net exporter of natural gas by 2020, something unheard of just a decade ago.

However, Alaska, whose economy is dominated by oil production, has been displaced as the leading oil producing state. Crude oil production in Alaska has fallen continuously since 1988, from a peak above 2 MMBopd, to approximately 500,000 bopd, falling behind Texas, North Dakota and California in national oil production.

To compound Alaska's woes, the future of TAPS, which has been transporting Prudhoe Bay oil to export markets for over 35 years, is in question. Dangerously low flow rates through the 800-mile system may test the engineering limits of the pipeline which could ultimately lead to its closure. The US Energy Information Agency projected that this could occur as early as 2026 without remedial action.

On 14m April 2013, the Alaska Legislature approved a series of tax reforms intended to attract the new investment needed to reinvigorate activity and reverse oil production decline. The previous progressive tax structure introduced by the Palin Administration (Alaska's Clear and Equitable Share) applied a base tax rate of 25%, that progressively rose to 75% as oil prices increased. Although this system resulted in healthy budget surpluses for the State, it made Alaska an uncompetitive investment environment.

Under the new legislation (Senate Bill 21) that was just passed 14 April 2013, production will be taxed at a flat 35% rate, while a series of investment incentives could reduce the effective rate to as low as 14%. These measures are intended to promote the development of existing commercially marginal projects and spur the exploration for new resources in one of the nation's most petroliferous basins. The bill is awaiting Governor Parnell's signature.



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# SHALE GAS: Promises, Challenges and Global Implications

As is well known, shale gas and other unconventional resources have revolutionised the hydrocarbon industry in the US, and the country is expected to become a net exporter of gas by 2020, according to the EIA. What is the significance of this for global energy?

## JANE WHALEY

"Several times in the past we have thought that we were running out of oil, when actually we were running out of ideas."

*Professor Parke A. Dickey  
University of Tulsa Petroleum Geology, September 1958*

*Dr. Basim Faraj has a PhD from the University of Queensland, Australia, and has worked as an exploration geochemist in conventional and unconventional oil and gas reservoirs on projects in Jordan, Japan, Canada, USA and Australia. From 2005 to 2010 he was the Unconventional Gas Specialist at Talisman Energy. Currently Basim is VP New Ventures, Tamboran Resources Pty Ltd in Calgary.*



*The Fayetteville Shale is an unconventional gas reservoir that extends across northern Arkansas.*

"When I started out in this industry 25 years ago, if someone had told me that shale could be a reservoir, I would have laughed," says Dr. Basim Faraj. "Yet now we realise that we have a substantial new resource – and it is spread throughout the globe!"

"The influence of shale gas has been huge in North America and I believe that its global impact is on the horizon, with Australia, Asia and Europe all set to benefit greatly from this new resource," Basim, who is Vice President of New Ventures with Tamboran Resources, explains. The Australian company is well placed to analyse the situation, as it holds permits and applications covering more than 120,000 km<sup>2</sup> of land, all prospective for unconventional oil and gas, including acreage in Ireland, Australia and Botswana.

Gas has been steadily increasing its proportion of the energy mix, but the huge increase in gas resources in the US has been driven largely by the discovery of five giant 'fields': the Eagleford, Haynesville, Montney, Horn River and Marcellus shales. Although these were all discovered since 2007, deep shale gas production had actually become a commercial reality in the 1980s and 90s, with the discovery of the Barnett Shale in North-Central Texas.

"Shale gas now accounts for about 25 Bcf/gpd – 35% of the total US annual gas production," Basim explains. "The Haynesville and Marcellus shales, which only started producing three years ago, together now account for production of 9.6 Bcf/gpd – that is over 130% of total Canadian annual gas production and 420% of the amount that Australia produces."

"To appreciate the huge size of these resources and their implication on global resources, it is instructive to compare them to the largest known producing play to date, the Zagros-Mesopotamian Cretaceous

to Tertiary petroleum systems of the Middle East. This has been producing since the 1960s and is estimated to have had a total resource of nearly 500,000 MMboe. The Bakken petroleum system is now considered to hold a similar amount and is ranked second in the world after the Zagros-Mesopotamian system. And the Eagle Ford shale system, which was not even mentioned four years ago, is now ranked in the top fifteen in world resources estimates."

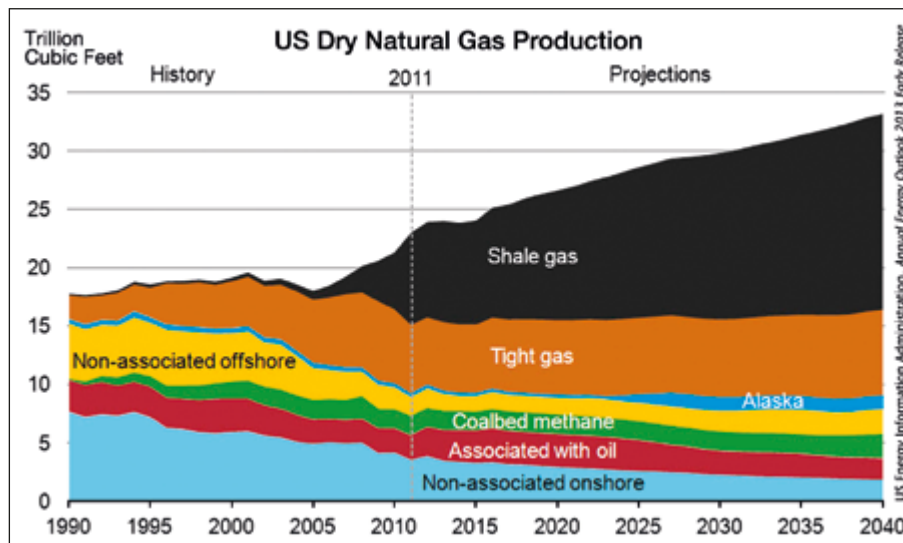
### Technological Innovation is Key

Basim believes that innovation in operational techniques is key to value creation in unconventional projects. "Shale is obviously very different from other reservoirs, and key to its development in the US has been constant technological innovation. Unlike, for example, coalbed methane, shale is a hard, brittle rock with a low TOC (Total Organic Content), but on the plus side it is usually found in units that are hundreds of metres thick, allowing us to go deeper and endeavour to get better production rates."

"Similarly, the tight nature of the rock – a 'good' shale has permeability of between 0.001 and 0.0001 mD, in comparison to the 0.01 mD permeability of sidewalk cement – means that innovative thought had to go into creating methods of commercially producing gas from shales. Persistence was key – as was not being blinded by accepted practices. Before fracking was found to be effective, a number of other methodologies, such as pumping propane and gel, were tried unsuccessfully in attempts to extract the gas from tight shales. Slickwater fracs were the answer: large volumes of water and sand pumped under high pressure (~100 barrels per minute)."

Another recent development which has proved important in the exploitation of shale gas is the use of micro-seismic technology. "This has shown that our standard models don't work," Basim continues. "As a result of this innovation, our understanding of frac geometry and stimulated rock volumes, and thence gas and oil recovery factors, has vastly improved."

"Operational techniques have evolved considerably over the past few years, in particular with respect to 3D seismic, which has been taken to a whole new level



Shale gas production is expected to increase from 5.0 Tcf in 2010 (23% of total US dry gas production) to 13.6 Tcf in 2035 (49% of total US dry gas production)

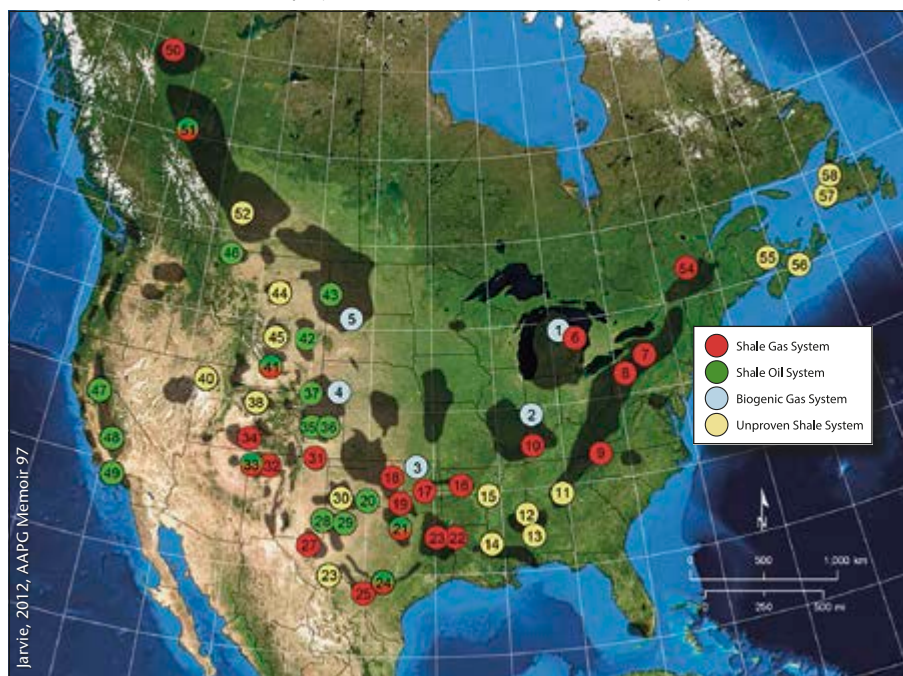
though shale gas exploitation. Maximum curvature analysis, for example, is being used to identify areas that are not highly fractured, to enable the most efficient placement of horizontal wells, which in turns increases productivity and recovery of hydrocarbons from the shale."

Difficult-to-reach terrain is often a challenge in shale gas production, due to the large number of rigs, pumps, water tankers and other equipment needed, especially when considering exploration outside the US. However, Basim believes that if the project is big enough and economic enough, getting

the equipment to it will not be an insoluble problem.

"Continuous technological improvement is the thing that is keeping costs under control," he concludes. "Initially, shale gas projects were very expensive, but the economics had to be improved before commercial production became a reality. For example, in 2007 Southwestern Energy estimated that an average well in the Fayetteville Shale had a lateral length of around 770m, produced about 2.5 MMcf/gpd and cost nearly \$3 million. Just two years later a similar well cost \$3.1 million, but was producing 3 MMcf/gpd

North American shale resource plays. Numbers refer to individual shale plays





from wells with a lateral length of 1,180m, while by 2012 the cost of these wells, nearly 1.5 km long and producing 3.6 MMcfcpd, had dropped to \$2.5 million. "It is this continuous innovation in a play that allows operators such as Southwestern to be commercially successful despite a relatively low gas price, and indeed positions them well for any upturn in gas prices as their production processes are extremely efficient. It is almost like the application of the Japanese 'kaizen', or continual improvement philosophy, to the shale industry.

"However, the price of gas in the US means that many wells are currently shut in," he continues. "Efficient operators are looking to reduce their cost per well to remain in the game or are switching to condensate and shale oil targets as these command higher prices."

Basim is also quick to point out that there are many myths about the impact and use of water resources – often a factor used to suggest that the development of shale gas may not be feasible in parts of the world where water is a scarce commodity. As he points out: "In Texas, more than half the total state water consumption is used by agriculture for irrigation, and 9% in manufacturing, in comparison to the less than 1% being used in the production of shale gas. In Arkansas, duck hunting clubs alone use a billion litres of water a day, 2.3% of the state's total consumption!"

### What Makes A Good Shale Play?

Basim remarks on how it is useful to look at the various properties and features of a good oil play, such as the Eagle Ford, to identify just what makes it successful – and how important it is to carry this information into exploration of other plays. "The Eagle Ford has some of the best rock properties of all US shale plays," he explains. "Porosity is between 6 and 7% and is distributed both intergranularly and intra-kerogen, which is ideal, while permeability can be as much as 0.003 mD – relatively high for a shale. The horizons are up to 137m thick, with TOCs of 3–7% and water saturation between 13 and 25%, and as a result, the recovery factor for wet gas is in the region of 30 to 40%.

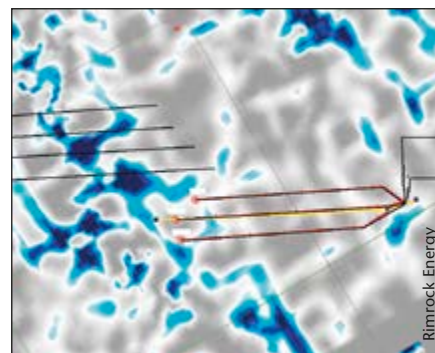
"These are the sorts of factors we are looking at in our licences outside North America. It is very important to check all the properties of each prospective formation

carefully, wherever it is in the world, and not make assumptions about the geology until new cores are cut and analysed.

"We believe that in the shale market, Australia will be the next big thing after Canada," he continues. "The Northern Territory Beetaloo Basin has shale oil potential and Tamboran signed recently a joint venture agreement with Santos for \$80 million to explore this area. Australia is looking at the large Japanese and other Asian markets for its gas production, but further work needs to be done in the area of developing efficient small scale GTL (gas to liquids) projects for the smaller fields before these can be economically produced. Other parts of our acreage, including Botswana, are under investigation, although it is too early to tell the full potential of these."

### Huge Impact

"Shale gas has had a major positive influence in North America," Basim points out. "However, there are interesting impacts of this resource development which are rarely discussed, but which have global influence. Take, for example, the petrochemical industry; Dow are closing plants around the world and moving them to Texas to use the cheap dry gas as feed stock for their petrochemical products. Elsewhere in the US, plans to build new import terminals have been switched to the construction of export terminals – and the export of that gas worldwide will have a crucial impact on the energy supply and balance in many countries, both those that expected to export hydrocarbons to the US and those that are now finding the supply of cheap gas is having a major



*Taking 3D seismic to a new level: maximum curvature analysis in the Barnett Shale*

effect on their own developments.

"As I have already explained, technological innovation and economics have been, and will continue to be, of fundamental importance in the effective exploitation of unconventional resources. We have undergone a steep learning curve in North America, and it is vital that we learn from mistakes made there when looking at the rest of the world, and don't repeat them. Natural variability is inherent to all unconventional plays, and this must be considered when evaluating the viability of new shale resources.

"The revolutionary concept of hydrocarbon production from shale is without a doubt the most exciting accomplishment of geosciences and petroleum engineering integration in the last several decades," Basim concludes. "For our industry to continue developing, we must use all available resources and innovate continuously. We must never run out of ideas, so we can continue providing the most needed commodity to the world: energy." ■

*The large number of rigs, pumps, water tankers and other equipment needed for shale exploitation can be a challenge – but if the prize is large enough, these will be overcome.*



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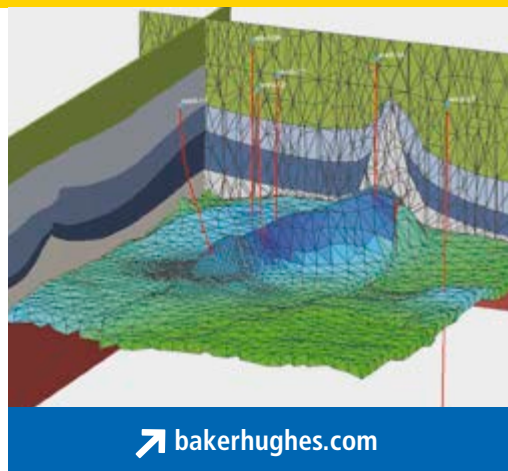
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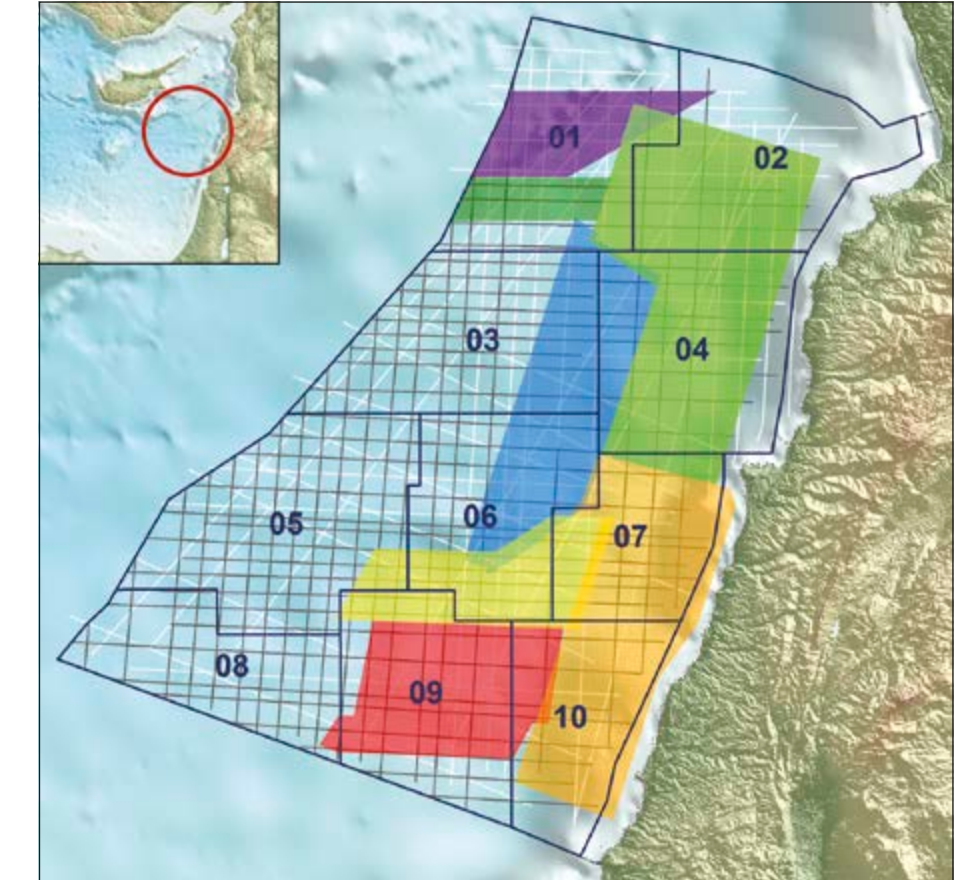
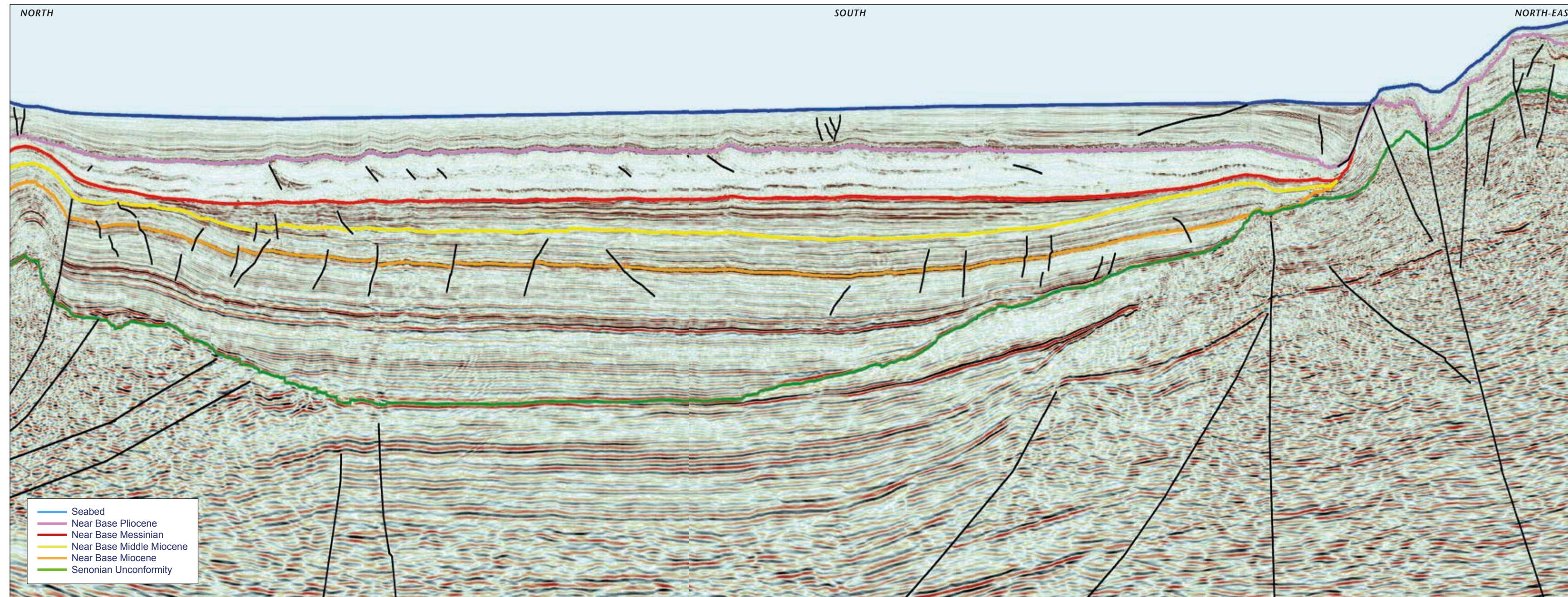




# Will Lebanon Be the Next Oil Province?

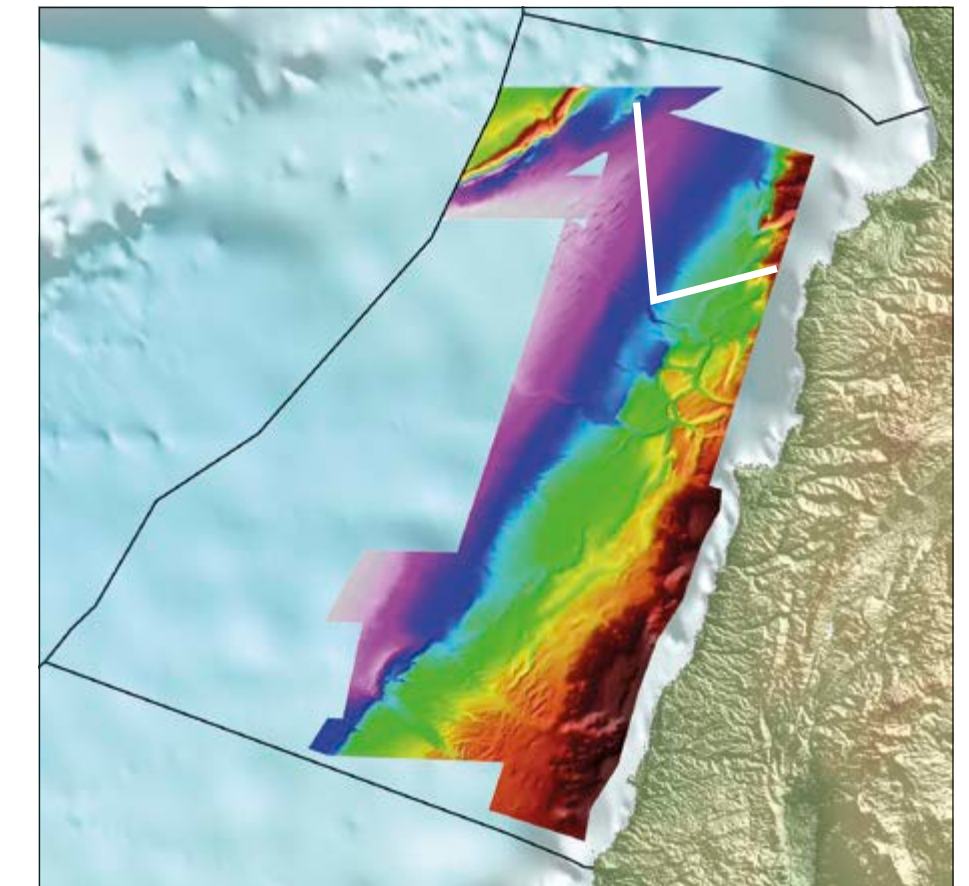
After several years of preparation the first offshore bid round in Lebanon is now open. Petroleum Geo-Services has acquired non-exclusive seismic data covering all the 10 exploration blocks of the 22,730 km<sup>2</sup> offshore area. The seamless Lebanon PSDM MegaSurvey, which is providing continuous seismic 3D coverage from north to south, is a powerful tool to understand the petroleum systems and to assess the potential prospects in this region, which will be the next hot spot for oil and gas exploration.

*The key regional reflectors have been interpreted on the data and all the MC3D surveys have been merged and re-processed with PSDM imaging. This arbitrary PSTM line example (65 km long) illustrates the variety of different play types offshore Lebanon.*



The 10 exploration blocks with the PGS MC2D and MC3D seismic data coverage in the background.

MegaSurvey seabed grid, with the location of the foldout line shown in white.





# MegaSurvey Key to Understanding Prospectivity

The Ministry of Energy and Water of the Republic of Lebanon opened their first bid round on 2 May 2013 with a closing date of 4 November 2013. Twelve companies qualified as operators and 34 as non-operators and bids from consortiums of a minimum of 3 companies are invited.

**ØYSTEIN LIE, JÖRN FÜRSTENAU and JOHN COMSTOCK, Petroleum Geo-Services**

Plays offshore Lebanon are stratigraphic, fault and/or fold related. The geological development of the basin is complex, well data is sparse and the area remains undrilled. However, the exploration blocks offered are covered by MultiClient (MC) seismic data (MC2D and MC3D; *see main foldout*), enabling a shortened timespan between block awards and exploration drilling. The seismic acquired includes a dense MC2D grid and multiple overlapping MC3D surveys, providing a consistent dataset for regional interpretation.

The seven MC3D surveys (total 10,000 km<sup>2</sup>) were acquired with different acquisition parameters and directions, but the fold of coverage has been optimised at the boundaries and seismic traces borrowed to produce a seamless MC3D MegaSurvey. The older MC3D seismic has been reprocessed using 3D SRME and other modern noise attenuation, to provide consistent high quality data. All MC3D surveys will be available with pre-stack depth migration (PSDM). The continuous MC3D coverage gives a clearer image of the regional structural pattern and allows interpretation of the depositional history of the northern Levant Basin, providing the key to identifying and understanding prospectivity.

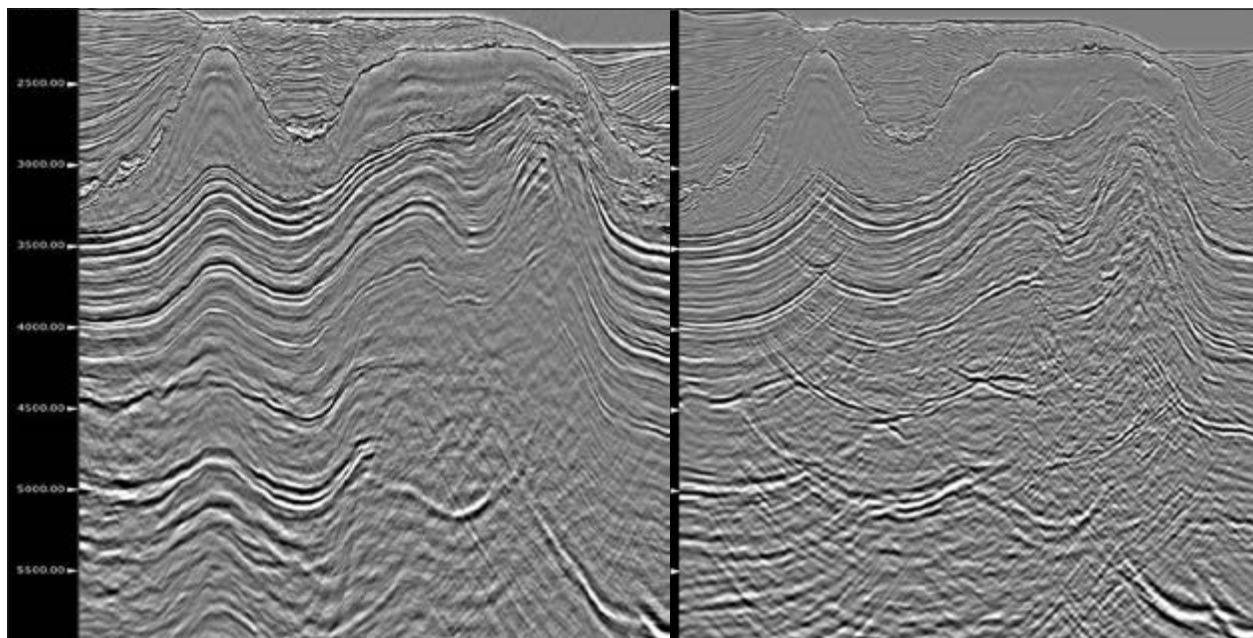
## Lebanon PSDM MegaSurvey

The individual MC3D surveys contain classic time imaging challenges: lateral velocity changes across faults, salt geometries, shadow zones and sub-salt structures. Water depth ranges from 200m on the margin up to 2,000m in the basin and, excluding the margin, a thick Messinian evaporite is present over most of the area. The MC3D MegaSurvey is therefore delivered with PSDM.

Velocity model building used hyperBeam technology and a hybrid velocity model-building workflow enabled the solution of complex velocity variations. The velocity model was built in a top-down fashion with tomography technology allowing construction of a model based on a slant stack of local seismic traces decomposed into wavelets. After solving for background velocity, high-resolution velocity updates were performed to account for rapid spatial variations of salt velocities. Structural updates of key reflectors and tomographic velocity inversion updates, including data masking, were undertaken iteratively. For anisotropy parameters a constant delta and a gradient epsilon function were included. Beam and Kirchhoff migrations were run with the final velocity model producing complementary

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*A comparison of Kirchhoff PSDM (left) and Kirchhoff PSTM (right). The PSDM image is stretched to TWT to enable a direct comparison, showing the significant improvement of sub-salt imaging.*





images. The dipscan process in the Beam PSDM gave a higher signal to noise ratio result than the conventional Kirchhoff PSDM. The Beam has an inherent noise reduction process and relatively clean appearance and is used for a more structural interpretation and the Kirchhoff, with its relatively higher spatial resolution, is used for more detailed interpretation.

### Structural Overview

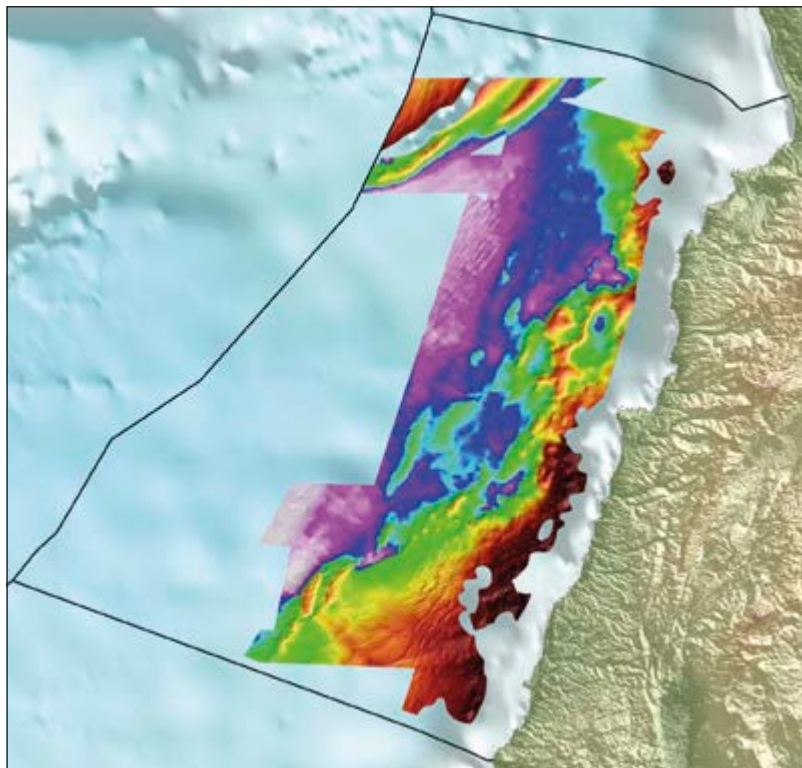
The structural system offshore Lebanon is dominated by left-lateral strike-slip motion of the Dead Sea Fault System and the north-east to south-west trending restraining bend that produces Mt. Lebanon and the Palmyrides. Features similar to the onshore strike-slip faulting are seen in the offshore seismic. Pliocene to recent faulting originates in the pre-Messinian and is characterised, in shallower intervals, by multiple flower structures resulting in pop-up features, anticlinal structures and occasional small-scale extensional basins exhibiting normal faulting. The north-east to south-west trend of the features is consistent with the expected orientation of transpression in a wrench fault system.

Movement along the strike-slip faults results in south-west translation of the thicker and older continental crust outcropping onshore Lebanon toward the Levant Basin, and structurally higher along the margin. Several of the dominant strike-slip faults merge with the north-west to south-east trending, so-called 'Piano Key' normal fault system in a manner suggesting that both sets are related to a single strain field created by the restraining bend in the Dead Sea Fault System. The 'Piano Key' faults are accommodation tears that formed contemporaneously with the strike-slip faulting and these are post-Messinian events. The Messinian evaporite sequence acts as a buffer between the deeper/older strike-slip/'Piano Key' fault systems and the overlying Pliocene sediments and younger normal faulting. The Pliocene sediments are translating north-west above the Messinian salt with extensional faulting seen near the margin and compressional folding and faulting observed basinward. Low angle normal detachment faulting within the older Pliocene section provides a timing horizon for the translation and uplift along deeper strike-slip/'Piano Key' faults.

### Sediment Transport Patterns Revealed

The PSDM MegaSurvey can be used to interpret sediment transport. The main sources of sediment are associated with the Nile and associated fan systems. Northward transport dominates in younger time intervals but during the Late Miocene there are indications of southward directed sediment dispersal in the northern part of the Levant Basin. The Levant Margin probably contributed sediment to the basin consistently but, although important for prospectivity, it is not regarded as a major contributor.

Key interpreted horizons provide a stratigraphic framework from Upper Jurassic to present [see main foldout]. The Lower



*The Base Mid Miocene grid showing the north-east to south-west trend of the en-echelon structures offshore Lebanon.*

Miocene package, proven as prospective in the southern Levant Basin, has a maximum thickness around southern offshore Lebanon and thins towards the east and north, facing central and northern Lebanon. Information on the geodynamic history is limited but the outline of the package indicates fan-like deposition. Seismic cross sections suggest the presence of individual fans, identified as high-amplitude packages within the Upper and Lower Miocene and fed by systems originating to the south-southwest.

Amplitude maps of the uppermost Miocene seismic interval indicate fan systems in the northern Levant Basin. Sediment transport is north-east to south-west, implying sediment sourcing from northern Lebanon and Syria with channelised systems feeding into fan and lobe distributary patterns.

Above the Messinian evaporite sequence the sediment pathways return to the south. South-west to north-east trending channels (parallel to the Levant Margin) are interpreted to originate from the south-south-west carrying sediment to the north-north-east and developing a fan system in the north-eastern part of the Levant Basin. These systems probably represent the distal Nile Delta Cone, with sediments from the African Margin transported initially by the Nile.

*All information about the licensing round can be found on the new official web page of the Lebanese Petroleum Administration: <http://www.lpa.gov.lb/>*

### Acknowledgments

*The authors would like to thank the Ministry of Energy and Water and the Petroleum Administration of the republic of Lebanon and colleagues in Petroleum Geo-Services for all the work and assistance with the Lebanon data. ■*



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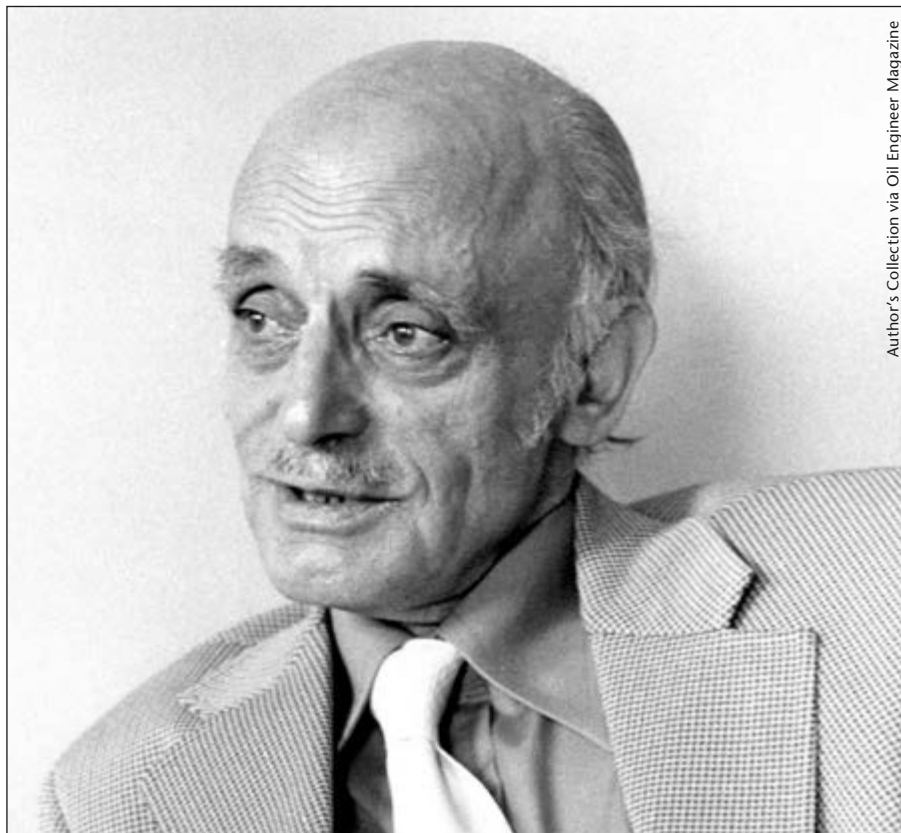
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# The Canadian Driller: A Life in Oil

Bert Blanche started his long career in the oil industry as a roughneck in Texas in 1930. His son Bruce, who became a geologist in the oil industry, tells us his story.

## BRUCE BLANCHE



Author's Collection via Oil Engineer Magazine

My father, Herbert 'Bert' John Blanche, was born in Montreal, Quebec on the 16th of September, 1909. His father, Edwin Josiah Thomas Blanche, had served with distinction in the Canadian Expeditionary Force in France during the First World War, where he had been a 'tunneller' on the Western Front. On his return, he resumed his career with the Canadian Pacific Railway and the family moved to Regina, Saskatchewan.

Bert was educated at the Holy Rosary School and Central Collegiate I in Regina. In

1925, he followed in his father's footsteps and joined the Royal Canadian Engineers, under the command of Lieutenant Colonel J G Bayner. At the same time, Bert was employed by the Canadian Pacific Railway Company in Regina. The experience and engineering knowledge that he gained from his 12 years in the militia stood him in good stead as a roughneck and driller.

### The Lone Star State

In 1935, at the age of 26, Bert Blanche left Canada to stay with his elder brother Ted

in Dallas, Texas. Ted was a well-respected oil field chartered accountant who also financed and invested in wildcat drilling in Texas. He had a lot of contacts – and a private pilot's licence so that he could fly to drilling sites around Texas.

As a result of his brother's contacts, Bert Blanche was quickly drawn to work as a roughneck in the booming East Texas Basin, which had become a prolific oil province in 1930 with the discovery and development of the East Texas oilfield. He started his long career in the oil industry with drilling

Edwin Josiah Blanche on left front, Herbert John Blanche on right front



Author's collection

Bert Blanche's first car – improvised from parts, c. 1933



Author's collection

# Prospectiuni's Seismic Expertise Reduces Risk And Provides Solutions

contractor, the Big West Drilling Company.

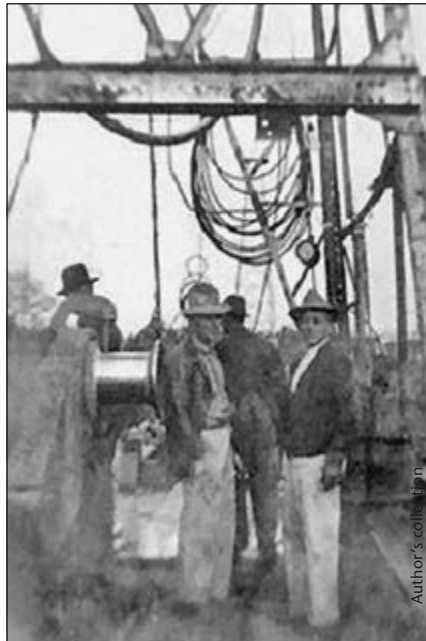
During his time as a roughneck and driller in East Texas, Bert drilled wells for a number of oil companies. Operating conditions were arduous and often dangerous and serious accidents were commonplace amongst the drilling crews. The most notable well he was involved with was Brooks-1, drilled in 1936 near Silsbee in East Texas by the Big West Drilling Company for the Republic-Houston Oil Company. The well was drilled to 2,088m and then caught fire and blazed for three months.

He also drilled wells in East Texas and western Louisiana in 1937 near the town of Beaumont, in the vicinity of the giant Spindletop oil field discovered in 1910 by the Lucas gusher (*GEO ExPro*, Vol. 5, No. 3). The Lucas geyser, located at a depth of 347m, blew a stream of oil over 30m high until it was capped nine days later and flowed an estimated 100,000 bopd. This started an oil boom in East Texas, increasing the population of Beaumont five-fold.

## Crossing the Pond

In late 1937, Bert Blanche left for a new life in the United Kingdom, arriving by ship in Southampton in September 1937. He was employed by the Anglo-American Oil company, the British subsidiary of Standard Oil (New Jersey), later Esso, and was to become the head driller for the company, primarily exploring in and around the East Midlands of England, which became one of the most prolific hydrocarbon provinces in the United Kingdom.

He also drilled in the Midland Valley of Scotland around Dalkeith in Midlothian, which was the 'home' of the Scottish oil industry. This area lies within the



*Al Goodman and Collie Brandt, fellow roughnecks.*

Late Palaeozoic Midland Valley faulted basin, which has a proven hydrocarbon system. Exploration for hydrocarbons had initially taken place during the period 1919–1922, when gas was discovered, together with oil, but the latter not in encouraging quantities. The first oil discovery was made by Anglo-American with the Midlothian-1 well near Edinburgh in 1937.

Bert was involved in the drilling of both Midlothian-1 and -2 and the five follow-up wells during the period 1937–1940. The field was shut down in 1967, having produced 330 MMcf (Hallet et al 1985).

## Declaration of War

At the declaration of war with Germany on the 3rd of September 1939, Bert Blanche

*The crater caused by the fire at the Brooks-1 well*



*Sgt H J Blanche*



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was drilling the Midlothian-4 well. The first German raids were in October 1939 on the Firth of Forth, very close to the drilling operations near Dalkeith. During these dark days of WWII when Britain stood alone against the Nazi regime, there was a great need to increase oil production from indigenous hydrocarbon resources. The strategic importance of discovering more oil in the UK was becoming critical to the war effort. Bert Blanche, by virtue of his experience, was given 'reserved occupation status' and was exempt from military service, much to his disappointment.

By 1940, fuel shortages and food rationing were all imposing difficulties, together with regular air raids against targets of value to the war effort, including oil and gas installations which had to be camouflaged to conceal them from any airborne reconnaissance. In 1940, Bert was transferred from Scotland to England to the East Midlands to drill exploration wells.

Despite the war, the move to England, and drilling wells in Nottinghamshire, Bert Blanche still had time to get married to Janet Rowland, a young lady he had met in the blackout during his time in Scotland. They were married in the small border town of Coldstream in Berwickshire on 10 June 1940.

The strategic importance of discovering more oil in the UK was becoming critical by 1942 as a direct consequence of the continued German U-boat threat to UK-bound convoys in the trans-Atlantic shipping lanes. Both the Anglo-American Oil Company and D'Arcy Exploration Company accelerated their exploration efforts accordingly. By the end of the war



Midlothian -1, 1937. Note the steam rig and boiler house



Midlothian-1. Bert Blanche at the drilling brake.



Johnny Maley & Bert Blanche, Midlothian-2, June 1938

Author's collection

some 170 'nodding donkey' pumping units, one per kilometre, were each producing an average of 64 bpd. Both Eakring and Dukes Wood were eventually depleted and shut down in 1989.

### To the Wilds of Borneo

Bert Blanche was released from his contract with the Anglo-American Oil Company in 1947 and was offered employment as a driller in Borneo by the Shell International Petroleum Company. He departed the UK for the Sultanate of Brunei and the Seria oilfield in November 1947. There were no seats available on the fledgling BOAC service to Singapore, so Bert was transported to Labuan by an RAF Short Sunderland GR IV flying boat – a journey which took a total of fourteen days.

Bert was deposited on Seria beach via an Australian Army landing craft. Although production had been restored and oil exports to the Lutong refinery near Miri, in north-east Sarawak, had recommenced in November 1945, 38 oil wells were still

burning following the Japanese oil denial programme and Allied bombing.

At first he lived with other expatriates on 'batchelor' status in pre-war wooden bungalows which had been occupied during the war by Japanese officers. However, my mother Janet, brother Edwin, aged 7 years, and myself, aged 2, left the UK by sea for Singapore in 1948. From there we were transported as passengers on a Shell tanker to Miri in Sarawak where we landed at the British Malayan Petroleum Company Ltd (BMP Co Ltd) facility at Lutong. We completed the journey to Seria by ferry and dirt road along the beach – a journey that took about four hours – arriving at the BMP Co Ltd oil camp at Seria on 6 June 1948.

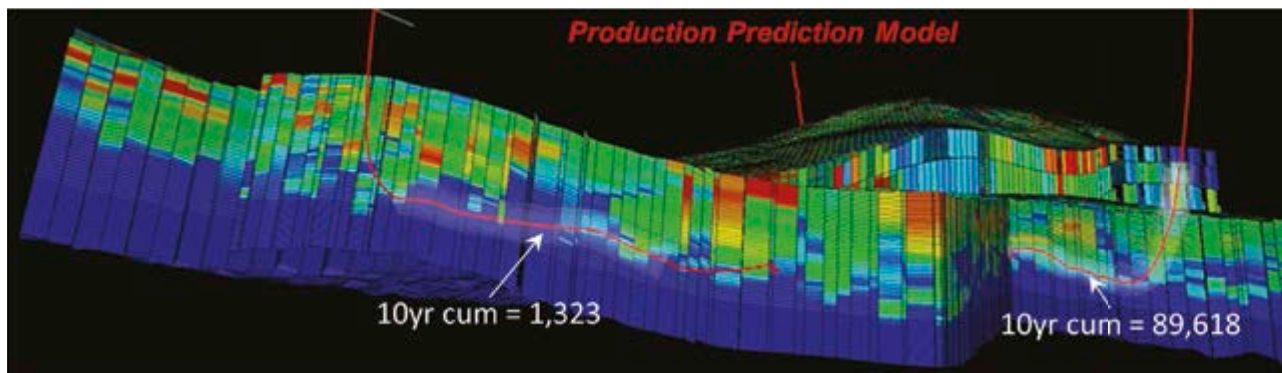
Operating and living conditions were difficult and the field infrastructure was poor in the immediate post-war period. Occasionally, the local wildlife would make their presence felt; crocodiles in particular were a danger in the rivers and the river mouths. Major supplies of food and other

Well Seria 259, where the pipe stuck and was unfishable in a deviated hole. Bert Blanche outside wooden bungalow in Seria, 1947

Wooden Kajang house, late 1940s



Author's collection

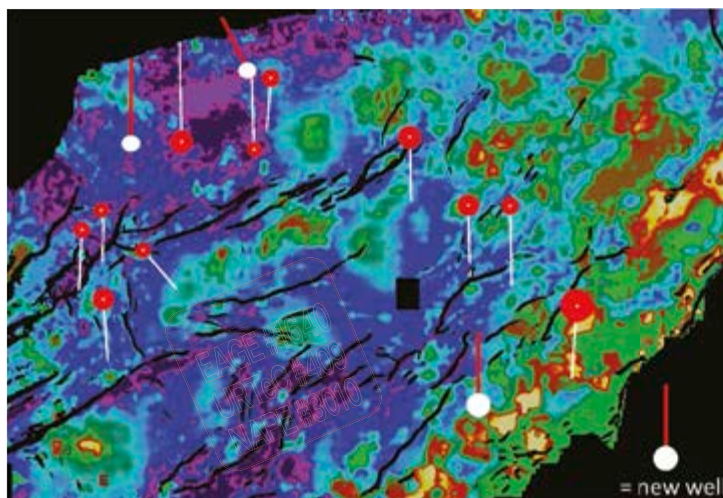


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essentials were imported from Australia by sea every few months. Adequate housing was also a problem along the narrow strip cleared from jungle. Staff family accommodation was in wooden kajang bungalows; snakes, scorpions and other wildlife lived under the house.

At the time of Bert Blanche's arrival in late 1947, the priority was to rehabilitate the war-damaged Seria Field, increase production and discover additional reserves by drilling both onshore and offshore along the shoreline. In the early 1950s, BMPC operated five aircraft from its airfield at Anduki, to enable the rapid supply of remote jungle and offshore drilling locations. The aircraft also provided transport for staff and their families and vital logistics support to operations.

### Exciting Times

Bert was responsible for drilling or supplying drilling materials for several wells during the period 1951–1960, designed to test the hydrocarbon potential of deltaic sands in faulted anticlines in the onshore Baram Delta province. The remote jungle locations in Sarawak often resulted in contact with the local Dyak tribal communities who lived in longhouses, usually close to rivers. The Dyaks were attracted to the drilling camps, perhaps looking for the opportunity to trade jungle goods and native crafts for salt or western food. Cultural honour dictated that the hospitality given at the drilling locations would be reciprocated to the 'ex-pats' who would be invited back to the longhouses. The visits to Dyak longhouses by Bert Blanche and his colleagues are recounted by Stanton Hope in his book *The Battle for Oil*, which was published in 1958. Following one of these visits to a

longhouse, Bert Blanche wrote an account of his time with the noble and hospitable Dyaks entitled *The Dyak is a Gentleman*.

The two British colonies of Sarawak and North Borneo, with the small Protectorate of Brunei sandwiched between them, occupied a 1,290 km strip of territory along the north-western seaboard of the island of Borneo. The rest of the island belonged to Indonesia (Kalimantan), whose President Sukarno had ambitions to bring the whole island under Indonesian leadership and control. When, in 1962, plans were drawn up in Whitehall and Kuala Lumpur to link Brunei, North Borneo, Sarawak, Malaya and Singapore into a Federation of Malaysia, President Sukarno saw his plans threatened and encouraged the People's Party in Brunei to rebel.

The Brunei revolt started on 8 December 1962. Some 43 Europeans and Asians, including Bert Blanche, were held hostage as bargaining tools. Bert managed to escape in the confusion after he and several other male hostages had been used as 'human shields' in an unsuccessful attempt to storm a police station, although several hostages were wounded and one was killed. He went to ground for several days in the jungle, before being rescued on 15 December by British troops brought into assist the Sultan in defeating the insurgents.

A few months later, after 15 years in Brunei, Bert was eligible for retirement. He left Brunei Shell Petroleum Company Ltd in March 1963 at the age of 54.

### An Easier Life

Bert Blanche returned to the United Kingdom in April 1963. After a period of retirement, in 1971 he became a director



Dyak headman, Subis 1951. Note the ceremonial dress to welcome visitors

of a new company, Oil and Mining Ltd., offering drilling and other related services to the international upstream oil and gas industry.

My father finally retired in 1980 at the age of 71, after a long and interesting career in the oil and gas drilling business. He died at home on 31 March 1987 at the age of 78.

### Acknowledgements:

The author would like to acknowledge the following organisations and individuals:

BP Petroleum, London; Brunei Shell Petroleum Co Sdn Bhd, Sarawak Shell Petroleum Company Sdn Bhd; Brunei Museum Negara; British Geological Survey; Department of Energy & Climate Change; East Texas Oil Museum, Kilgore, Texas; Geological Society Library; American Oil and Gas Historical Society, Washington DC, USA; Robert Hale Publishers, London for permission to quote from *The Battle for Oil* (Stanton Hope, 1958); *Offshore Engineer Magazine*, Houston to quote from *Wooden Derricks of Texas to North Sea Sophistication* (Jackman, 1975); Mrs Jean Blanche for her valuable support and patience.

A bibliography can be found attached to this article on the GEO ExPro website. ■

Rig and boardwalk at sunset immediately offshore, Seria Field. Access to shallow water wells was via wooden boardwalks



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# Broadband Seismic Technology and Beyond

## PART III: THE INTERACTION BETWEEN OCEAN WAVES AND RECORDED SEISMIC DATA

**LASSE AMUNDSEN**, Statoil and  
**MARTIN LANDRØ**, NTNU Trondheim

*"There's nothing wrong with enjoying looking at the surface of the ocean itself, except that when you finally see what goes on underwater, you realise that you've been missing the whole point of the ocean. Staying on the surface all the time is like going to the circus and staring at the outside of the tent."*

**Dave Barry**  
American writer, Pulitzer Prize winner 1988

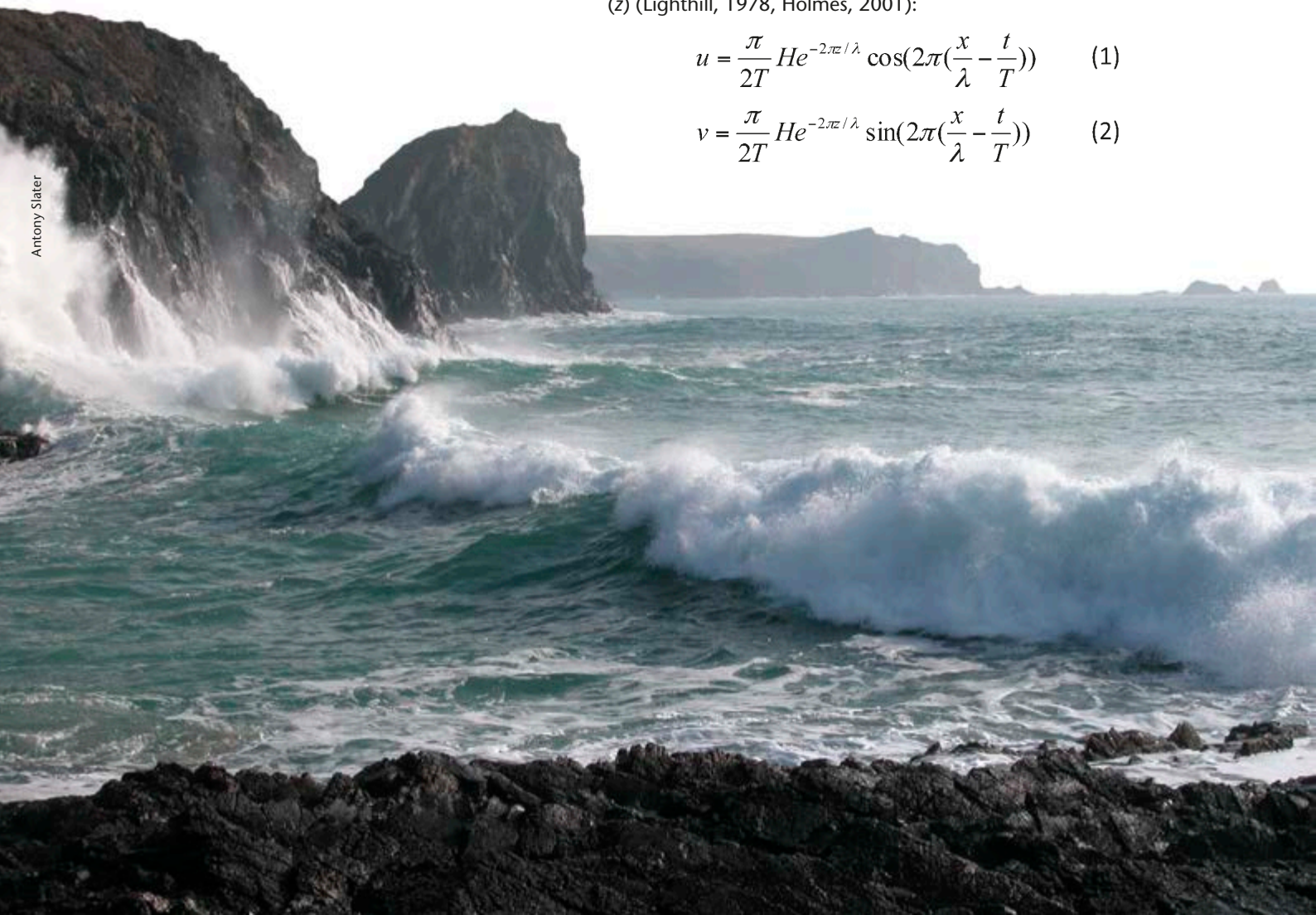
Broadband seismic technology is designed to reduce the influence of the ocean waves on seismic data. To understand and appreciate this, we need an understanding of the interaction between the mighty ocean and the seismic streamer beneath the ocean surface. How quiet is life below the waves?

### Sinusoidal Ocean Waves

If we assume that the ocean surface is represented by a sine wave, analytical equations enable us to calculate the horizontal ( $u$ ) and vertical ( $v$ ) particle velocity and the pressure ( $p$ ) as a function of depth ( $z$ ) (Lighthill, 1978, Holmes, 2001):

$$u = \frac{\pi}{2T} H e^{-2\pi z / \lambda} \cos(2\pi(\frac{x}{\lambda} - \frac{t}{T})) \quad (1)$$

$$v = \frac{\pi}{2T} H e^{-2\pi z / \lambda} \sin(2\pi(\frac{x}{\lambda} - \frac{t}{T})) \quad (2)$$



Here  $H$  is the wave height,  $T$  the period of the ocean wave and  $\lambda$  the wave length, while  $x$  and  $t$  are the x-position and time, respectively. We have assumed that the water depth is large compared to the wavelength. The corresponding expression for the pressure has a similar exponential decay with depth. The particle velocity represented by these equations can be represented as circular (elliptical if the water depth is shallower) shaped particle orbits.

The dispersion relation for ocean waves depends on the water depth. However, if we assume large water depths, it is simply given as  $\omega^2 = gk$  where  $g$  is the gravitational acceleration ( $9.8 \text{ m/s}^2$ ),  $\omega$  is the circular frequency ( $\omega = 2\pi/T$ ) and  $k$  is the wave number. From the dispersion equation we can estimate the period of a sinusoidal ocean wave if the wavelength is known, since  $k = 2\pi/\lambda$ . It is clear that disturbances caused by the ocean wave will decrease with depth, and hence it might be a good idea to tow seismic streamers at large depths.

Typical time periods ( $T$ ) for ocean waves are more than a second; sitting at a beach we can usually count eight seconds between each wave. This means that the noise both on the pressure component and the velocity component will be outside the typical frequencies of interest for a seismic experiment. However, as we are striving for lower and lower frequencies (see *GEO ExPro*, Vol. 10, No. 1) the noise caused by slow variations in particle velocity close to the streamer might influence our data. For streamer depths larger than 20m, the typical particle velocity caused by the ocean wave shown in the figure is less than 0.1 m/s and very low frequency (0.2 Hz). Since both the pressure variations and the velocities caused by water waves decay exponentially with depth, the direct influence is assumed to be minimal for normal seismic frequencies (above 4–5 Hz). This exponential decay rate is controlled by the streamer depth divided by the wave length (equations 1 and 2 above).

During heavy storms it is known that ships crossing the North Sea via, for instance, the Dogger area, which has shallow water ranging from 20 to 60m, get sand on deck, indicating that the waves have sufficient energy to lift sand from the sea bed to the surface. Close to shore this phenomenon is well known, as a thick layer of sand foam can be observed on the beach after a storm.

### Wind Speed and Wave Height Correlation

The close relationship between wind speed and ocean wave height is well

known. For fully developed ocean waves it is commonly assumed that the wave height increases with wind velocity squared, and a recent example showing wave data from the Gullfaks field in the North Sea is shown in Figure 1.

We observe a surprisingly strong correlation between the smoothed average wave height and the wind speed. Furthermore, we observe that the ocean waves for some periods lag behind the wind: first the wind calms down and then the waves. The average wave height measured at the Gullfaks Field in 2012 was 2.7m. Pierson and Moskowitz derived an empirical formula for the energy of a fully developed sea state as a function of frequency, known as the Pierson-Moskowitz-spectrum, which showed that the peak wave energy decreases as the wind velocity increases.

Another crucial parameter that is used to describe ocean waves is the wave steepness,  $s$ , which is equal to the wave height divided by the wavelength. If  $s$  is larger than  $1/7$ , the wave will break. This value might vary significantly. Typical average values for the North Sea are between 0.06 and 0.006 (Torsethaugen, 1993). This means that for the Gullfaks example

Figure 1: Smoothed measurements of wave height (black solid line) at the Gullfaks Field in 2012 and corresponding modelled wave heights by assuming a quadratic relation (red solid line) between wind velocity and wave height. The average wave height is 2.7m. ( $a=0.025 \text{ s}^2/\text{m}$ ;  $b=1 \text{ m}$ ).

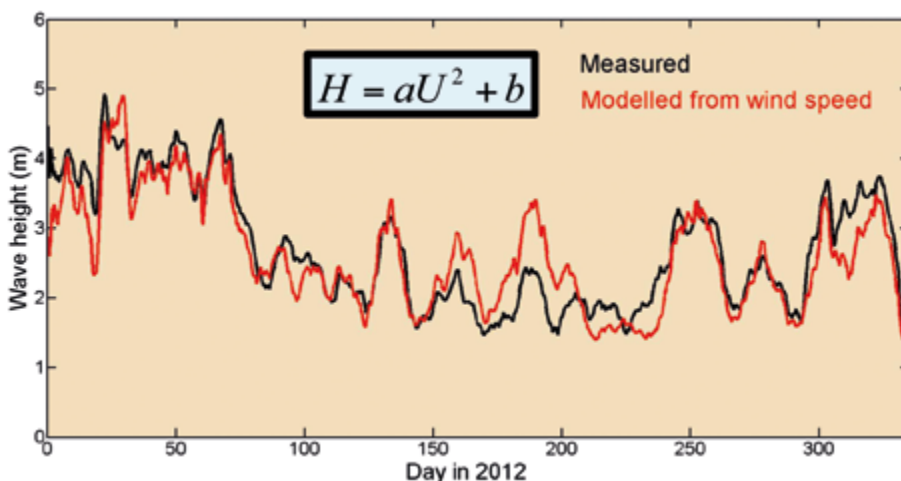
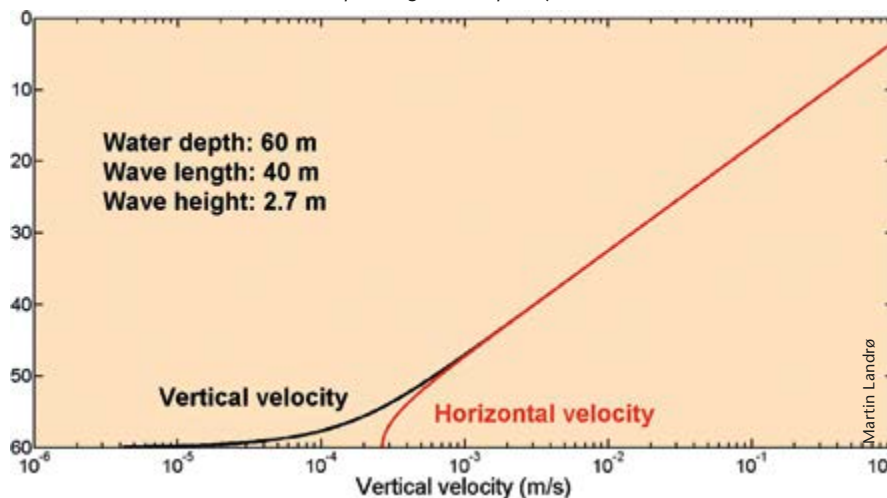


Figure 2: The decay curve for particle velocity versus depth. Here we have used the exact dispersion relation without assuming that the water depth is much larger than the wavelength. The vertical velocity at the seabed (60m) is actually zero; the deviation is caused by the logarithmic plot. The period of this wave is 5 seconds, corresponding to a frequency of 0.2 Hz.





shown in Figure 1, assuming a steepness of 0.06, the average wavelength is 40m, corresponding to a period of 5 seconds. One of the largest waves observed precisely was reported by *USS Ramapo* in a storm in the Pacific Ocean in 1933. An officer on the deck used the crow's nest to estimate the wave height and corresponding wavelength, knowing that the length of the ship was 146m. The estimated wave height was 34m and the corresponding wavelength was 342m, yielding a wave steepness of 1/10.

### Turbulent Flow Around Streamers

In addition to noise created by ocean waves, there are currents in the water layer, and close to the streamer the flow is not necessarily laminar, as shown in Figure 3. Elboth *et al.* (2010, 2012) studied this flow in detail, and demonstrated that the surface material of the streamer is crucial. By using a superhydrophobic surface material they revealed that the towing noise could be lowered by approximately 10 dB in the frequency range between 1 and 10 Hz. This observation is crucial for broadband seismic, where especially the lower frequencies are important. The broadband paradigm shift that we witness today is multi-causal: the streamer depth has increased, the manufacturing of various types of streamers has improved significantly, especially with respect to noise attenuation, and finally the algorithms for data processing have also improved. The result is high quality data, enabling an improved image of the subsurface.

### Noisy Birds and Tugs

In order to control its depth, a streamer is equipped with devices that enable adjustment of the vertical (and in some cases also the horizontal) position. These devices are called 'birds' and are attached to the streamer at certain intervals, typically a couple of hundred metres. A noise record obtained in calm weather is shown in Figure 5, where we can notice a significant increase in noise level close to the birds and also close to the front and tail ends of the streamer. Trace 120 is closest to the seismic vessel, and we observe a slight decrease in noise level (red dashed line) as we get further away from the ship. This indicates that some of the noise observed is actually vessel noise caused by the ship propellers and engine.

The slightly increased level at the head and tail (6–8 microbars) is probably caused by tugging from the vessel, tail buoys and lead-in sections. As the sea condition gets more marginal, this tugging noise will increase and create unwanted vibrations along the streamer. As the streamer



Figure 3: Turbulent flow around a seismic streamer, visualised by a single hole dye release.

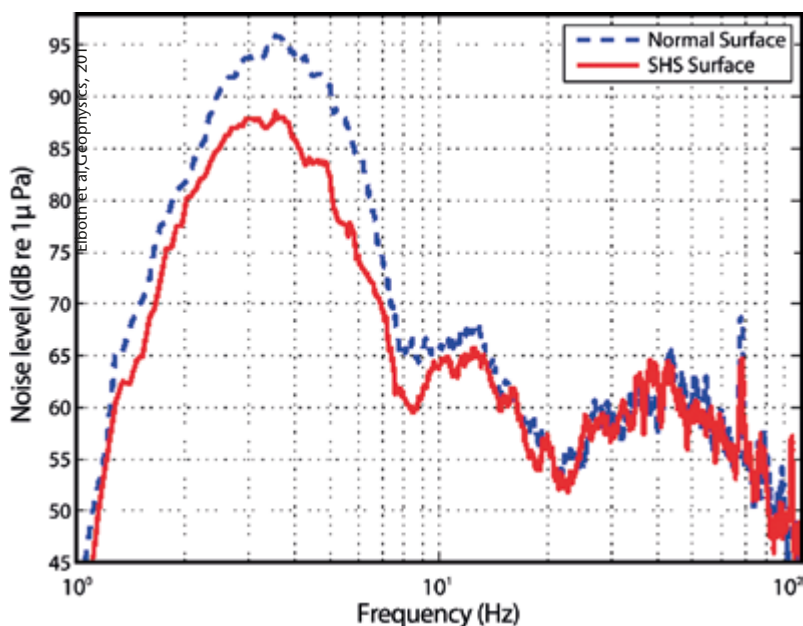


Figure 4: Noise spectra with and without superhydrophobic (SHS) surface on the streamer. We observe a significant noise reduction for frequencies between 1 and 10 Hz.

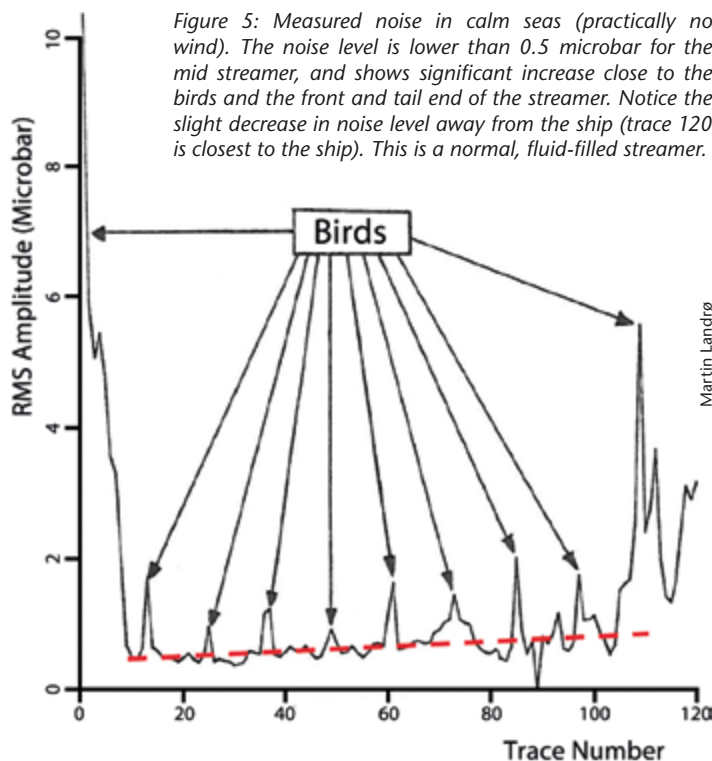


Figure 5: Measured noise in calm seas (practically no wind). The noise level is lower than 0.5 microbar for the mid streamer, and shows significant increase close to the birds and the front and tail end of the streamer. Notice the slight decrease in noise level away from the ship (trace 120 is closest to the ship). This is a normal, fluid-filled streamer.

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depth increases, the angle between the head and tail buoys rises, leading to extra tug noise. This additional problem is normally solved by introducing passive sections prior to the active receiver sections in the streamer. However, there is no doubt that when we are solving one problem by towing the streamer deeper we create a new problem by introducing a more complex towing pattern for the streamers. Furthermore, introducing passive sections (with rapid depth variations) limits the available near offset information somewhat.

During the last two decades most seismic contractors have replaced the fluid surrounding the receivers in the streamer with a gel-like or solid material, which reduces or completely removes the noise caused by movement of the fluid inside the streamer, as shown in Figure 6.

It is reasonable to assume that the difference shown in this figure will increase for acquisition in more marginal weather conditions.

### Broadband Seismic Development

There has been tremendous development in new streamer design, new ways of towing streamers and new ways of processing and utilising the data acquired by broadband systems. Most contractors have developed their own system aiming for increased bandwidth and improved signal-to-noise ratio. Compared to a decade ago, it is evident that more and more seismic is acquired using deep towing depths, often down to 20–30m below sea surface. In the next issues we will present some of these new technologies and show examples demonstrating the progress made up to now.

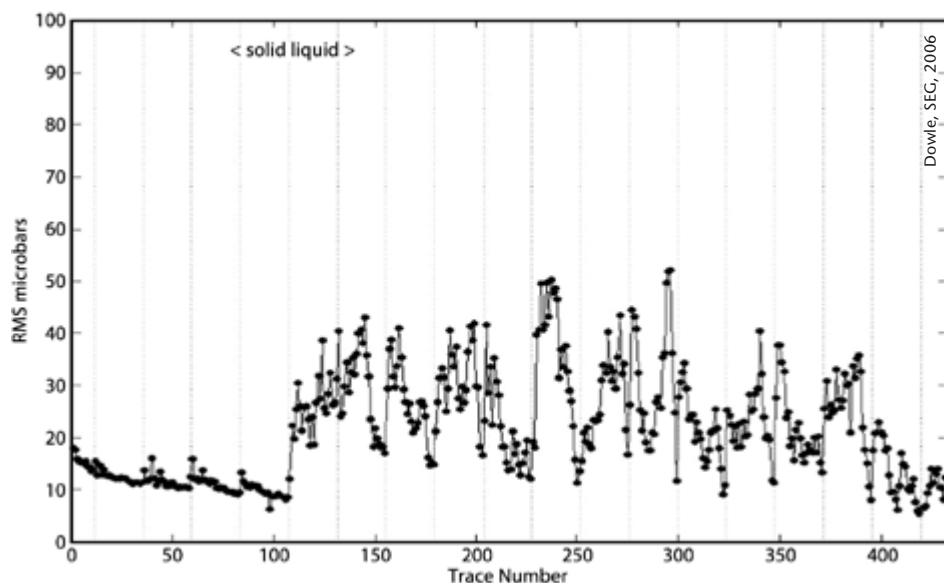


Figure 6: Noise comparison of solid streamer (traces 0–100) and fluid-filled streamer (traces 100–450), measured for moderate seas.

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## Types of Waves

It is common to distinguish between five types of waves that might occur at the sea surface. The tidal wave is well known and the dominating force creating this wave is gravity (from moon and sun). Tsunamis are typically created by earthquakes or landslides. In closed basins (lakes) seiches – standing waves generated by wind or air pressure changes – might occur. These were first observed by Forel (1890) at Lake Geneva. Wind waves are waves generated by wind at the sea surface. The wave height of wind waves range from less than a metre up to 30–40m.

When the wind stops the continuing waves are called swells, which are hardly affected by new local winds, as their driving mechanism is gravity. Ripples or capillary waves appear on smooth water and are generated by weak winds. They will disappear if the wind ceases.

Wind waves have a certain amount of randomness: subsequent waves differ in height, duration and shape, with a limited predictability. They can be described as a stochastic process, in combination with the physics governing their generation, growth, propagation and decay.

Antony Slater



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Most people are familiar with the use of fibre optic cables in the communications industry. Light is shone into an optical fibre and, using the property of total internal reflection, can be transmitted across long distances with little attenuation. The fibres allow the transmission of high data rates or bandwidth and are in increasing use in Internet connections rather than carriers such as conventional telephone wires. Fibres have also been used in the oil and gas industry to relay downhole measurements from boreholes and in some cabled seismic acquisition systems.

But there is another property of fibre optic cables that can be exploited to make measurements. Minute pressure changes along the length of a cable create strain on the fibre. When light is passed down the cable, some of it is reflected back as a result of the strain differences.

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This property of fibre optic cables is being used by specialist fibre optic sensing company Silixa in a wide variety of industrial applications, including an acoustic detection security system that detects breaches of boundaries. (See *GEO ExPro* iPad App 4, 'New Technologies'.) A development of this system is called iDAS (intelligent Distributed Acoustic Sensor).



## iDAS for VSPs

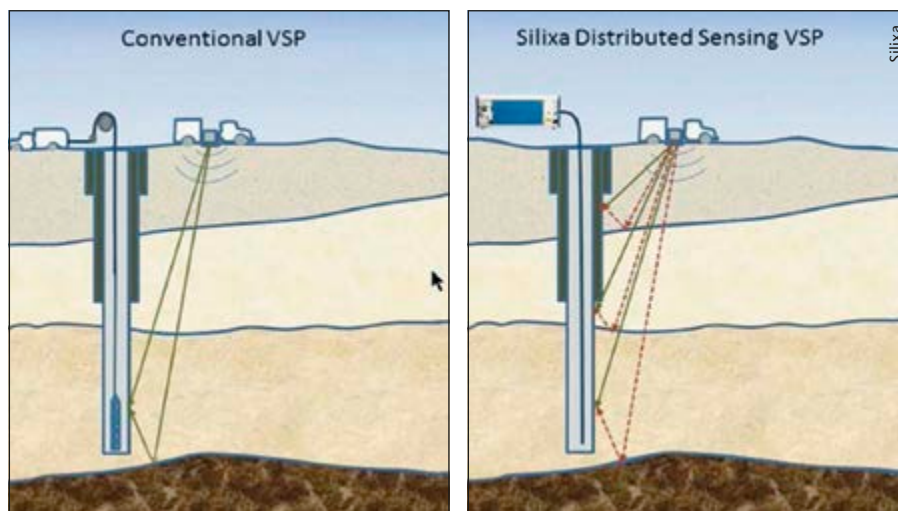
Using proprietary processing technology, the company can measure the full acoustic pressure field over a wide frequency range and with a 120dB dynamic range at every point along the fibre. Directivity, equivalent to three-component recording with geophones, can be measured by configuring the fibre to shape its directionality. Using the measurements of many adjacent recording points, large scale directivity can also be obtained by array processing and beam-forming techniques.

Silixa realised that the continuous acoustic measurement possible along a fibre cable could be of great benefit when recording a Vertical Seismic Profile (VSP). Rather than recording the acoustic signal on wireline at discrete intervals – a process that can take several hours as the tool with the detectors is pulled up the hole and clamped in place at each location – the entire acoustic signal could be recorded at one time on an optical cable placed down the borehole. Silixa's proprietary cables are acoustically sensitive to enable these measurements to be taken. However, even where the technology is retrofitted to pre-existing fibre cables that are less sensitive, many records can be taken quickly and summed together, still saving substantial time and cost.

In March 2011, the company embarked on a test VSP at a site in Texas that had also been used for conventional VSP testing. The results of the onshore VSP test demonstrated the potential of the method and compared well with a previous conventional VSP test. In this test, the cable was coupled frictionally to the borehole – it is expected that with a permanent emplacement where the cable is cemented in place that the results would be even better. In 2011, Silixa also conducted a successful offshore VSP test in a near horizontal well in the Norwegian North Sea. Such systems would be ideal for permanent borehole monitoring or seismic applications.

## Identifying Seeps

Silixa has a companion DTS (Distributed Temperature Sensor) system to iDAS that also uses fibre optic cables – the Ultima. This can measure downhole temperatures with a spatial resolution of 25cm. By using the Ultima and iDAS in tandem, the



*An entire VSP is recorded in one go with iDAS*

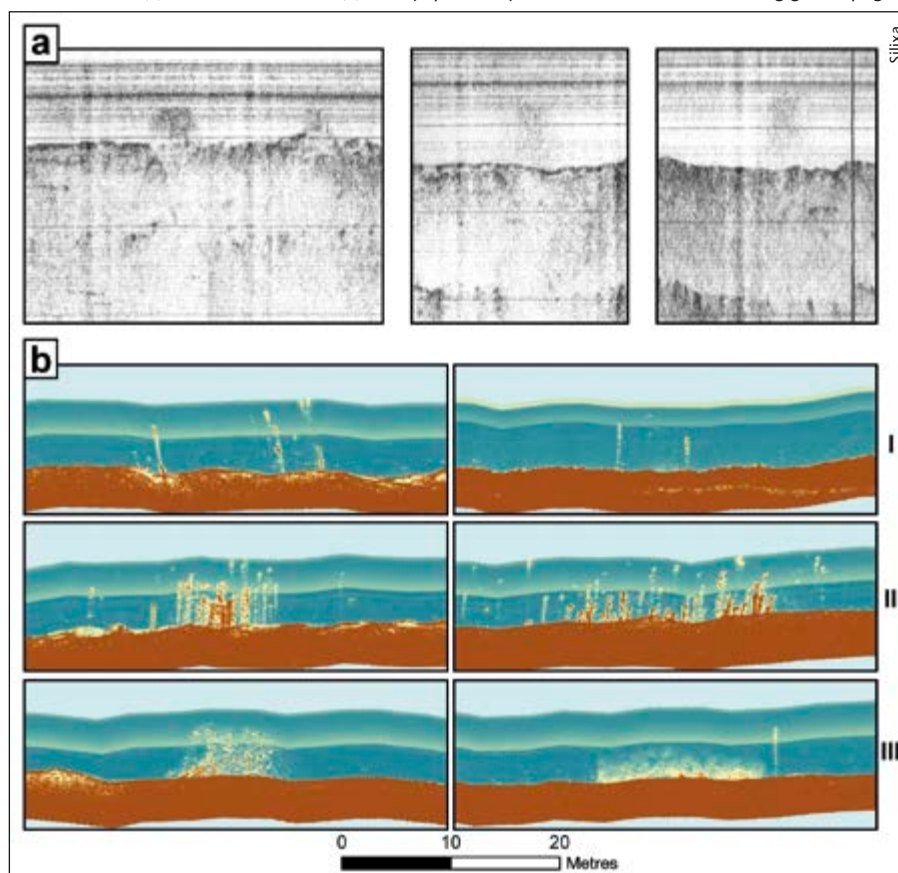
temperature and acoustic profile can be monitored together. Silixa has developed a method to do this using the fibre cables that is called Distributed Thermal Acoustics (DTA). This technique can be used to identify discharges such as gas seepages and monitor the temperature and acoustic profile of the seabed over a large area.

Leakage and movement of liquid and gaseous hydrocarbons from offshore vents and fractures can provide valuable

information for many studies, including petroleum geology, exploration tectonics, geo-hazards and global warming. Observations of marine seeps with bubbles dissolved in the water column are difficult to interpret and most techniques merely identify the seep locations. Quantitative measurements can provide much more information and a permanent emplacement could offer real-time seabed monitoring.

In 2012, Silixa conducted a subsea

*3.5 kHz seismic (a) and side scan sonar (b) surveys previously conducted at Katakolo showing gas seepages.*

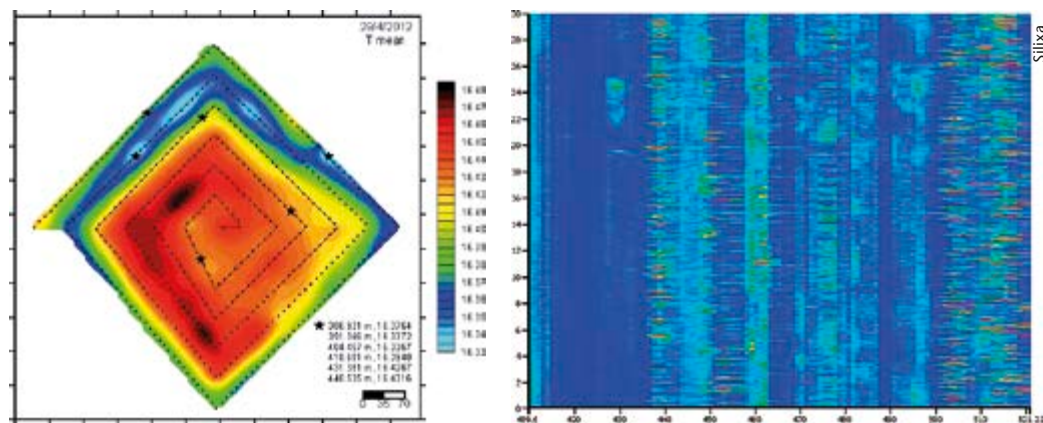




gas survey feasibility study together with the University of Patras in Greece in the harbour of Katakolo, a small town in the western Peloponnese, Greece. Katakolo is visited by large cruise ships as it is the closest port to the site of Ancient Olympia. The harbour also contains a prolific thermogenic gas seepage zone where faults reach the seabed. Because of its accessibility and scientific interest, the seepage zone has been studied extensively and many surveys have been conducted over it, including sub-bottom profiling, side-scan sonar, long term gas flux and isotopic composition measurements, etc.

When the gas bubbles are released into the water column, they 'ring' with characteristic resonance frequencies. These can be detected and recorded by the iDAS acoustic system. The methane gas is also expected to be at a lower temperature than the surrounding ambient temperature, so thermal measurements using the Ultima system can show seep locations. As the seep locations are well known here, Silixa used a system where the cable carrying four fibre optics was wrapped around a pyramid-shaped metal frame placed at 7.5m water depth in the harbour. This allowed three-dimensional spatial distribution of the measured parameters and also the sensors to be tested, together with tidal effects.

The initial results demonstrated that the DTA system can be used to both detect seeps and make measurements of their acoustic signatures. Further experimental work is planned to refine the method and add to the observations by, for example, trying to detect seismic activity. Analysis of the results is in progress in order to try to correlate the measurements with the known properties of the seeps.



DTS thermal plot (left) showing temperature distributions as a colour scale and (right) iDAS acoustic plot of recording time vs. distance along the fibre cable, where colour represents amplitude variations.

### Future Possibilities

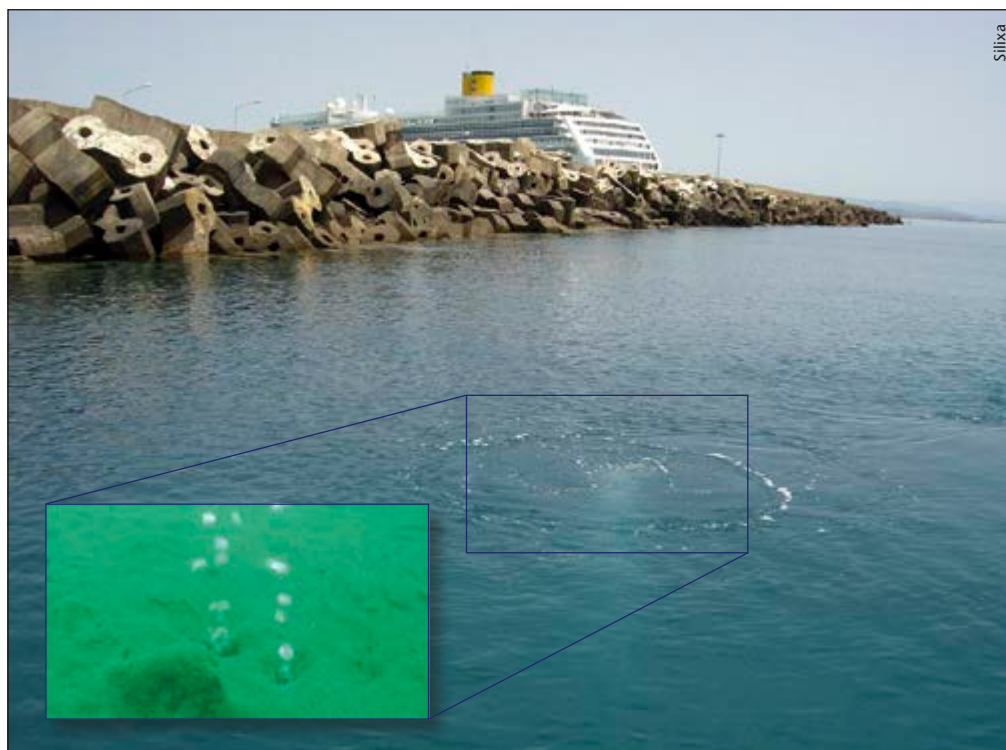
Silixa has already developed systems for continuous borehole monitoring with iDAS and a concept for profiling the flow of fluids in a producing well. The VSP test in a horizontal borehole demonstrated the potential of the system offshore. As well as permanent borehole instrumentation, it could also possibly be used in future permanent seismic sea bed installations, removing the need for costly sea bottom receivers. Silixa has also conducted tests for onshore seismic where the fibre cable was buried just below the surface.

The many other possible uses that can be envisaged are shown by the Katakolo

example that uses the combined DTA system. Permanent emplacements could monitor offshore seeps remotely, or mobile systems be used to characterise them for a variety of studies.

Silixa is working with academia, oil companies and service companies to develop and apply iDAS and DTS capabilities. Several borehole systems are already in place. Wherever we need to measure acoustic signals or thermal profiles, it should be possible to do it without additional sensors, in a cost effective way, yet with much finer spatial sampling than is possible with conventional equipment. ■

*Katakolo is visited by large cruise ships as it is close to the site of Ancient Olympia. The harbour also contains a prolific thermogenic gas seepage zone, with bubbles of gas visibly rising to the surface.*



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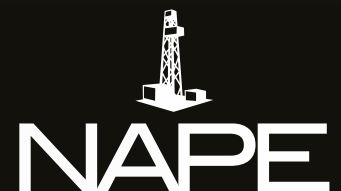
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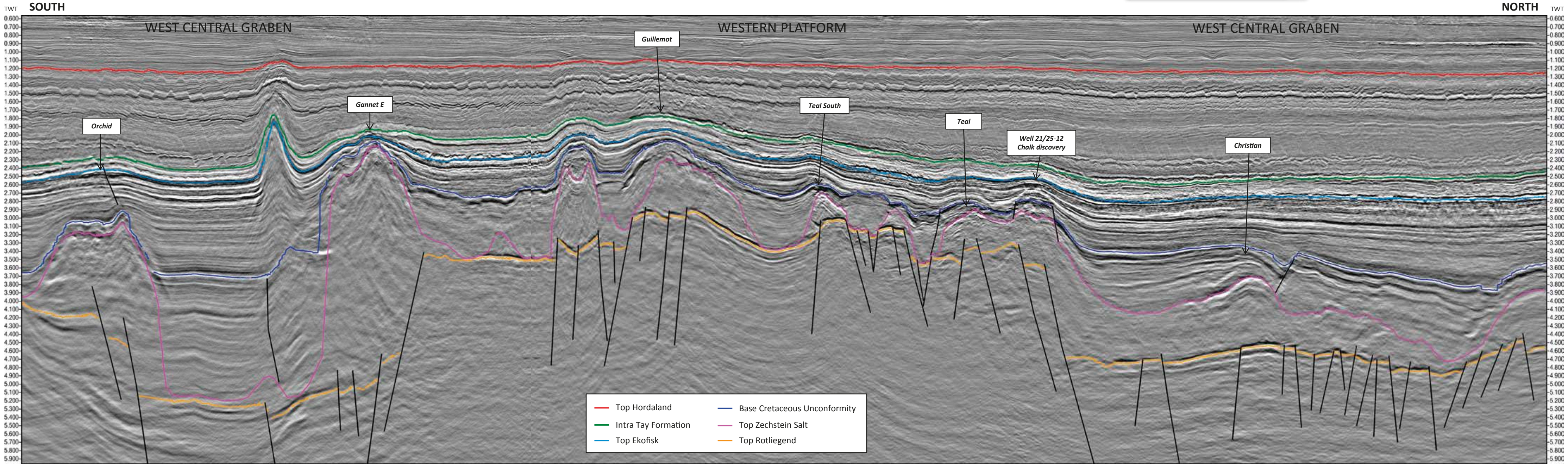
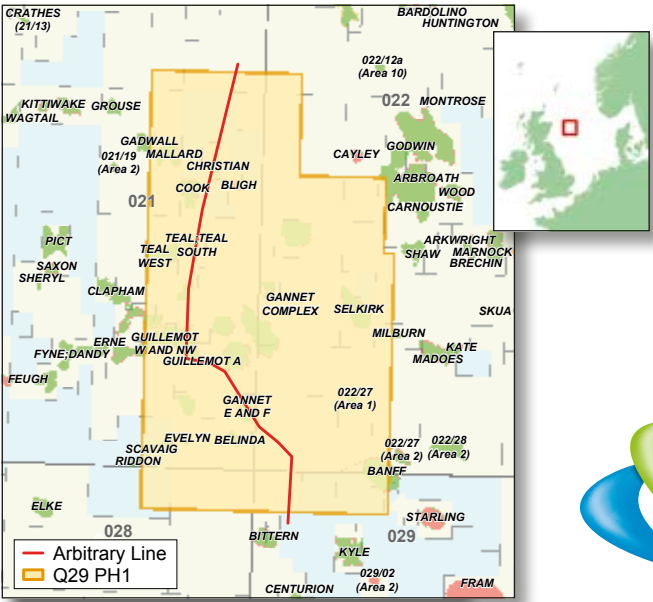
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# The UK West Central Graben: A Broadband Seismic Perspective

*This interpreted broadband seismic line runs along the margin of the West Central Graben in the UK North Sea. It intersects a number of known fields and discoveries in the area which demonstrate the value of broadband seismic imaging from the Tertiary Tay Formation through the Upper Cretaceous Chalk section to the deep Jurassic sands.*

As part of the ongoing effort to discover the remaining oil reserves in the North Sea, a broadband seismic dataset was recently acquired by CGG in the West Central Graben Margin area. The survey covers approximately 2,100 km<sup>2</sup> within UK Quadrants 21 and 22. By using the latest advances in broadband seismic technology it has brought a new level of understanding of the various stratigraphic levels to unveil the remaining hydrocarbon potential. The area is already populated with a number of producing fields and discoveries such as the Gannet and Guillemot fields in the Tertiary Tay Formation, the Orchid discovery in the Upper Cretaceous Chalk and the Teal and Christian fields in the Jurassic Fulmar sands.





# New Insights with Broadband Data

New seismic acquisition and processing techniques can be used to shed new light on a very mature basin like the UK North Sea.

**GREGOR DUVAL, CGG**

Recent advances in seismic acquisition and processing technology such as broadband seismic help the geologist to understand the subsurface structure and properties in greater detail. Using its curved variable-depth streamer solution, BroadSeis™, CGG recently acquired a new broadband survey in the UK North Sea West Central Graben (WCG) area with several objectives in mind:

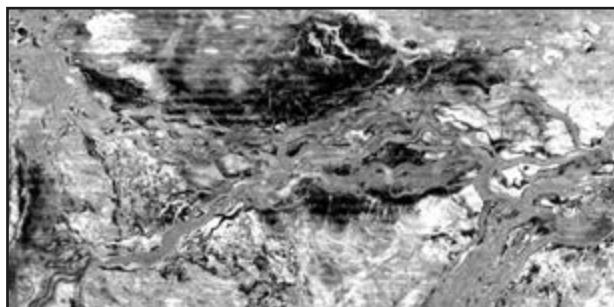
- Provide high-resolution imaging of the shallow subsurface to help identify potential drilling hazards and better constrain the Pleistocene channels geometry;
- Resolve in greater detail the Lower Tertiary geology, especially the Tay Formation which represents a major exploration target in the area;
- Improve the understanding of the Chalk facies and fluid distribution, knowing that several discoveries and prospects have been identified over the West Central Graben Margin;
- Help with the geological interpretation of deep targets below the Base Cretaceous Unconformity aided by the deeper penetration of the low seismic frequencies.

## Geo-hazards and the Shallow Subsurface

The western part of the Central North Sea is known to have numerous channels near the seabed inducing sharp velocity contrasts in the shallow section, which can create unwanted pull-downs on the seismic data. If these velocity contrasts are not accurately accounted for, these channels can have a detrimental effect on the interpretation of structures in the depth domain and exploration companies may potentially leave behind some missed pay intervals.

This new broadband dataset provides high-resolution imaging of the near-surface to tackle this problem in the

*Seismic time slice showing high-resolution imaging of shallow channels in the West Central Graben area.*



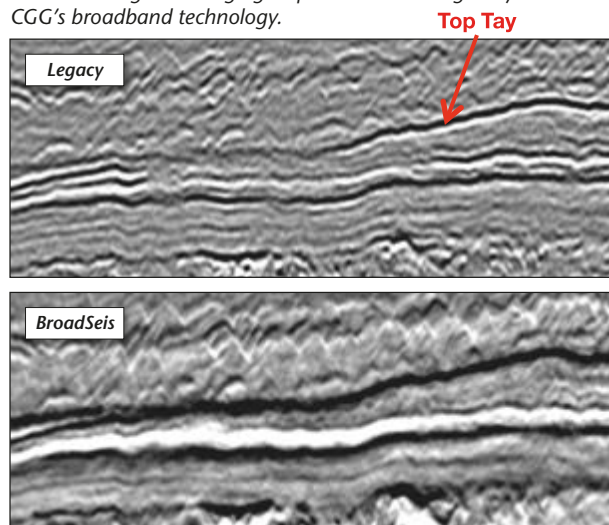
West Central Graben. There are also benefits for drilling hazards identification, reducing the uncertainty on the location of potential shallow gas caps.

## Mapping the Tay Sands

A number of producing fields are found within the Tay sands in the WCG area where these reservoir sands can show porosities of up to 35% with high net-to-gross and high permeabilities. The Guillemot and Gannet field clusters have been producing from this reservoir for about two decades. The Guillemot field is characterised by a high-amplitude seismic anomaly highlighting the presence of hydrocarbons within the Tay reservoir sands, which is made more evident by the low-frequency component of the broader bandwidth of the seismic data. Typically, the top of the Tay Formation is defined by a bright continuous reflector on seismic data, marking a sharp transition from clay-dominated Eocene sediments to clean turbidite sands.

Looking at seismic data from an interpreter's point of view, the benefits brought by broadband seismic are twofold. First, the introduction of lower frequencies into the signal reduces the side-lobes of the zero-phased wavelet which interferes with the picking of a specific reflector. This is illustrated in the figure below, where we can see that conventional, band-limited data display

*Seismic section comparison focusing on the Tay Formation and demonstrating the imaging improvements brought by the use of CGG's broadband technology.*





a prominent side-lobe (i.e. the white halo appearing above and below the Top Tay reflector) around the actual Top Tay reflector.

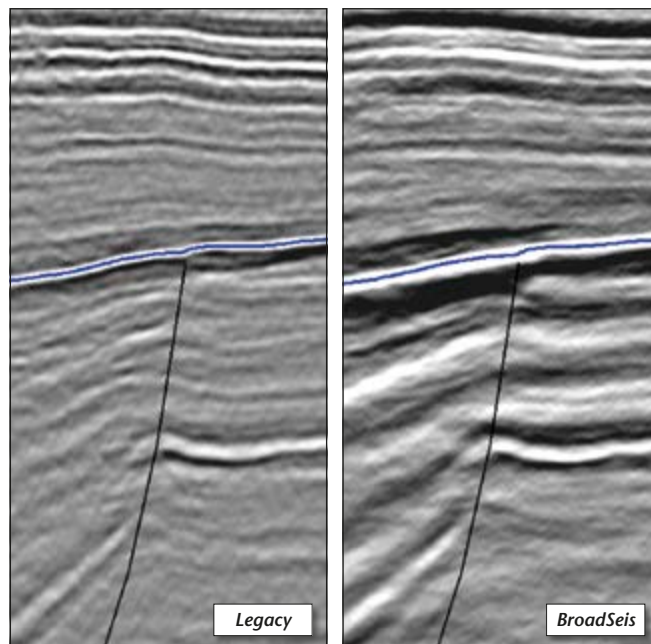
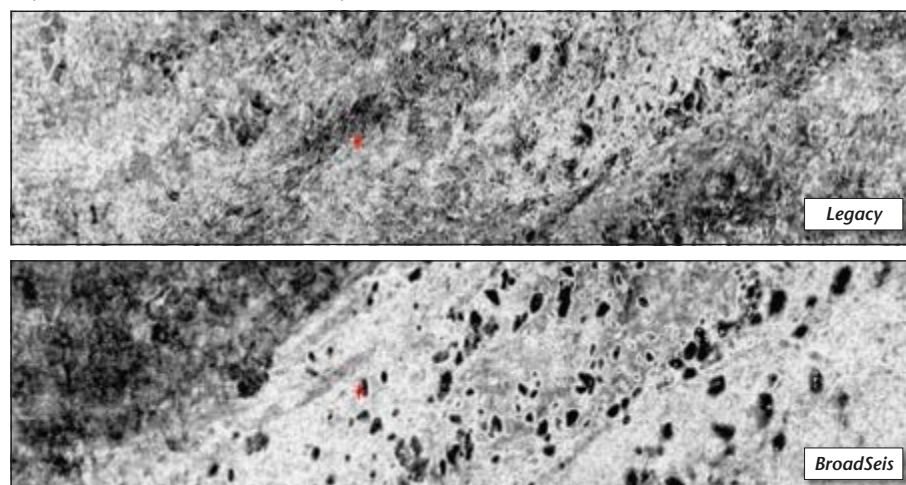
Secondly, the introduction of higher frequencies sharpens the central peak of the wavelet, pushing the tuning limits further and increasing the resolution of top and base of thin beds and subtle structures. This image also shows the presence of a dim zone on the conventional data through the central part of the section which affects the Top Tay reflector, which is not the case on the BroadSeis data. This demonstrates that broadband seismic brings additional, useful information from outside the conventional seismic bandwidth to better image the Tay sands, hence supporting the identification of potential new traps in the West Central Graben.

### Chalk Facies in the West Central Graben

Back in 1993, well 21/25-12 discovered oil in the Ekofisk and Tor formations. An amplitude anomaly is visible at that level in the seismic section shown on the fold-out on the previous page. This was never developed, but then, in 2012, the Orchid discovery was made within UKCS Block 29/1c. This is now pending development, bringing the interest in Upper Cretaceous Chalk plays in the WCG area to the next level. The amplitude anomaly is also clearly visible on the seismic data and is probably due to a combined porosity and oil saturation response. In the light of these discoveries, it is easy to understand that mapping facies variations within the Chalk is of paramount importance in the search for new prospects, especially knowing that the upper Chalk section is affected by various diagenetic events, re-working of the sediments and carbonate dissolution.

The figure below illustrates the improvements brought by broadband seismic in mapping these facies. With an identical RMS amplitude extraction method, we can see that conventional seismic data struggles to define dissolution features within the upper Chalk interval, whereas they are very well delineated with broadband data (i.e. black features on the map). Also, the lower frequencies highlight a regional facies trend: marlier, softer chalk in darker grey shades, while the white and lighter grey shades indicate the presence of carbonate-rich, hard chalk.

*RMS amplitude map comparison of the Maureen-Ekofisk interval – Chalk facies mapping is highly improved with the use of variable-depth streamer seismic.*



*Extra low frequencies brought by the BroadSeis technology below the BCU (in blue) help correlate Jurassic formations across fault blocks in the West Central Graben area.*

### Deep Jurassic Interpretation

A number of fields have been discovered in the Jurassic Fulmar sands in the WCG area: Christian, Cook, Teal, Bligh and Selkirk to name a few. As low frequencies penetrate deeper into the earth, the broadband seismic data helps the imaging of these deep targets in the West Central Graben. These low frequencies also give more character to the seismic data, which provide useful information to correlate deep Fulmar sands across adjacent fault blocks (see figure above). In addition, knowing that a number of those deep fields in the WCG area are considered high-pressure/high-temperature, the extra low-frequency content of broadband seismic data can potentially be used to determine pressure gradients more accurately from seismic velocities.

### A Powerful Technology

Located in an established producing area of the Central North Sea, this BroadSeis survey recently acquired in the UK West Central Graben demonstrates the huge value of the broadband curved variable-depth streamer solution. The exploration industry is now using these enhanced seismic data to unveil the remaining potential of the area. Further broadband seismic datasets are being acquired across the Central North Sea, which will no doubt shed new light on our geological understanding of an already very mature basin. ■

*Images courtesy of CGG Data Library.*

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# The Levantine Basin: Prospects and Pitfalls

Discoveries of gas in the Eastern Mediterranean have surprised the world. Will they help build bridges of peace or simply exacerbate tensions in this conflict-prone area?

**NIKKI JONES**

Less than ten years ago there was almost no interest in exploration in the Mediterranean. Now the Levantine Basin, stretching from Egypt across to Turkey, is the site of the world's biggest deepwater gas discovery of the last decade and new waves of interest are lapping south and westward, to the coasts of Egypt, Malta, Italy and Spain. For the three independents that are investing most heavily in these recent discoveries there remain issues of regulatory uncertainty, particularly their need for Israeli export licences that will make the next level of investment viable. For the world, there is the question whether this unexpected resource wealth will heighten tension in such a fractious neighbourhood or whether it might, as some hope, help build bridges towards peace.

The US Geological Survey estimates that there are 122 Tcf of natural gas in the Levantine Basin. Since 2009, 35 Tcf has been discovered in Israeli and Cypriot waters, almost all in three fields

– Aphrodite, Tamar and the 'super-giant' field Leviathan. It is estimated that almost 1.7 Bbo also wait to be tapped.

## Significant Finds for Israel

Significant on and offshore gas finds in Egypt in the 1990s persuaded Israeli entrepreneur, Gideon Tadmor, to begin drilling, first onshore and eventually moving out into deepwater. His company, Avner Oil and Gas, later part of the Delek Group, soon realised they needed foreign expertise for such depths. Many oil companies were reluctant to invest for fear of jeopardising their relationships with neighbouring Arab countries but the small Samedan Oil Corporation signed up, later becoming Noble. In 1999 the partners drilled their first well and a year later made their first commercially viable discovery of 1 Tcf at the Mari-B field in the Yam Tethys gas field.

However, it was another ten years before the next significant find. Tamar, approximately 90 km off the coast of Haifa, was discovered in 2009 and began

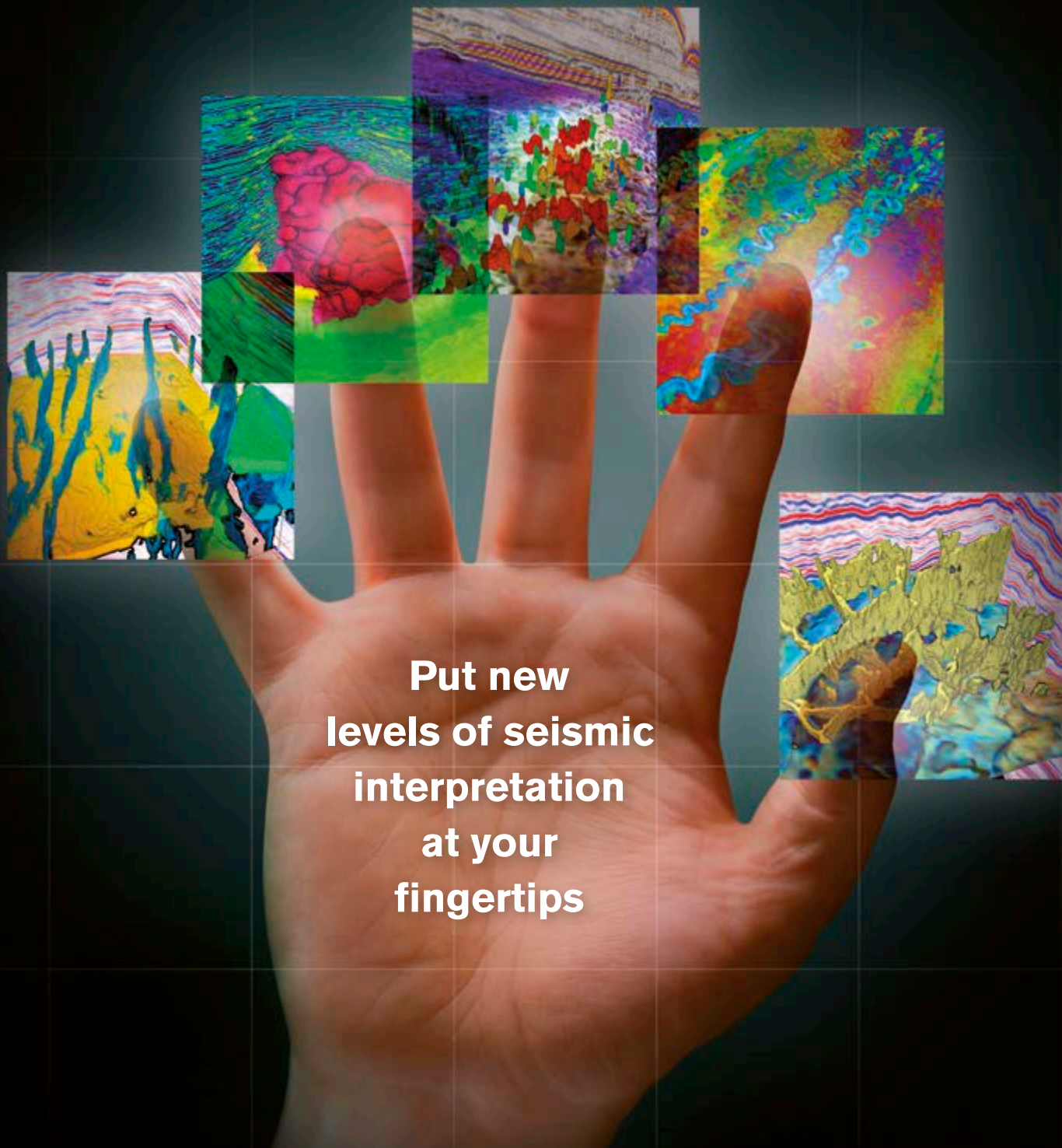
producing gas in March this year. The field lies in 1,700m water depth and required drilling of almost 5,000m to reach the sub-salt, lower Miocene structure. However, its estimated 10 Tcf has been dwarfed by the Leviathan field's 17 Tcf, approximately 50 km south-west, discovered in 2010. In total, there have been six discoveries in Israeli waters, with a total of approximately 36 Tcf gross resources. In addition, in 2011 Noble announced a further discovery, Aphrodite, 34 km west of Leviathan and in Cypriot waters. This field has an estimated 3–9 Tcf.

## Leviathan Unexploited

For the moment, Leviathan remains unexploited. The most contentious, but not the only, issue to be resolved is the amount the Israeli government will allow to be exported. An Israeli inter-ministerial committee submitted a report last August recommending that just over 50% of production – 35 Bcf – should be exported while the remainder should be used for

*The burgeoning port of Haifa is approximately 90 km east of the Tamar discovery*





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domestic consumption in Israel. This was seen as a victory for the investors but there is no final agreement. In December 2012 Australian company Woodside Petroleum announced that it is poised to take a \$1.25 billion stake in Leviathan, alongside Noble and Delek, dependent on government approval of a high level of exports. The three largest investing companies are also hoping for a guaranteed level of taxation, Noble having already experienced a punishing increase from 35% to near 65% in 2010 after investing \$1bn into Tamar. In a further complication, Delek and Noble are also waiting on a ruling from the Israeli competition watchdog on whether they currently control too much of the sector.

The value of the finds depends on several other factors, including how the gas is transported and its destination. Gas from Tamar is being piped to the Mari-B structure and onwards through an existing pipeline to the Ashdod refinery in southern Israel. However, the increased volumes predicted to come from Leviathan require new thinking. The most obvious target market is Turkey, which would allow onward shipment to Europe. To this end, Israeli Prime Minister Benjamin Netanyahu has made moves towards an apology for the 2010 storming of the Mavi Marmara Gaza-relief flotilla, when eight Turkish citizens were killed plus one American-Turk, but he has stopped short of Turkish demands for compensation and the lifting of restrictions on civilian goods into Gaza. Relations between the two states remain tense, leading the US to urge Turkish President Erdogan to put off a planned May visit to Gaza, a visit that Israel perceives as an act of hostility. Should the Turkish export plan succeed, one possible method of delivery would be an under-sea pipeline going through Cypriot waters, effectively bypassing Lebanon and Syria.

A second option that would allow Israel to gain access to the European market is to pipe the gas to Cyprus where it could be processed and then exported. However, cooperation with the island is likely to antagonise Turkey, which has already warned oil companies off exploring Cypriot waters. Russia is also unlikely to be happy with increased competition for the European market.

Alternative plans include a relatively

short (and therefore less expensive) pipeline to the smaller market of Jordan. Reversing the pipeline that currently brings cheap Egyptian gas to Israel through the Sinai Desert – and which has been repeatedly bombed since the Arab Spring – is also under consideration. A liquefied natural gas plant, either at sea or onshore, is a further option that might allow Israel to access the wider Asian market and in February this year it was reported that talks were underway with Russia's Gazprom regarding the possibility of building a massive floating LNG vessel.

### Increased Tensions

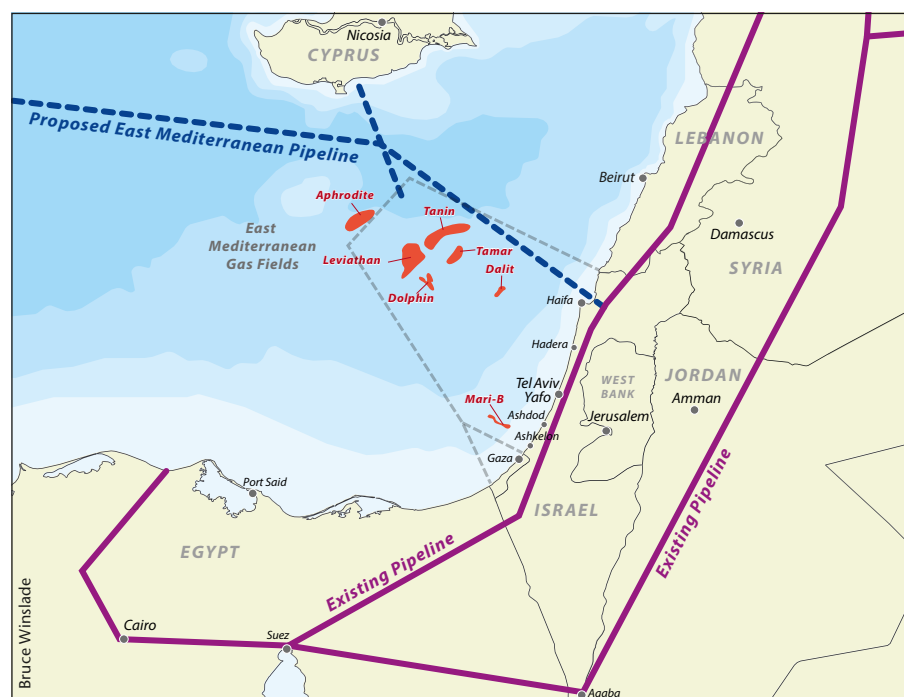
So far, there has been no outright conflict with Lebanon over ownership, although the Lebanese claim that Leviathan extends into their subsea waters and have submitted maps to the UN to back their claim: the difficulty is that Israel has never ratified the 1982 UN Convention on Law of the Sea which divides world subsea mineral rights. The Lebanese also claim Tamar as theirs and are reportedly supported by the Obama administration. In the meantime, the Lebanese are pursuing the possibility of fields clearly within their waters, with some experts suggesting they could be commercially produced before the end of the decade (*see page 36*).

The exacerbation of conflict between Israel and the Palestinian Authority is more likely, however. Development of the Gaza Marine gas field, approximately 30 km

offshore and therefore within Palestinian waters, has been on hold since the late 1990s, primarily because of disputes over Israel refusing to pay market prices for surplus gas and concerns over revenues going to the Hamas government.

Meanwhile the Cypriot government has offered shares in the country's future oil and gas wealth as an incentive to keep investors in the country as it grapples with its financial crisis. However, that wealth is dependent on further discoveries and even Noble is not bidding for the one block with confirmed discoveries, Block 12. One discouraging factor may be strong objections from Turkey, the only UN member to recognise Northern Cyprus as an independent entity, and which has the prospect of discoveries in its own waters. Turkey has been exploring its south coast since 2007 and farm-outs and joint ventures with the Turkish Petroleum Corporation have been offered since 2011. In 2013 companies seem more energised by prospects off the coast of Egypt, where a recent oil licensing round attracted a large number of bids.

Given the many different players and the complicated dynamics of the Eastern Mediterranean, the extent to which the Levantine Basin will eventually be exploited is open to question. In the meantime, it unfortunately appears more likely that the discovery of hydrocarbons will fuel tensions, rather than bring peace to this conflict-ridden neighbourhood. ■



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# Don't Wake Up Mungibeddu!

STEFANIA HARTLEY

Where would you go if you wanted to find pristine rock which has never seen the light of the sun before? And if you wanted a fertile soil, ideal for growing a vineyard? Do you fancy snow in summer and ski slopes with a sea view?

The answer is simple: 'Mungibeddu' – or Mount Etna, as it is better known.

'Mungibeddu' ('the mountain' in the Sicilian dialect) has impressive credentials. It is a candidate to join UNESCO's World Heritage list, and was designated as a 'Decade Volcano' by the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) – one of 16 volcanoes deemed worthy of particular study in light of their history of large, destructive eruptions and proximity to populated areas. It is the biggest and tallest active volcano in Europe, measuring more than 3,300m in height – and it is one of the most active volcanoes in the world, with almost continuous eruptions from its summit craters and frequent lava flows from fissures which open on its flanks. In addition, Parco dell'Etna was the first nature park to be instituted in Sicily, back in March 1987.

Etna, like Vesuvius and Krakatoa, is a

stratovolcano, characterised by a conical shape with steep sides, created by several layers of solidified lava, ash and pumice. The magma in a stratovolcano has a medium to high content of silica which makes it more viscous than an iron-rich magma. As a consequence, the lava covers a shorter distance before solidifying, hence the steep conical shape. The exact height of Etna changes following each eruption.

Harbouring silica-rich magma in your magma chamber can be catastrophic. Stratovolcanoes periodically experience explosive eruptions: trapped gases, unable to escape to the surface, build up inside the thick magma. If the blockage or some other part of the volcanic mountain suddenly gives way, the pressure is released quickly with an explosion of searing gas and a rain of extremely hot large boulders or volcanic bombs and

finer ash in the form of pyroclastic flow. A tell-tale sign of such occurrences in the rock record is the presence of graded bedding, with larger rocks at the bottom and smaller rocks, ash and dust towards the top, as well as pumice stones.

## A Brief History of Etna

Etna started its life as an underwater volcano during the Quaternary era, about 600,000 years ago. The area lies above the convergent margin between the African and the Eurasian plates which causes the presence of other volcanoes – nearby in the volcanic Aeolian Islands, for example – as well as devastating earthquakes. The earthquake of the nearby towns of Messina and Reggio on 28 December 1908 is considered one of the worst natural disasters of the twentieth century and the biggest ever recorded in Europe,



based on number of victims. But eruptions have been recorded throughout human history, with the Roman poet Virgil writing what was probably a first-hand description of an eruption of Etna in *The Aeneid* about 20 BC.

Etna has experienced a variety of eruption styles and for some time has extruded basaltic (iron-rich) as well as silica-rich lava. Since the 1970s more explosive eruptions have been observed, especially from the four craters at the summit: 'paroxysms' which included lava fountains and gas and ash columns. Eruptions can also occur from the craters along the side of the volcano, all the way down to a few hundred metres above sea level. The summit craters have been generally active continuously for many years, while the side craters have periodic interruptions in activity, although in the last forty years these have only lasted two years on average.

The longest eruption of the twentieth century, lasting 473 days, started in December 1991 and spurred the inhabitants into quick action, with diggers working round the clock to create an earth barrier 20m high to protect the town of Zafferana Etnea. It worked, but in 2001 this technique was not sufficient to keep the lava flow away from inhabited areas. On that occasion the Italian navy had to use 7 tonnes of plastic explosive (C4) inside the main canal.

### Agriculture on Etna

So, who on earth would want to live near such a dangerous 'beast', above such an unstable spot on our planet? As a matter of fact 25% of the total population of the island of Sicily does! Catania, the 10th biggest town in Italy, is situated just a (pumice) stone's throw from Etna's craters and it has been periodically destroyed by it. You might think that the fatalistic attitude of Sicilians has made them particularly resigned to live under the shadow of an active volcano. But in fact it was the fertile soil that attracted their ancestors to live there.

When volcanic rock breaks down and releases its precious minerals, a rich volcanic soil is created. Vineyards, olive, pistachio and hazelnut tree groves and orchards of local varieties of apples are still being lovingly tended along the slopes of Etna. Particular attention is devoted to organic



*The plume from Mt Etna can clearly be seen in this satellite image*

agriculture and the conservation of rare varieties of apples, to preserve biodiversity.

The importance of agriculture and the human influence on the landscape of the volcano, with all the richness of tradition and culture, has been acknowledged by the Ente Parco dell' Etna, which manages the nature park. While in the area designated as Zone A no human settlements are allowed, Zone B is made of smallholdings, with beautiful old farm houses, terraces storehouses, millstones, and wine-processing structures, as well as the old landlords' villas. Zone C and D are different still, mostly devoted to tourist facilities

### Special Flora and Fauna

As you can imagine, living on a volcano can be an unsettling experience for a plant: as well as the harshness of the weather and the lack of water, at higher altitudes at least you also have to factor in periodic lava flows which could burn down entire forests. At lower altitudes we can find oak forests as well as the orchards of hazelnuts, apples and sweet chestnuts. From over 2,000m above sea level we find beeches, reaching here their southernmost distribution limit, and a very special tree – the *Betula aetnensis* (Rafin.). This is a rare relict species, endemic to Etna. This species of *Betula* has had to adapt its vascular system in order

*Etna with lava fountain erupting from the south-east crater*







Parco Etna Archive

*Etna seen from Contrada Fontanamurata*

to survive extreme heat and cold, and it is only found on the east and west slopes of Mount Etna, between 1,300 and 2,100m, where other trees cannot survive. Higher still we will find astragalus, senecio, violets

and cerastium and pioneer plants. Beyond the limit of the astragalus, between 2,450 and 3,000m, the conditions are so harsh and the rock so new that no vascular plants are to be found.

*Igneous rock samples on sale in the tourist shops at the ski lift station*

Giorgio Hartley

Although wolves, wild boars and deer have long disappeared from Etna, we can still find porcupines, foxes, wild cats, martens, rabbits and hares, together with weasels, hedgehogs, dormice and several species of mice and bats. As well as many insects, snakes and birds of prey are common: the poisonous viper has increased in numbers in recent years due to the fall in the numbers of its predators. Among the diurnal birds of prey we can count sparrow-hawks, buzzards, kestrels, peregrines, and the golden eagle. Nocturnal birds of prey include the Barn Owl, the Scops Owl, the Tawny Owl, and the Long-eared Owl. Jays, rock pigeons, and the rock partridge have also been sighted, as well as many song birds – warblers, tits, cuckoo, and many others. A special mention goes to the wheatear, which can be seen flying its irregular flying style around the lava fields.

### Waking the Volcano!

Etna is one of the most accessible active volcanoes in the world, so much so that even a young family can visit it. During our trip to Mount Etna in spring 2010, our youngest daughter, then aged five, asked us with a certain amount of apprehension if the volcano could erupt. We told her that the volcano was 'asleep' (in Italian, 'dorme', meaning sleeps, sounds very much like the English 'dormant') although strictly speaking that was not true. All through the trip she whispered and told us off if we raised our voice – in case we woke up the sleeping volcano!

A few days later our trip came to an end, but we found we could not fly back home: nothing less than an enormous cloud of volcanic ash had enveloped Europe and paralysed air traffic. It was no use trying to explain to our youngest daughter that the volcano which had caused the airport chaos was not Etna but the unpronounceable Eyjafjallajökull, many miles further north, in Iceland. All she knew was that she had told us to be quiet, we had ignored her advice and we had woken up the volcano!

Check out Etna's live webcams (including thermal camera) on the website of the Catania section of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) (National Institute of Geophysics and Volcanology) on: [http://www.vulcanoetna.it/it\\_etna\\_cam.php](http://www.vulcanoetna.it/it_etna_cam.php). ■

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# A WORKFLOW FOR Success in Shales

**TED HOLDEN, JOHN PENDREL, FRED JENSON and PETER MESDAG, Jason, a CCG Company**

Following a rock properties-based workflow for shale plays makes it possible to gather intelligence which not only defines where to drill and how to frac, but also better predicts the economic outcome.

As with conventional plays, the economic case for developing and producing an unconventional field is based on how much resource exists, whether it is gas or oil, and how much can be extracted at what cost. The answers for shale plays lie in the volume and maturity of the total organic carbon (TOC) and the ability to create an effective fracture network that will conduct the hydrocarbons to each borehole. This in turn requires an understanding of mineralogy, lithology, relative rock brittleness, natural fracturing and the directionality of in situ rock stresses.

Shale play sweet spots are typically characterised by mid to high kerogen content, lower clay volumes, higher effective porosity, low water saturation, high Young's Modulus and low Poisson's Ratio. Using these properties as a guide, reservoir engineers can define a drilling programme that focuses on the best targets in the field and optimises the recovery from each well.

Petrophysical analysis is the starting point, combining laboratory measurements, core data and well logs. Rock physics then establishes the relationship between petrophysical and elastic properties of the formation and enables the creation of synthetics for missing and bad log data. Seismic data analysis moves the analysis beyond well control to the whole field. At the conclusion of the workflow there should be sufficient information about the reservoir character to select optimal drilling locations, as well as orientation and placement of horizontal wells for the most effective production programme.



## Step 1: TOC and Mineralogy

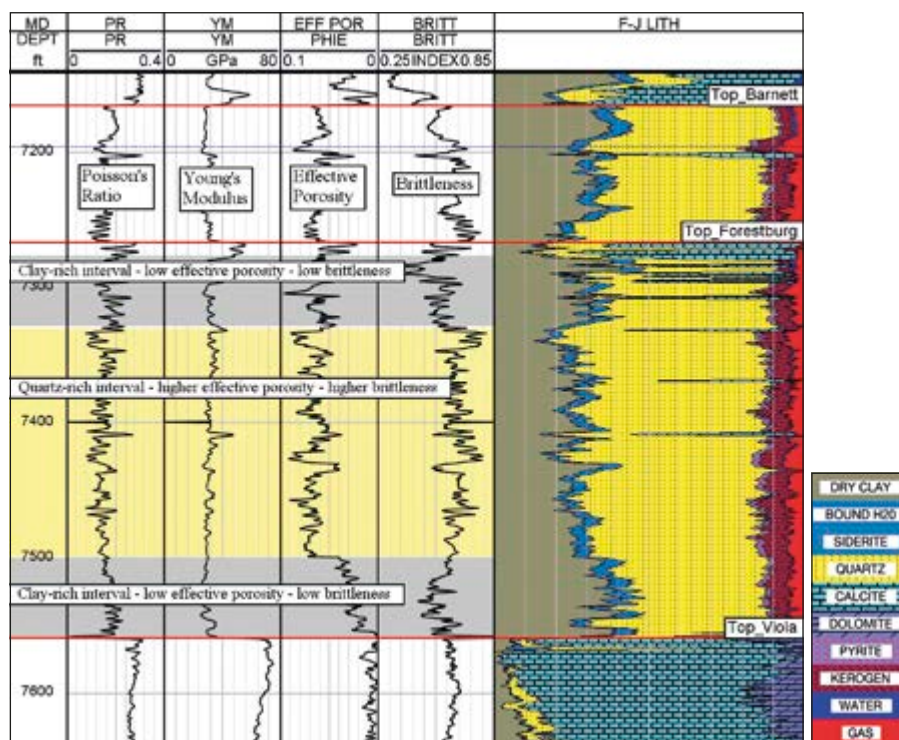
Determining TOC and mineral composition within the zone of interest is a critical first step in unconventional formation evaluation. The relative quantity and distribution of minerals and TOC are key to understanding the formation, and optimising production from it. For example, certain minerals, such as quartz, are more prone to fracture, while clay tends to fill and close fractures. Large volumes of pyrite can decrease measured resistivity. Kerogen type and maturity determine the oil/gas ratio, and volume establishes whether there is sufficient economic potential to continue the analysis.

The highly laminated nature of most shales presents a challenge for traditional analysis, as they harbour consolidated and compacted parasequences of shallow marine sediment, clay, quartz, feldspar, and heavy minerals. They exhibit ultra-to-low inter-particle permeability, low-to-moderate porosity, and complex pore connectivity.

A stochastic or statistical model is used to estimate relative volume and distribution of TOC and minerals. First, the presence and volume of some constituents are determined directly from core and well log measurements, such as shale volume from gamma ray or natural gamma ray logs and dry clay bulk density from crossplots of porosity and resistivity. These constituents are used as input to the model to estimate relative volume and distribution of TOC and minerals. If mineral composition is well understood, a deterministic approach can be taken instead.

Core data is the optimum control mechanism to validate the model. Passey and Modified Passey methods can be used as a quality control check on TOC volume, and uranium, a strong indicator of TOC, has the same use. The methods work best in shale sections with high clay content and no permeability. If the reservoir is self-sourcing and self-sealing, TOC is directly proportional to the kerogen volume, which can be determined by calibrating log responses to core data for at least one well in the area under study.

Density plays an important role in the analysis, given the disparity between various constituents, with pyrite having high density and a smaller volume



Log plot displaying a quartz-rich zone bounded by two clay-rich zones identified in Jason FaciesID™. The quartz-rich sweet spot is characterised by relatively higher porosity and higher brittleness.

and kerogen a larger volume percent than indicated by weight. Core-XRD mineralogy provides bulk-rock mineral weight percent, but excludes porosity and kerogen, whereas volume percent includes all minerals plus kerogen.

After the model is built and validated against well and core data, it can be applied to other wells in the field within the same general lithology. Geoscientists can then compare water saturation, porosity, and mineralogy with confidence.

## Step 2: Field Level Lithology

Once well and core data are interpreted they are combined with seismic data to extend the understanding of rock properties to the space between wells. This allows a better understanding of lithological detail across the field and leads to identification of the most attractive facies.

Shales present several challenges to seismic interpretation. Laminations cause polar anisotropy, distorting seismic data which must be corrected during seismic processing or inversion, and are also below normal seismic resolution, so special averaging must be performed to accurately reflect the composition of the formation. A tie must be interpolated

between well and seismic data, such that data at any wellbore can be recreated by the seismic; this well tie is what enables characterisation and modelling of the field away from well control.

Simultaneous AVO inversion produces a deterministic set of rock properties that can be QC'd against core and well log data. The inversion process accounts for AVO anomalies and reduces tuning and interference effects that can be problematic in simple seismic data analysis. Because laminations are below seismic data resolution, Backus averaging is employed to transform them to the seismic scale. Detail is added through a low frequency model generated as part of the inversion workflow.

Geostatistical inversion provides additional layer detail necessary to simulate flow. It simultaneously inverts impedance and lithology, producing more objective and geologically plausible models than other methods. The models have realistic detail, and also include uncertainty estimates. Integrating 3D seismic into geostatistical modelling can be challenging. The physical relationship between petrophysical properties and seismic measurement must be specified directly or by analysing well log data in conjunction with rock



physics modelling, establishing a proper multivariate statistical relationship between elastic and petrophysical properties, such as impedance and porosity, that accounts for uncertainty.

Petrophysical properties are simulated by constraining them to the relationship (specified or statistical) and inverted together with the elastic properties, which simultaneously produces detailed volumes of petrophysical properties, elastic properties and lithology. Alternatively, combined with the volumes of elastic parameters and lithology from geostatistical inversion, cosimulation yields highly detailed models of lithology-dependent petrophysical properties.

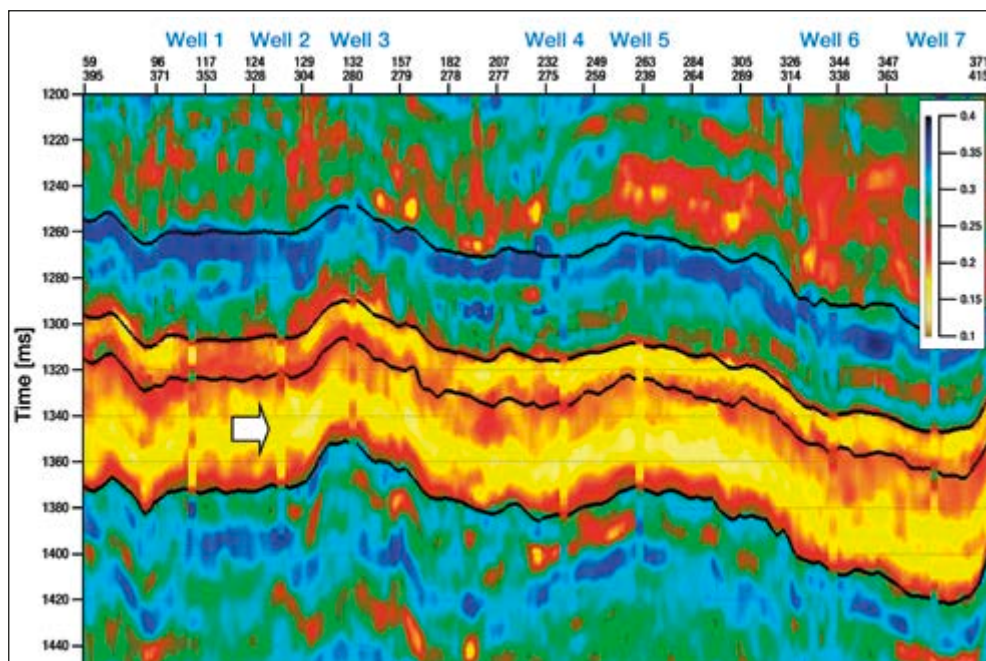
Following seismic inversion and analysis, there should be sufficient detail about TOC and minerals distribution across the field to make a preliminary assessment of the distribution of the reservoir facies for production. Potential well bore trajectories can be defined and refined with brittleness, rock stress and directionality information.

### Step 3: Brittleness and Ductility

Once TOC, mineralogy and lithology are understood, the formation can be evaluated for relative fracability. Brittleness – the likelihood of fracturing under stress – is key. Ductile shale naturally heals, while brittle silty shale with a quartz fraction is more likely to fracture. Geomechanical properties help determine relative brittleness or ductility, providing valuable input into completion and fracture stimulation design.

A combination of static testing (triaxial compression) and dynamic testing (ultrasonic velocity) establishes a relative brittleness measure. Zones with high Young's Modulus and low Poisson's Ratio will be more brittle and have higher reservoir quality (TOC and porosity are both higher).

Calculating Poisson's Ratio from seismic data is straightforward as it depends strictly on  $V_p/V_s$ , obtained from the ratio of P- and S-impedance. Young's Modulus requires a measure of density, usually unavailable due to the



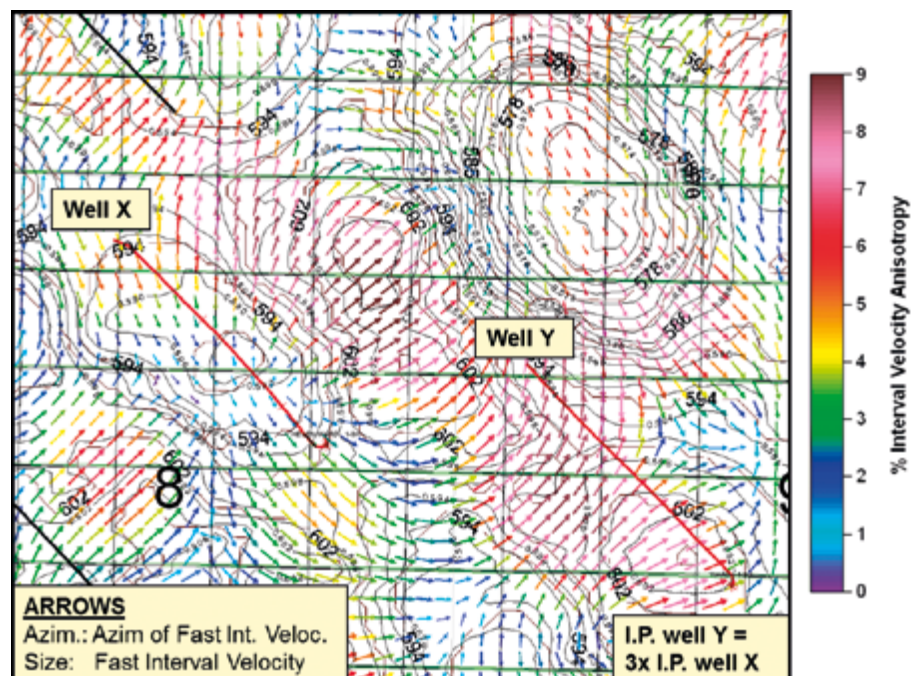
Poisson's Ratio computed from P-Impedance and S-Impedance using Jason RockTrace deterministic simultaneous AVO inversion. The plot is overlain with Poisson's Ratio from logs. The white arrow indicates the reservoir level in the lower Barnett. Low Poisson's Ratio rocks are more brittle.

limited range of angles in the seismic data, so it is necessary to evaluate several different potential proxies for density to determine the best one for the particular geology. The starting point, although rarely sufficient, is P-impedance, with other proxies involving a combination of S-impedance, Poisson's Ratio, and a

regression of P-impedance; the method chosen depends on the specific lithology. Core analysis is then used as a real world confirmation at each well location.

Brittleness is a relative not an absolute measure. It is based on a combination of core and sonic data and assumes that fractures open and remain open better

Map of Interval Velocity Anisotropy from the Fayetteville shale. Colour indicates magnitude of anisotropy; arrow length indicates magnitude of fast velocity. Arrow directions represent azimuths. Initial production from Well Y was three times that from Well X. (Courtesy Southwestern Energy)



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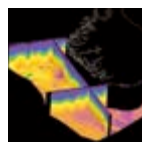
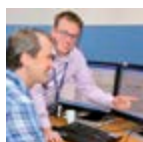
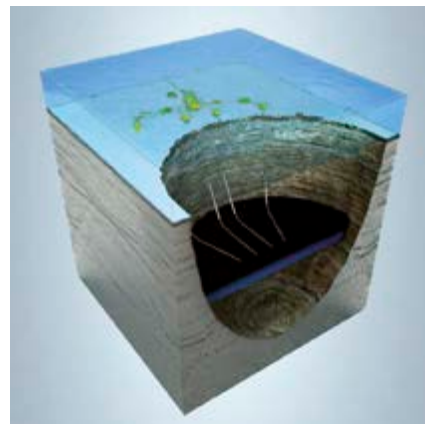
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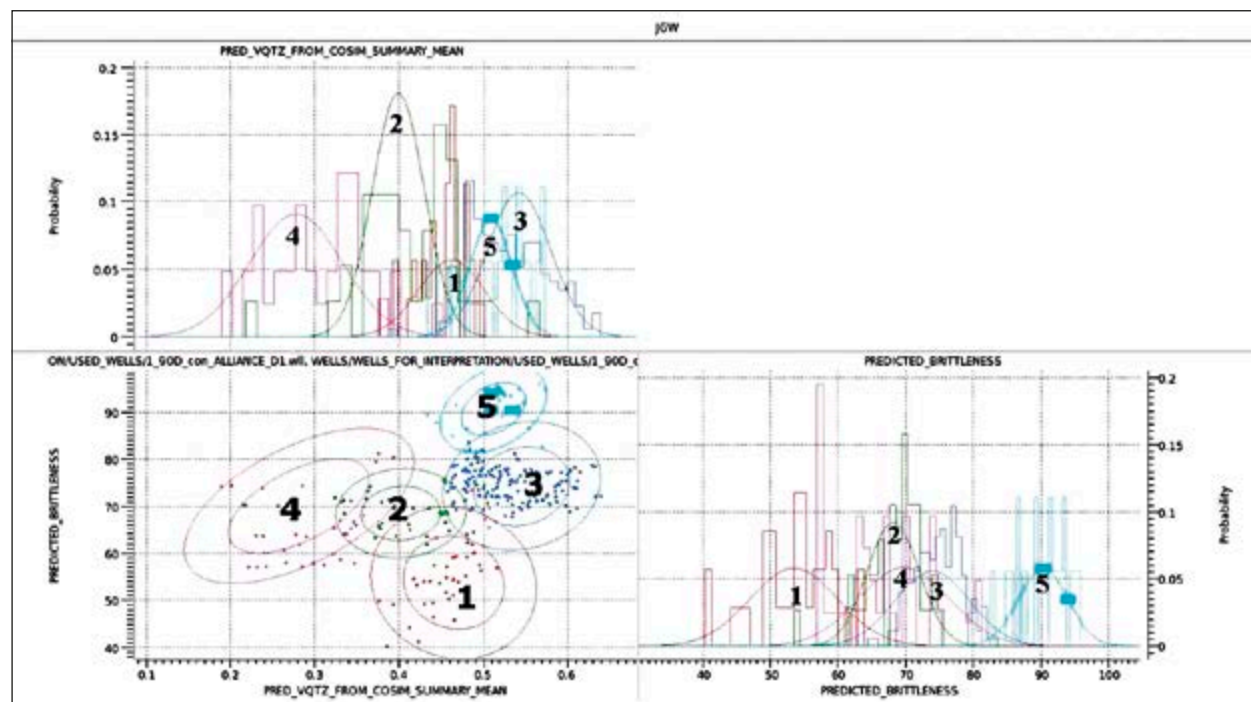
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PDFs (Probability Density Functions) of predicted volume of quartz vs. predicted brittleness displayed in Jason Facies and Fluids Probabilities™. The five numbered zones each enclose similarly coloured clusters of data points that indicate the different lithotypes.

in brittle rock. Shale formations are quite distinct from each other and vary in quality internally.

Facies can be identified from deterministic inversions following a Bayesian scheme. The inputs to the process are the inversion outcomes and PDFs (Probability Density Functions) representing the facies to be determined, estimated from log data or analogues. The outputs of the process are probability volumes for each facies and a most-probable facies volume, as shown below.

#### Step 4: Fracture Directionality

Following brittleness analysis, the areas most prone to fracturing should be well understood. The next step is to determine the best well bore direction for optimised conductivity and production.

Productivity is a function of fracture direction, induced fracture extent, network intensity, propensity to sustain fractures, effective conductivity and matrix permeability: all governed by mineralogy and rock stresses, and all evaluated from seismic. Determining these properties improves sweet spot identification, reserve estimation, well placement, completion design, stimulation effectiveness, and production enhancement.

Fractures occur when rock is stressed naturally or with stimulation. Induced

fractures run perpendicular to the direction of minimum rock stress, and open fractures created perpendicular to the well bore, typically vertical, provide the best opportunity to drain the area around it. If the formation is incorrectly fraced, the fractures may close, extend into water areas, or ineffectively conduct hydrocarbons.

The three principal components of rock stress allow estimation of how rocks are likely to fracture under stress during fracture stimulation. The vertical stress component is the overburden pressure of the rock on top of the reservoir. Differential horizontal stress components (minimum and maximum) are consequences of tectonics.

The effects of rock stress can be seen on borehole images, with natural fractures quite apparent. Differential effective stress squeezes the borehole causing breakouts in the direction of the minimum stress effect. The structural model from seismic also shows how the rock is stressed, and seismic structural attributes can be used to indicate fractures below accepted seismic resolution. The coherence attribute, used to detect faults or discontinuous features, can pick up swarms of parallel fractures.

Directional stress is determined using azimuthal anisotropy analysis. The distinct

layers of organic material in laminated shales exhibit electrical anisotropy – electrical conductivity in one direction different from another. Sand reservoirs have high resistivity (low conductivity) whereas shales have lower resistivity. Anisotropy has a first-order influence on shear and mode-converted PS-waves, which split into fast and slow modes with orthogonal polarisations. Because fractures and faults are mostly in the vertical direction and aligned along the direction of maximum horizontal stress, the result is azimuthal anisotropy (HTI). An azimuthal map can show the direction of the fast component, its magnitude and a measure of the difference between the maximum and minimum velocity, data which helps determine drilling direction, well positioning and hydraulic fracturing strategy.

The differential horizontal stress ratio can be calculated from seismic parameters without any knowledge of the stress state of the reservoir, preferably using wide angle, wide azimuth 3D seismic. Greater differential stress and/or higher fracture density results in greater anisotropy. By mapping the anisotropy at the reservoir level, geoscientists can see the direction, magnitude and difference between the maximum and minimum stress directions. A combination of Young's Modulus and

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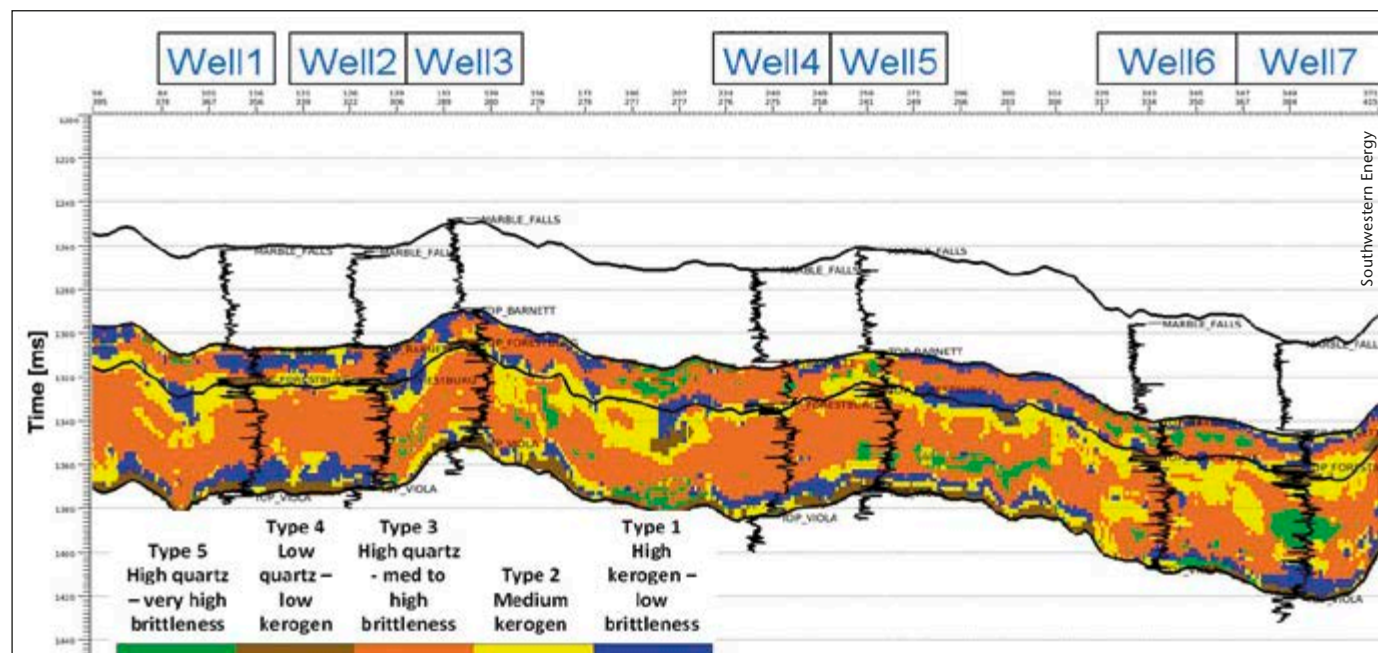
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Cross section of the most likely lithology correlated across all of the wells from the Top Barnett to the Top Viola, computed using Jason Facies and Fluids Probabilities.

differential horizontal stress indicates high potential areas for creating fracture networks, optimal drilling locations and best well bore orientation.

Azimuthal anisotropy is typically caused by near-vertical systems of aligned fractures and microcracks, pinpointing higher-potential producing areas. Anisotropic analysis identifies both higher differential stress and natural fracturing, but the difference between them is dependent on the play and cannot be separated mathematically.

Through these analyses, geoscientists can find natural fractures and areas with low anisotropy prone to fracturing. More fracturing may be needed where there are many faults. Effective fracturing determines the production rate and drainage area recovery. Complex fractures appear to be preferable, and drainage is very efficient when a high-relative-conductivity primary fracture is present, rather than a uniform-conductivity network.

### Step 5: Planning the Well Trajectory

By this final step in the workflow, there should be sufficient information to determine detailed well placement and fracture stimulation. Planning each well trajectory is an important element of success, given the heterogeneity common in shales.

Target facies, consisting of mid to high kerogen content, low clay and brittle rock, are identified through petrophysical and lithological analyses and refined with brittleness analysis. Because shale is laminated by nature, these targets may vary in height of pay interval and proximity to each other (laterally and/or vertically), requiring adjustments to the well bore trajectory to optimise contact.

Results from rock stress analysis identify the optimal well bore direction for fractures that will remain open and provide effective conductivity to the well bore. Placement of the vertical segment of each well can then be guided by the optimal horizontals in combination with surface considerations.

Each well can be drilled in the optimum stratigraphy throughout its entire length, avoiding water and ductile zones. Known fracture conductivity barriers can be used to separate the well bore from water zones. Stimulation can be managed to limit frac height growth and avoid communications with adjacent water-bearing zones. High clay zones can be mapped so that fracturing is not wasted. Fractures must remain open to be conductive, so proppant may be required to prevent oil and gas from being trapped. To maximise fracture complexity, operators may use closer

spacing of perforation clusters with more fracture treatments, small proppants at higher injection rates, closer spacing between laterals, and simultaneously alternate fracture treatments in offsetting wells to focus stimulation energy. Success depends on a strong understanding of the rock properties and rock stresses unique to each field and well.

### Specialised Software

Shale plays require special analysis to consistently obtain optimum results from each well. By combining all the well and field data, including cores, well logs and pre-stack 3D seismic data, geoscientists can understand key characteristics that enable them to estimate reserves, place well bores in the most appropriate trajectory and define the overall drilling completion and fracture stimulation programme.

All of this analysis is enhanced and accelerated by specialised reservoir characterisation software for methodical analysis of TOC, minerals, natural fractures, rock stresses, fracture orientation, brittleness and other aspects of the play. Using these tools and methods, geoscientists can make better decisions about where to drill and how to frac, and can better predict economic outcomes.

### References:

For a full list of references, see article online at [www.geoexpro.com](http://www.geoexpro.com) ■

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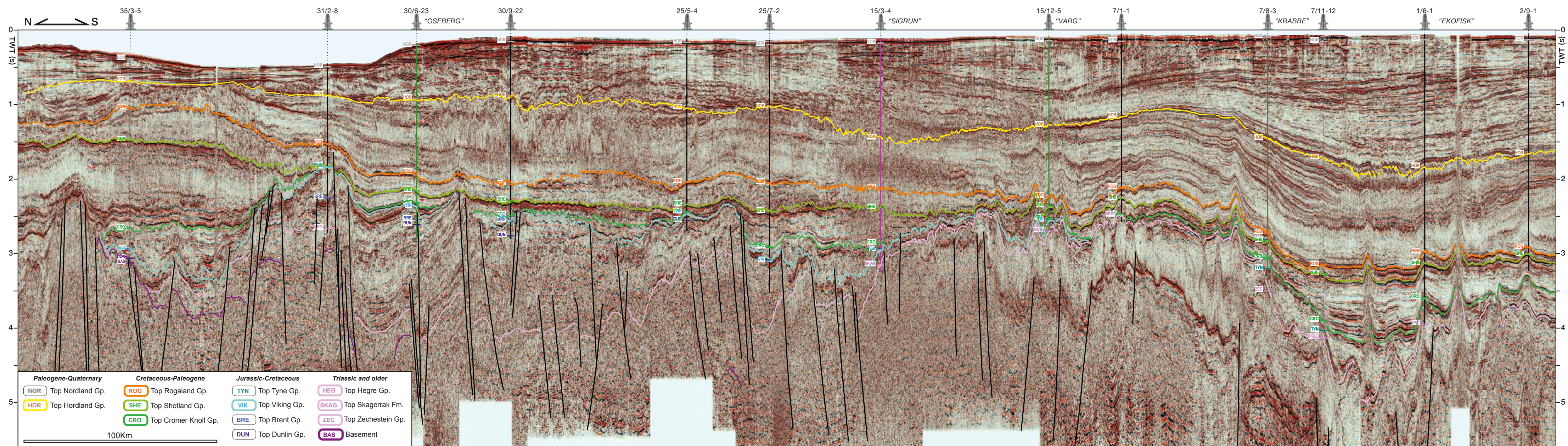
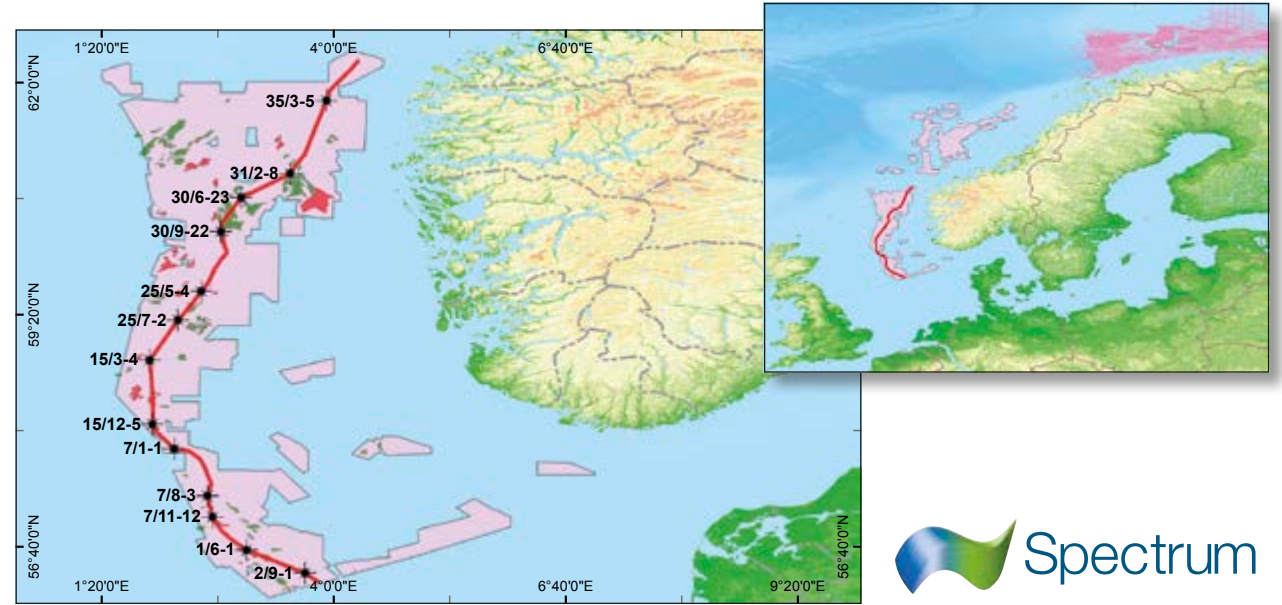
# A Stitch in Time!

The Norwegian Continental Shelf can now be imaged through the wide-screen of non-stop 3D over most of the margin. We call this dataset:



The seismic line shown below (TWT, Sec) is over 810 km long and is comprised entirely from high quality 3D data, tied to key released wells. This dataset has been created from released 3D, painstakingly matched and merged so that interpreters can glide from one survey to another – seamlessly.

Stitching together this dataset has released an extraordinary scaling power: being able to view basins, sequences and structures at regional scale, then zoom to examine well ties and prospects with the same modern, high resolution 3D seismic dataset. It is providing interpreters with their weapon-of-choice for chasing prospectivity, from regional play fairways to appraisal targets, when squeezing the ample remaining prospectivity from the Norwegian Continental Margin.





# A Cross Section of Norway

By assembling and merging a fragmented dataset of 3D seismic, it is possible to release the hydrocarbon potential of the Norwegian Continental Shelf.

**KIM GUNN MAVER, HELGE AVEN, NEIL HODGSON and PAOLO ESESTIME, Spectrum**

## Putting the Pieces Together

Since the start of hydrocarbon exploration in Norway in the 1960s a phenomenal amount of 2D and 3D seismic data has been acquired on the Norwegian Continental Shelf. This data was acquired piecemeal, focused on small areas with specific targets. Fortunately the data has been well managed by the Norwegian government and released into the public domain on a regular basis. By assembling this fragmented dataset we facilitate a unique geological tool for imaging and analysis of the Norwegian Continental Shelf.

The 'seismic shift' in this concept has occurred recently from the merging of released 3D datasets into vast carpets of data that realise the potential for efficient new assessment of the Norwegian Continental Shelf at both regional and field or prospect specific level. Oil companies are therefore able to view their assets in a regional 3D seismic perspective, re-assessing released wells as well as performing petroleum system modelling, potential field modelling and seismic attribute analysis.

## More Than a Jigsaw Puzzle

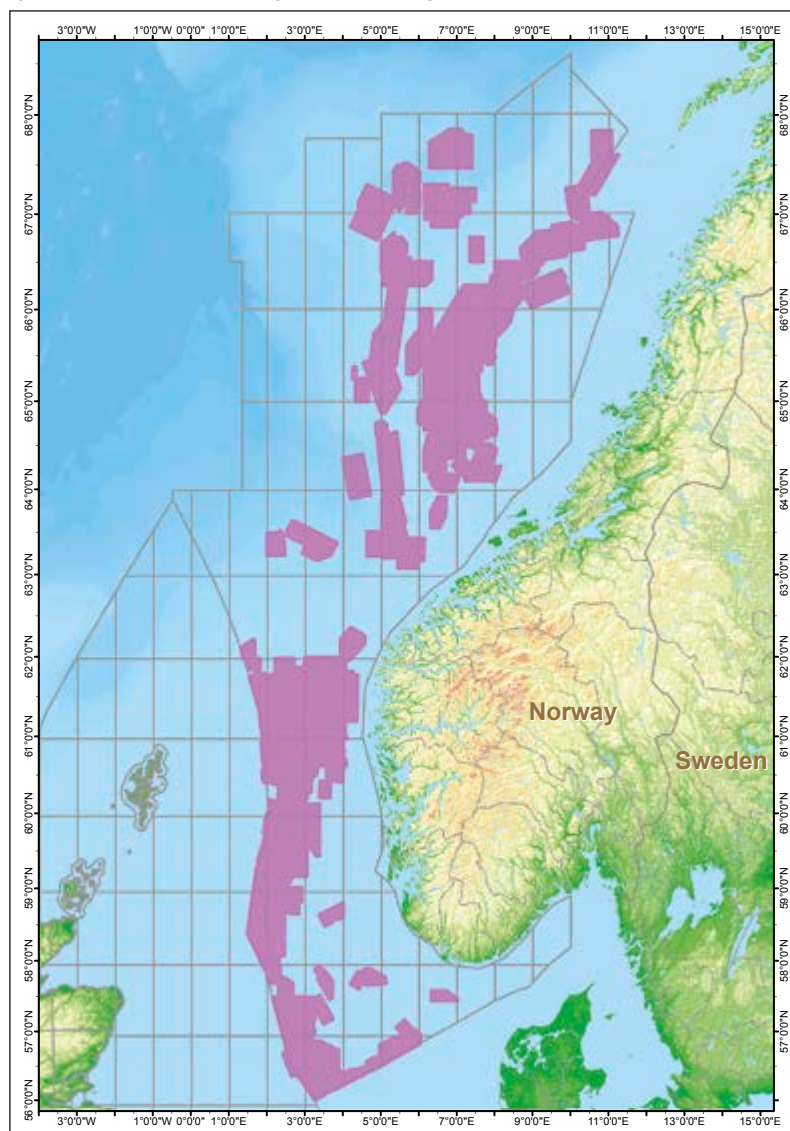
However, merging numerous 3D seismic surveys together to create a uniform dataset is far from a straightforward exercise. Each piece of the jigsaw puzzle overlaps the adjacent pieces, has different acquisition orientations and varying processing sequences and therefore varies in quality (bandwidth and signal to noise ratio).

Spectrum's Seamless Seismic product has been constructed taking all these factors into account, creating a merged dataset where the joins between surveys are, rather as you would expect, seamless (see merged seismic line fold-

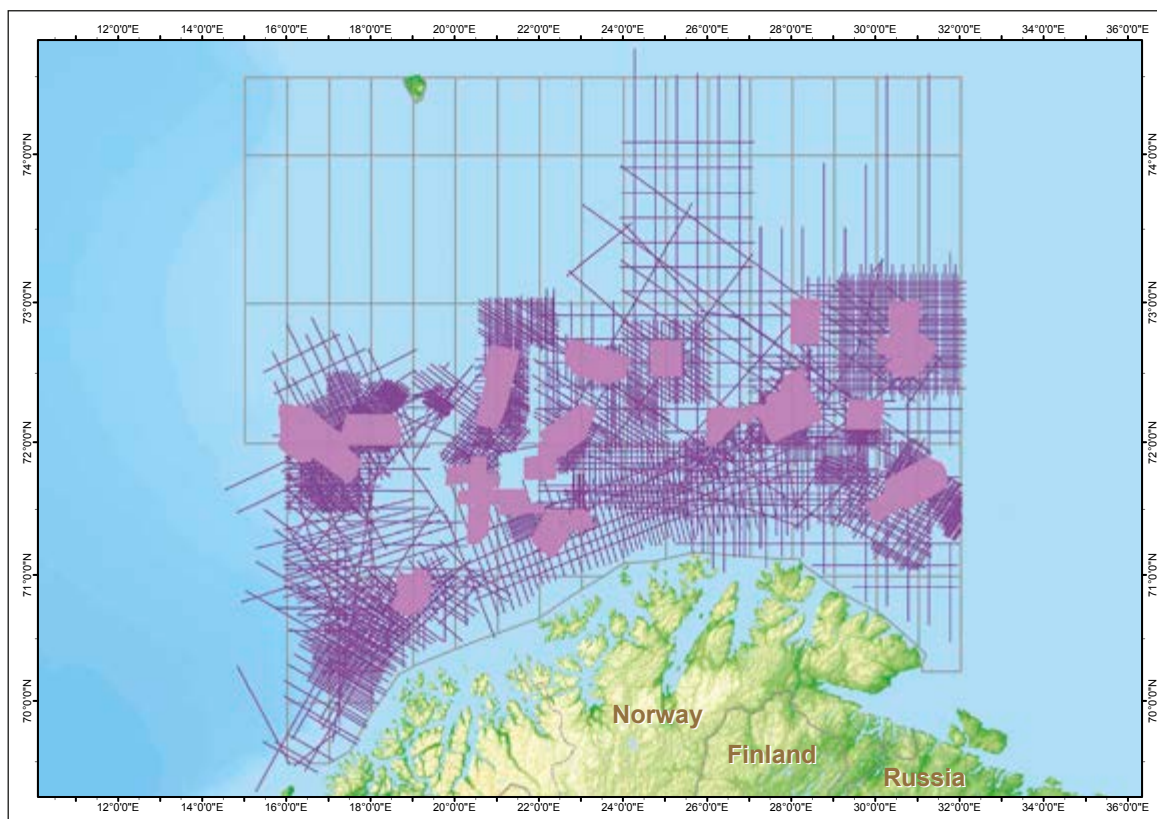
out on previous page). Additionally the dataset is dynamic as we are continuously integrating the stream of new 3D surveys being released.

The source data quality does vary from survey to survey, and to prevent mis-stacking when the final merge is applied, some processing is required prior to merging.

*Spectrum's 3D seismic coverage on the Norwegian Continental Shelf*







*Spectrum's 2D and 3D seismic coverage in the Barents Sea*

Our guiding philosophy is to try and keep as much as possible of the original character of the data, whilst maintaining the overall quality of the final seamlessly merged volume.

The standard processing scheme includes:

1. Seismic and navigation data validation
2. Survey regridding
3. Survey matching
4. Survey merging

### Basin to Burner Tip Interpretation

The Seamless Seismic product has to-date accumulated over 125,000 km<sup>2</sup> of 3D data from the Norwegian Shelf. This dataset extends from the Norwegian Southern North Sea Basin through to the Eastern Barents Sea. The foldout on the previous page is an example of a broadly south-north strike line through the Southern and Northern Basins.

At a regional scale this extraordinary line, over 810 km long, illustrates the difference between the Southern and Northern Basins. In the south, early Permian rifting develops the thick Permian salt sequence which dominates the Mesozoic potential. Extension and deposition in the Jurassic and Triassic developed diapirs and salt walls yield intricately short wavelength sediment pod and intrapod plays, in addition to later Cretaceous dome and down-building plays. By comparison, in the north the Mesozoic plays are dominated by simple extension and Jurassic and Cretaceous fault blocks on a grand scale. Over both basins the Tertiary thermal sag deposited thick clastic sequences, except in the far north where significant late basin inversion has significantly thinned the Tertiary sequence.

Whilst such observations are apparent on 2D data, the elegance of being able to correlate over multiple basins seamlessly allows locally developed geo-phenomena to be put into a regional context, and insights used to drive exploration concepts. And it is here that the multiple working scales of this seamless dataset open the opportunity not only to re-evaluate held and open acreage, but also to burrow down to take another look at old wells and abandoned fields, with the context of basin scale petroleum system analysis.

Contextualising the hard-won insights of the oil industry at all scales will generate new, untested concepts and open new exploration creaming curves in this exciting margin.

### Tie with Released Well Data

The Norwegian authorities have also released well data into the public domain, and so the next step for this dataset is to tie log data into the seismic dataset. The 3D seismic merged database already incorporates all released 3D surveys, and work is ongoing to incorporate the well data. This will generate a cost-effective tool to give access not only to the imagination-food of seamlessly carpeted 3D seismic but also the ground-truthing power of drill bit experience.

### The Future

During the next six years a minimum of 200 3D surveys are due to be released over the Norwegian Continental Shelf. These will be combined continuously into the existing dataset, in addition to all released well data, creating a dynamic and ever evolving insight-engine to release the barely touched hydrocarbon potential of the Norwegian Continental Shelf. ■

[www.spectrumasa.com/seamless](http://www.spectrumasa.com/seamless)



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# The Present is the Key to the Past

The Principle of Uniformitarianism gives confidence in selecting well sites through looking at Holocene facies analogues

**CLIF JORDAN and RICK SCHATZINGER**

The Principle of Uniformitarianism states that the causes and rates of geologic processes that are in operation today are the same as those that existed in the geologic past. Reefs behave the same today as they did in the past, although their main frame-builders have evolved through time. Sand bars and tidal flat settings also behave as they have in the past. More simply stated, the principle says that 'the present is the key to the past.'

This article describes several examples from the modern world, where primary patterns of sedimentation give tremendous insight into subsurface distributions of reef, sand bar and tidal flat settings – the three principal types of depositional settings for hydrocarbon reservoirs that produce from carbonate rocks.

## Methodology

Think of a modern-day sediment map as a time slice; it just happens to be the latest one – the Holocene. To make such a map, bottom samples must be collected and analysed for several properties, such as the percentage of mud, sand and gravel, the abundance of non-carbonate material in each size fraction, and the type of grains observed.

A shorthand system of symbols is used to reduce these data to mappable entities:

*sediment name* = (sediment descriptor) (dominant grain type) (secondary grain type) (texture) + (remark)

An example of this system would be:  $\odot \wedge G + \Upsilon$  which translates to head-coral mixed-skeletal grainstone with branching corals. Other examples include ooid grainstone ( $\odot G$ ) and algal stromatolite boundstone ( $\pi B$ ). This notation treats sediments as if they were rocks, making comparison with subsurface lithologies and patterns more direct and meaningful.

In the maps presented on these pages, red indicates reef facies, and yellow indicates shoals. Other colours are used for various carbonate facies, and shades of grey are used for shales.

*The tidal flats and reefs of the Red Sea seen from the air – a good way of putting a reservoir analogue into perspective.*



### Example 1: A Patch Reef Complex, Indonesia

300 bottom samples were collected from Kepulauan Seribu, a chain of islands north of Jakarta (Jordan, 1998). Depositional environments and sediments here consist of the following types:

**island** (brown):  $\ominus \backslash G$  coral-fragment mixed-skeletal grainstone

**reef facies** (red):  $\ominus \# B$  head-coral encrusting-red-algal boundstone with a matrix of coral-fragment mixed-skeletal packstone  $\ominus \backslash P$ , occurring between reef frame-builders

**near-reef facies** (yellow):  $\ominus \backslash G + \Upsilon$  coral-fragment mixed-skeletal grainstone with branching-coral fragments and  $\ominus \Phi P + \Upsilon$ , coral-fragment molluscan packstone with branching-coral fragments

**reef-sediment slope** (light blue):  $\ominus \Phi P$  coral-fragment molluscan packstone

**interreef lagoon** (light grey):  $\text{F} \ominus \Phi P + \oplus$  argillaceous benthonic-foram molluscan packstone with goethite nodules

**middle shelf** (dark blue):  $: \ominus \Phi SH + \oplus$  arenaceous foram molluscan shale with goethite nodules

These types of coral-reefs and associated islands are common throughout Indo-Pacific areas today. Reefs act as factories, exporting sediment in a radial pattern away from the reef centre. Large volumes of carbonate sediment form noticeable concentric white sand rims in near-reef and reef-sediment-slope environments, as observed in satellite images as well as in typical air photos. Red areas on the Kepulauan Seribu map show a rim of living reef, growing up to sea level, that surrounds each individual platform. A maximum depth of about 40m occurs in interreef lagoons between platforms. Note that reef platforms are largest in the southern part of the reef complex and smaller to the north, reflecting greater subsidence to the north, where reefs are struggling to keep up with a relatively rising sea level. Yellow-coloured areas dominate this map, showing more parts are covered by reef-derived sediment than by the reef itself. This suggests that in ancient settings the drill bit is more likely not to penetrate true reef facies, but near-reef sediments instead.

This map compares well with that of the giant Arun gas field of Miocene age in the North Sumatra Basin. The carbonate settings of the two areas show similar platform shapes and sizes and have comparable coral faunas, similar facies diversity, similar forams, similar subsidence patterns, and even the same windward side (the eastern side). Here one can swim today over the same species of corals that occur 3,000–3,350m deep at Arun, so there is no doubt about the environment of deposition for Miocene reef builders.

*The corals seen growing around the Indonesian Kepulauan Seribu chain of islands are the same species as the Miocene corals found at the giant Arun field.*



*Sedimentologic map of Kepulauan Seribu, Indonesia*

### Example 2: Barrier Reef System, Belize Shelf

Over 800 samples make up the data base for the sedimentologic map of the Belize Shelf in Central America, which demonstrates a barrier reef system and atolls. Again, red is reef, and yellow represents grainstone shoals. The map shows a wide variety of muddy sediment types on a broad shelf behind the Belize Barrier Reef, which is about 180 km long, making it the second longest barrier reef in the world. Barrier reefs also rim three offshore atolls; patch reefs occur behind the barrier to the west and in the centre of the atolls.

A mixed carbonate-clastic shelf occurs behind the barrier, and the northern and southern shelves have marked differences. Nearshore clastics occur along the coast of the southern shelf, supplied by rivers flowing east from the Maya Mountains, and do not occur on the northern part. The southern half of the shelf has more topographic relief, with more middle-shelf patch

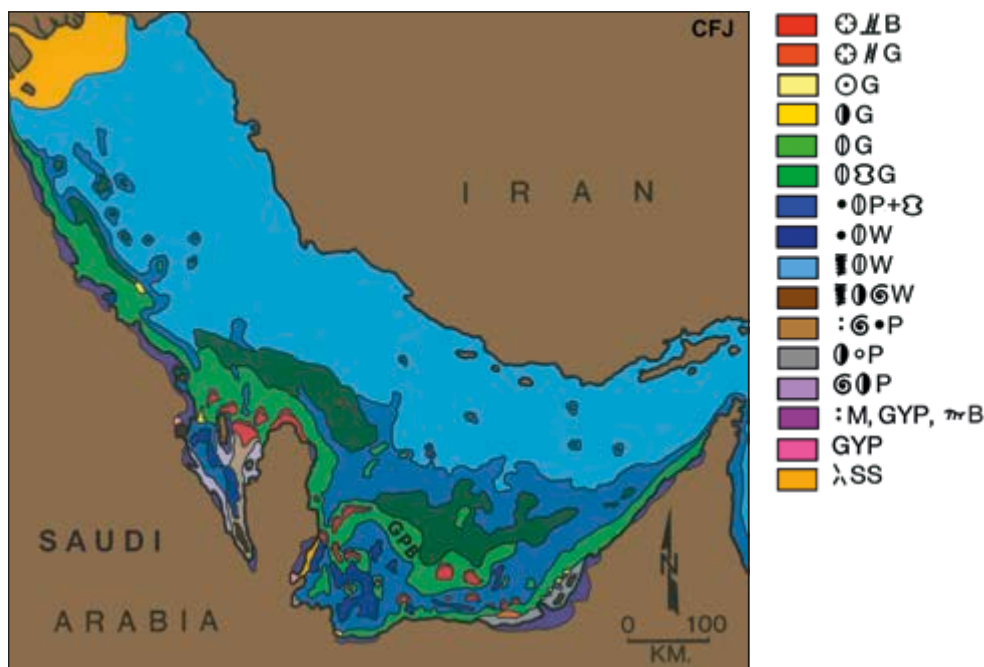




Sedimentologic data of Purser (1971) were field checked, reformatted, and used to create a sedimentologic map of the entire Arabian Gulf, which is dominated by tidal flat deposits, ooid bars, reefs and shell banks. The regional setting is one of a ramp profile, and the deepest part of the Gulf is not in the middle, but is offset to the north, closer to Iran. Sediments across the gulf are dominated by muddy carbonates with abundant molluscs, the Great Pearl Bank being the most famous example. Reefs (in red) are not common and are generally best developed as local features on top of salt domes. Ooid grainstone shoals (in yellow) are very rare, occurring as local tidal delta deposits off the Abu Dhabi coast north-west of the capital city. What the Arabian coast is most famous for are its extensive, well-developed tidal flats, consisting of algal-stromatolite boundstones with gastropods. These deposits provide excellent insights into processes of dolomite formation. The best modern-to-ancient comparisons of these tidal flats are the giant fields of the Jurassic Arab Zones in Saudi Arabia, where each of the Arab A, B, C, and D cycles are capped by such deposits.

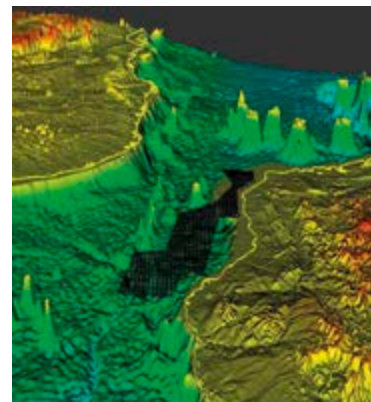
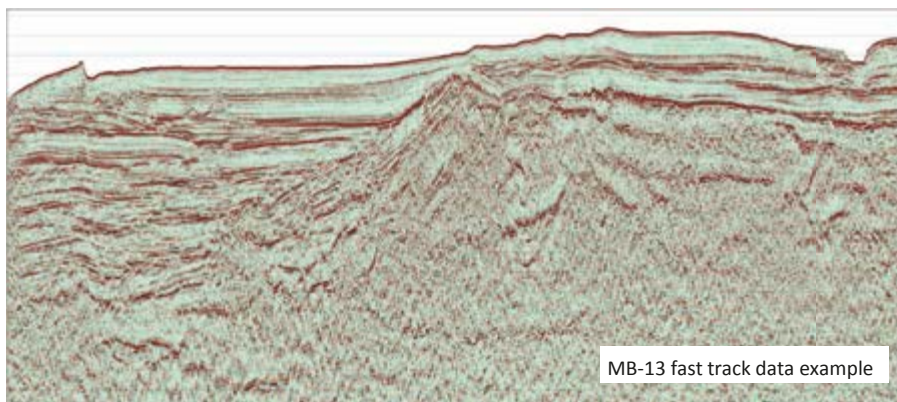


*Sedimentologic map of the Arabian Gulf*





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### Example 4: Oolites and Reefs, Great Bahama Bank

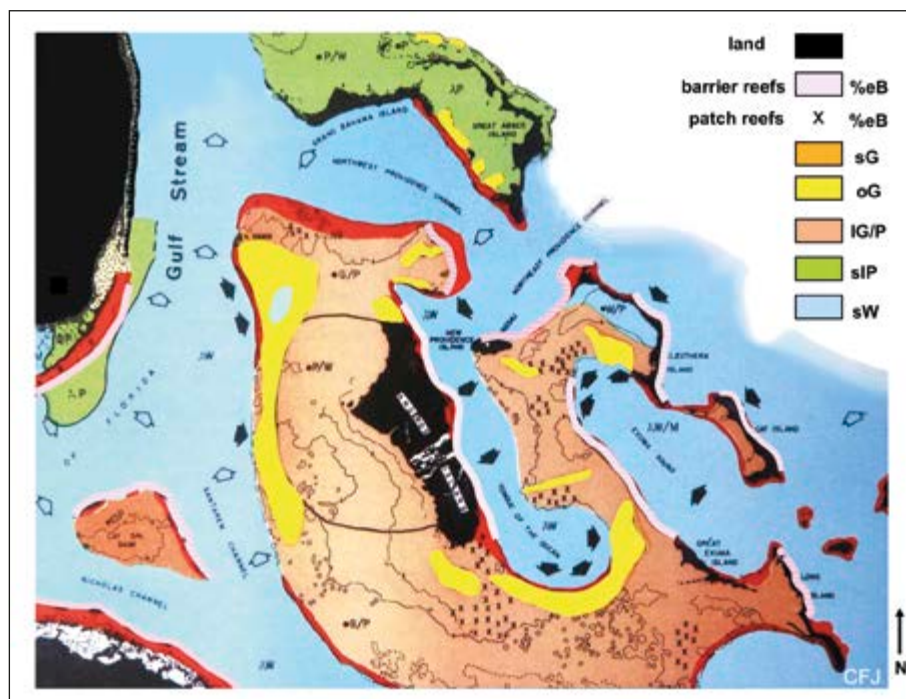
Hundreds of samples provide the basis for the sedimentologic map of the Great Bahama Bank, which consists of several types of oolite bars, plus tidal flats and reefs. Many researchers have contributed to this understanding, but the name of Ginsburg stands out above the rest.

The Great Bahama Bank is the largest carbonate platform in the world, with a drop-off profile on all sides. Its shelf-margin deposits consist either of ooid grainstones (yellow areas) or branching-coral encrusting-red-algal boundstones (red areas). Middle-shelf sediments consist of broad expanses of muddy carbonate facies but include some local sand shoals and patch reefs. Inner-shelf sediments host algal-stromatolite boundstones, formed on tidal flats, especially those along the west coast of Andros Island, the largest island on the platform. Underlying Pleistocene topography, especially aeolianite deposits, greatly influences the distribution of Bahamian Holocene sediments.

Zooming in on the regional sedimentological map one can see four different models for the formation of ooid bars. Other local areas of interest include the barrier reef along the east coast of Andros Island, the third-longest barrier reef in the world, with a narrow shelf west of it, consisting of skeletal sands and small patch reefs. Another area of detailed study is the Turks and Caicos, which shows a well developed outer-shelf barrier reef only on its northern, windward side; skeletal sands (with no patch reefs) occur on the southern side of this current-swept, isolated platform and has oceanic depths surrounding it on all sides.

### Anyone for a Field Trip?

There is nothing quite like seeing rocks and sediments in the field, so to make these comparisons personally, the reader is



On this regional sedimentological map of the Great Bahama Bank, one can see four different models for the formation of ooid bars: 1) Schooner Cays and southern end of Tongue of the Ocean (tidal bar belts at the outer shelf), 2) Joulter's Cay (a shelf-edge sheet deposit that includes ooid packstones), 3) the Exuma Islands (narrow passes between paleotopographic highs at the shelf edge), and 4) the shelf-edge Cat Cay ooid bar south of Bimini, which measures several tens of kilometres long.

invited to participate in upcoming field trips offered by the authors ([www.carbonaterocks.com](http://www.carbonaterocks.com)). The main objective is to show living examples of reservoir facies encountered by the drill bit. It is an enjoyable way to learn and has the added benefits of team-building. It is especially beneficial to take a flight over an area, so that the scale and 'map view' are put into perspective, especially the odds of drilling into targeted facies belts. ■

### References

- Jordan, C. F., 1998, *The Sedimentology of Kepulauan Seribu: A Modern Patch Reef Complex in the West Java Sea, Indonesia*, Indonesian Petroleum Association, 81p.
- Jordan, C. F. Jr. and Abdullah, M., 1992, Arun Field-Indonesia, North Sumatra Basin, Sumatra, in Foster, N. F. and Beaumont, E. A., eds., *Stratigraphic Traps III, Atlas of Oil and Gas Fields*, Amer. Assoc. Petrol. Geologists, *Treatise of Petroleum Geology*, p.1-39.

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# Folds and Folding Part I

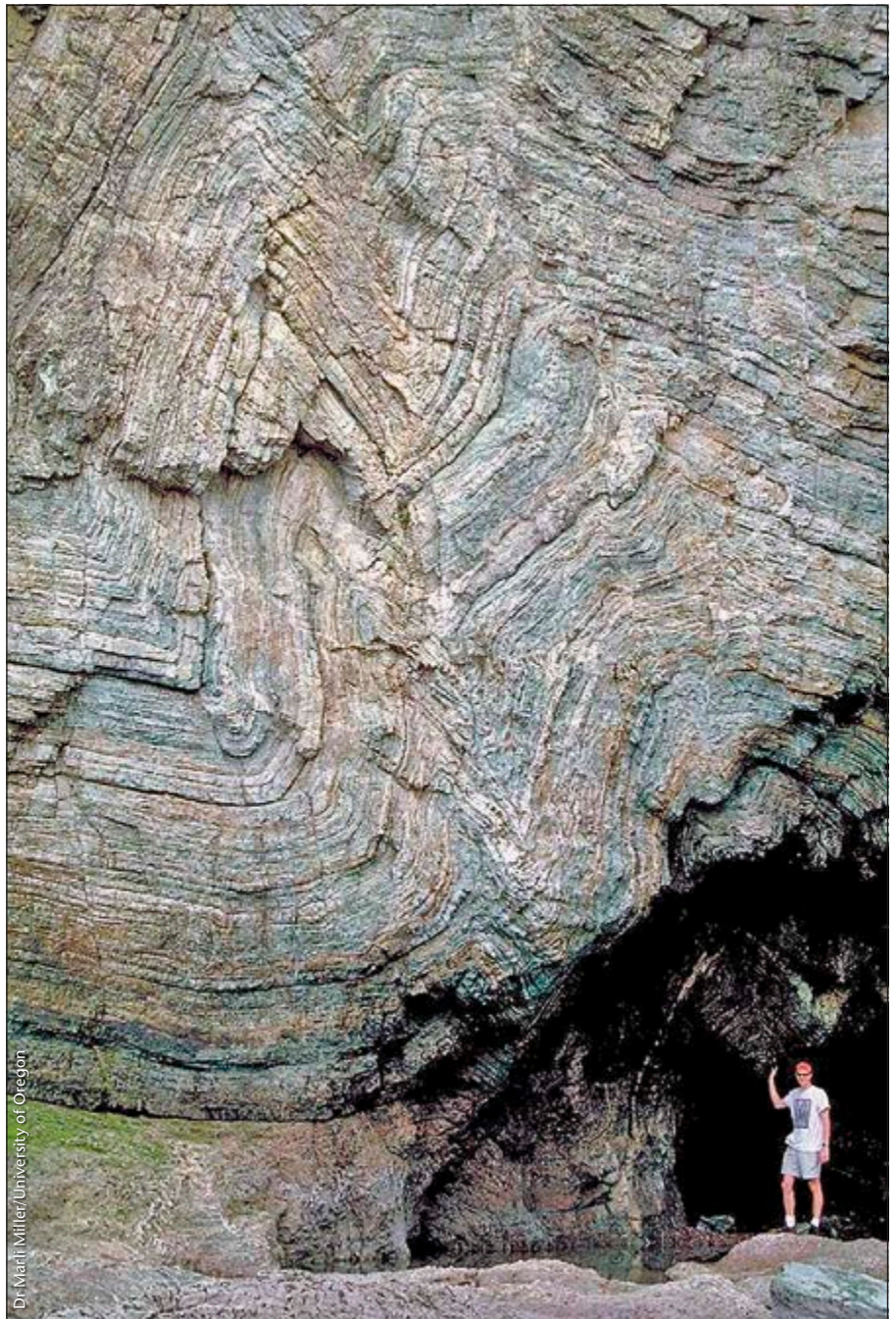
**RASOUL SORKHABI, Ph.D.**

Folds, faults and joints are the main types of structural deformation in the Earth's crustal rocks. Of these, folds often create the most spectacular geological scenes. Petroleum exploration has historically been associated with folds more than with any other geological structure. In 1861, two years after Drake's successful discovery well in Pennsylvania, E.B. Andrews, a professor at Marietta College, Ohio published an article in the *American Journal of Science*, in which he observed: "I have recently found a most interesting line of uplift and dislocation... As seen in Ohio it presents a well-marked anticlinal axis but with the eastern slope more steep than the western. Near the anticlinal axis are the oil and gas springs." In the same year, T. Sterry Hunt of the Geological Survey of Canada also proposed that oil accumulations "occur along the line of a low broad anticlinal axis which runs nearly east and west through the western peninsula of Canada" (*Smithsonian Institute Annual Report*, 1861). Thus was born the 'anticlinal theory of oil accumulation.' The industry's fascination with folds still continues.

Fold structures are found in various shapes and sizes, and can be very complex. Nomenclature of folds can also be confusing. We can observe folds on rock samples (hand specimens), outcrops, seismic images, and on satellite and aerial photographs. Millimetre-scale folds can be observed in thin-sections. The complete picture of a fold structure may not be visible in an outcrop due to erosion or non-exposure. Therefore, to reconstruct and analyse fold structures

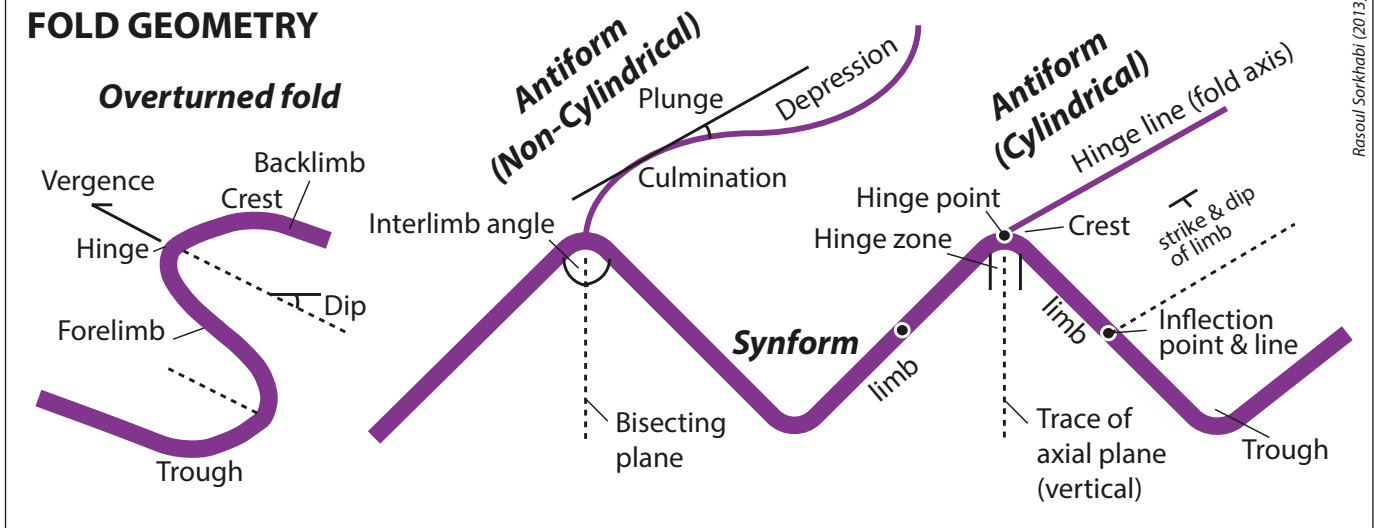
Rock folds are found in various shapes and sizes on Earth, and people are often amazed to see how large blocks of hard rocks have been folded like ocean waves. But fascination with folds is also shared by the petroleum industry. In this two-part article we unfold rock 'folds' to better understand their geometry and genesis.

*Chevron folds on Ribbon Chert (deepwater radiolarian chert, part of the Franciscan accretionary complex), Oregon*



Dr. Marli Miller/University of Oregon

## FOLD GEOMETRY



it is important to understand their basic elements – their anatomy.

### Hinge and Limbs: Fold Geometry

For simplicity, let us consider a single fold. A fold is a rock structure in which two curved surfaces, or **limbs (flanks)**, are joined at a **hinge line** (or a **hinge point** on a 2D profile) or practically speaking a **hinge zone**. The hinge is the line of maximum curvature. The hinge line may be straight, in which case it forms a **cylindrical fold**, or it may have a **plunge** (vertical angle between the hinge line and intersecting horizontal line) which creates a **non-cylindrical fold**. According to the plunge of the hinge line, we classify folds as horizontal (negligible plunge up to 10°), plunging (10–80°) or vertical (80–90°).

Large folds with long hinge lines undulating along the strike will have **culminations** and **depressions**. Folds plunge away from culminations and plunge toward depressions. A **doubly-plunging fold** is one in which the hinge line plunges in two opposite directions. Large doubly-plunging anticlines are especially important because they provide **four-way dip closures** for oil and gas accumulations.

Horizontal and vertical folds have straight hinge lines which can be considered as **fold axis**. A fold axis is a geometric (imaginary) straight line which when moved parallel to itself through space generates the shape of the fold. Non-cylindrical folds (with curved hinge lines) do not have fold axes, and for the purpose of detailed

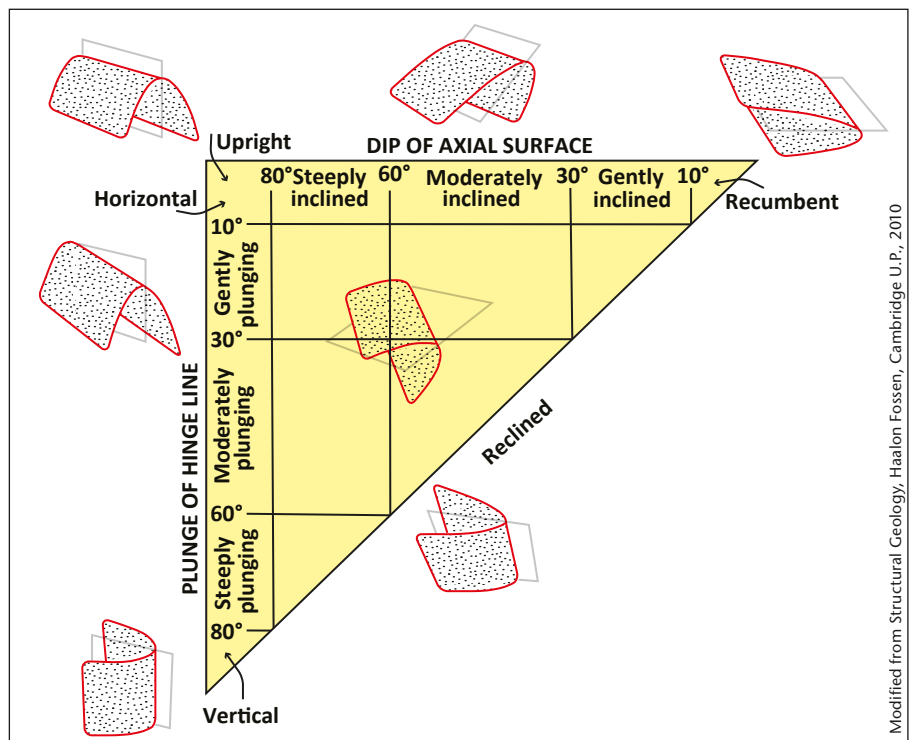
structural analysis (for example, stereographic representation), it is necessary to subdivide them into several cylindrical folds, each with a relatively short, nearly straight hinge line.

For each rock layer in a folded structure we can represent a hinge. The **axial plane** connects all the hinge lines in a folded stack. The axial plane is also called **axial surface** because it may be a curved plane. In profile (cross-section) view, the trace of the axial surface of a fold passes through all the hinge points; such line is called the **axial trace** of the

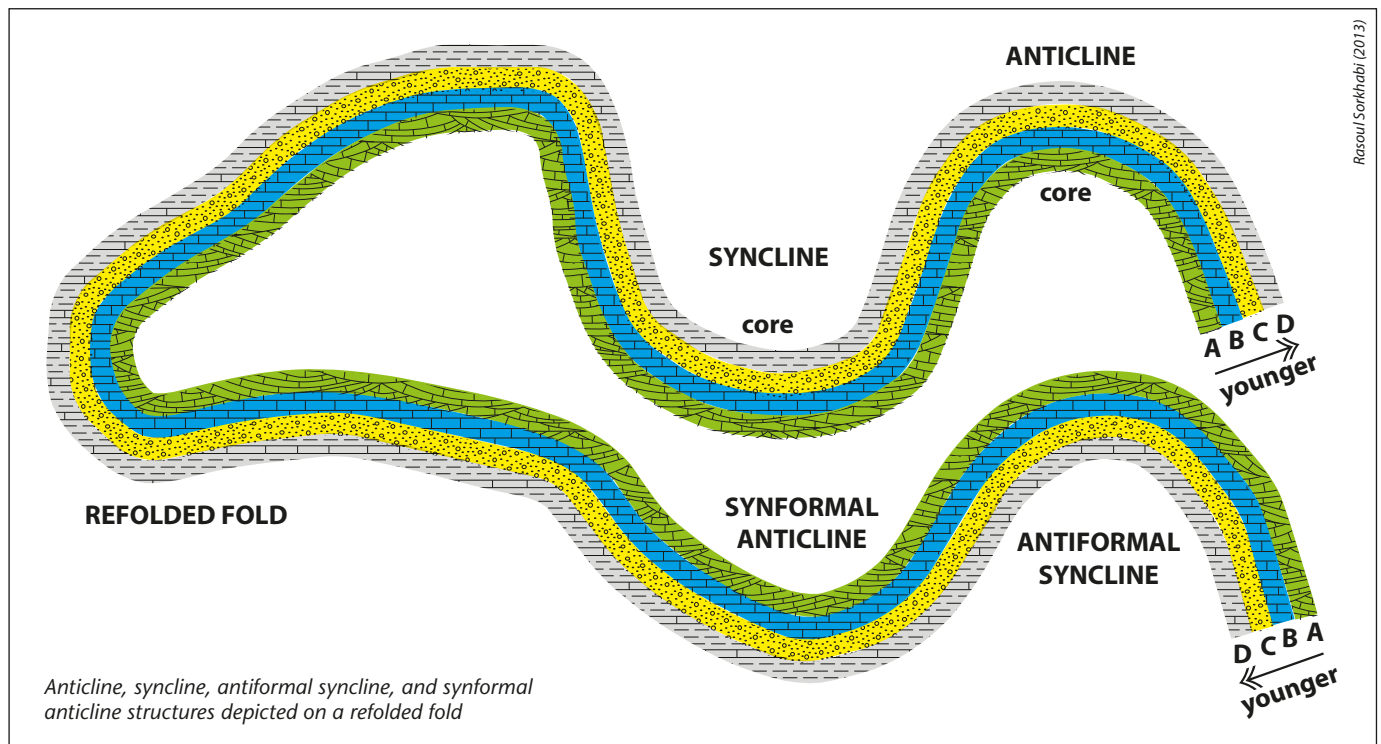
fold. The **attitude** (orientation) of an axial surface is measured by its strike and dip (inclination). According to axial plane dips, a fold may be **upright** (dips of 90–80°), **inclined** (80–10°) or **recumbent** (10–0°).

**Vergence** is the direction toward which the axial plane of fold has tilted. In other words, it is the sense (direction) of displacement of the upper limb relative to the lower limb of the fold. For example, a fold axial plane may have a strike of N 25° E and dip at angle of 30° SE, and thus a north-west vergence.

*M.J. Fleuty (GSA Bulletin, 1964) has proposed a classification of folds based on dip of axial plane and plunge of hinge line. This scheme is useful to characterise the geometric position of a fold.*







An upright fold is also a **symmetric** fold; inclined folds are **asymmetric**. An **overturned** fold is an inclined (asymmetric) fold in which both limbs dip in the same direction but with different angles. In this case, the **backlimb** (the gentler limb) retains the normal stratigraphic position while the **forelimb** (the steep limb), that has rotated more than 90°, possesses overturned (reversed or inverted) stratigraphy. A recumbent fold, where the axial plane is in the 'lie-down' position, is an extreme case of an overturned fold. Highly overturned and recumbent folds of large dimensions are sometimes called **fold nappes** or **nappe structures**. They are found in collisional mountains like the Alps and the Himalayas. An **isoclinal** fold is one in which the two limbs have parallel dips irrespective of whether the axial plane is upright or inclined.

### Anticlines, Synclines and Monoclines

A fold that is convex upward, that is the limbs dip down, is called **antiform**, while one that is concave upward, that is the limbs dip up, is **synform**. If we know the stratigraphy of the folded layers, then we can respectively use the terms anticlines and synclines. In an **anticline**, the rocks become older toward the core of the

fold; in a **syncline** the rocks become younger. It is also possible for the fold to have the shape of an antiform but strata become younger toward the core; it is then called an **antiformal syncline**. Or the fold has the shape of a synform but strata become older toward the core; it is then called a **synformal anticline**. A fold that is neither antiform nor synform

is called neutral fold. Examples include vertical plunging folds and recumbent folds.

Orogenic belts usually have regional anticlines and synclines. When the limbs of a major anticline are further folded into second-order and third-order anticlines (composite anticlines), it is called an **anticlinorium**. Similarly, when

*An anticlinal fold of Miocene sediments in Sarawak*



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the limbs of a major syncline are further folded into second-order and third-order synclines (composite synclines), it is called a **synclinorium**. The second, third and higher order folds are also called **parasitic folds** because they develop on the main, regional fold structures.

Folds have **crests** and **troughs**. In a symmetric (upright) fold, the crest corresponds to the hinge of the antiform, and the trough to the hinge of the synform. But in an asymmetric or overturned fold, the crest is the highest topographic part of the fold and the trough its lowest topographic part. Circular antiforms and synforms are sometimes called **domes** and **basins**, respectively.

A **monocline** is a local steepening of an otherwise horizontal sequence of strata. A monocline is thus a sub-cylindrical fold with only one inclined limb. **Homocline** ('same inclination') is a general term for

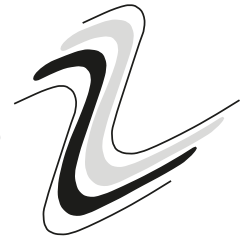
### FOLD SHAPES



(A) PARALLEL FOLD  
(Same thickness and attitude)



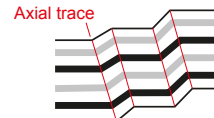
(B) CONCENTRIC FOLD  
(Parallel but with circular fold surfaces)



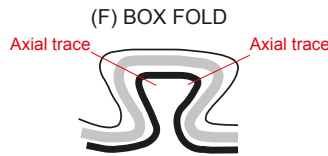
(C) SIMILAR FOLD  
(Same shape but thickening in the hinge and thinning in the limbs)



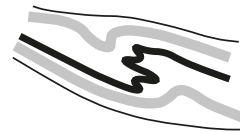
(D) CHEVRON  
(ZIG-ZAG) FOLD



(E) KINK BAND



(F) BOX FOLD



(G) DISHARMONIC FOLD  
(Fold surfaces are variable)  
Note: A-F are harmonic folds.

Rasoul Sorkhabi (2013)

any structures that have the same attitude (strike and dip), for example beds tilted in a parallel direction, one limb of an

anticline or syncline, an isoclinal fold, or monoclines. ■

**Part II to be continued**

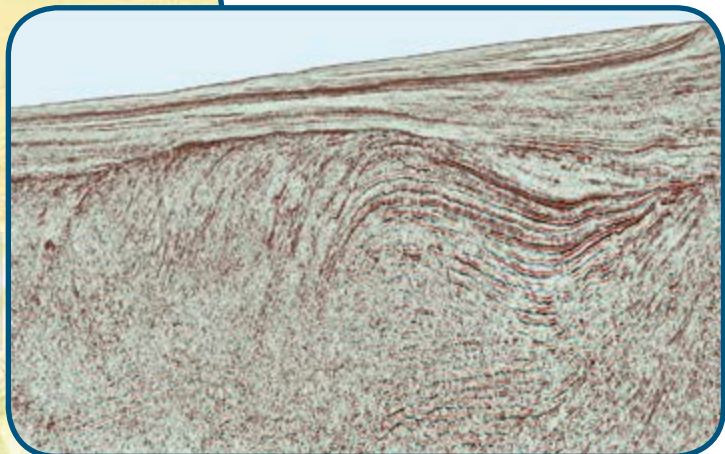
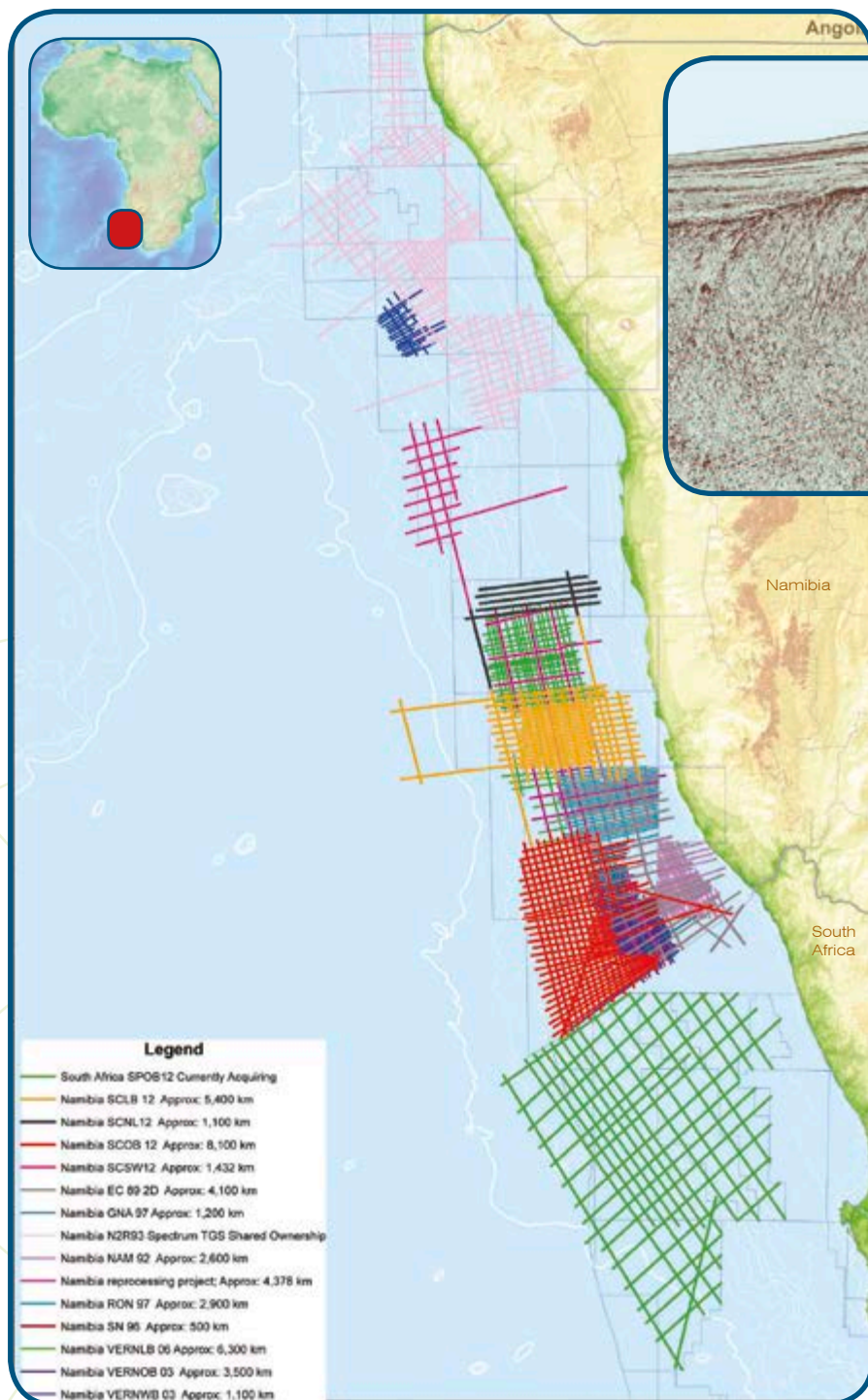
*An anticline structure on Marble Cathedral in the General Carrera Lake in Patagonia, Chile.*





# South-West Africa

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Depth Imaging example from the SCOB12 survey offshore Namibia

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# Stavanger: From Canned Herring to Oil Barrels

Stavanger's rise to 'fame' began about the same time as Norway was first unified under one monarch, King Harald I, in the Battle of Hafrsfjord around the year 872. At this time the area around Hafrsfjord and Stavanger was populated by fishermen and farmers, and was already an economic and military centre. Over the next few hundred years, it grew to become a bustling market place and also a focus for the church. Stavanger was officially founded in 1125, with the completion of its cathedral.

## Economy and the Sea

The economy of the city prospered over the next half of the millennium, but gradually lost its significance as a centre for the church after the Protestant reformation in 1536. With the loss of the bishopric to Kristiansand in the 17th century, the economy also took a downturn. Since then the city's economy has fluctuated between several booms and recessions, starting with the rise of the herring fisheries in the 19th century. Other important industries for the city have been the fish canning industry, shipping and shipbuilding, always tying its economy to the riches found in the ocean.

Today, Stavanger is still riding the wave

of its latest economic boom, and it seems to never come crashing down – although this time the growth is associated with the riches found under, rather than in the oceans. With the discovery of oil in Ekofisk in 1969 (*GEO ExPro*, Vol. 8, No. 1), Stavanger has never looked back. In fact, it has become the third-largest populated area in all of Norway, as it has practically grown into its neighbouring city, Sandnes. But being a rich oil city has some negative consequences, such as being frequently ranked as one of the world's most expensive cities alongside Tokyo.

In the wake of the oil industry, Stavanger has also become a centre for technology and higher education. It is not surprising that the university turns out a high rate of professionals for the oil and gas industry, and many stay in the city, seeking employment with established companies or becoming entrepreneurs. It may be more surprising to discover that Stavanger was selected as the 'European Capital of Culture' in 2008, during which year the city hosted over 1,100 events, small and large, giving its cultural scene a real boost.

## Exposing the Troll Field

For everybody working in the oil

industry, a trip to Stavanger is not complete without a visit to the iconic Norwegian Petroleum Museum located in the harbour. On the inside, you can experience a cleverly prepared exhibition about the oil industry. In addition, the 'Geopark' on the outside, a playground created by leftovers from the offshore oil industry, is just as fun to experience. This recycling project is a model of the most valuable oilfield offshore Norway, the Troll field, which is buried 2–3,000m below the seabed. The topography of the playground is based on the geological strata of the field, reconstructed to a scale of 1:500. The sedimentary layers of the field are dedicated to activities such as biking, climbing, playing and hanging out, while the reservoir, including the wells, has become a skatepark. The geological folds have become walls for graffiti and street art. The park was originally planned as a temporary installation for Stavanger's year as the European Capital of Culture, but has since become a permanent feature of the city.

## Stafangr – Vågen

Although historians cannot agree on the real origin of the name Stavanger, it



Halfdan Carstens



The author's sister on Kjeragbolten, a 5m<sup>3</sup> boulder wedged in a crevasse 1,000m above Lysefjorden, about a two-hour drive from Stavanger.

comes from Old Norse Stafangr, which could be the original name of the inlet now called Vågen. ('Angr' means inlet or bay, while 'Stafr' means staff or branch.) This may be a reference to the straight shape of the inlet, or to the hill Valberget in the centre of Stavanger, with a very steep wall, on the east side of Vågen.

The Stavanger cathedral marks the entrance to the old town, and to Vågen, with its many bars and restaurants. Most of the wooden houses were built in the 18th and 19th centuries, and are considered a part of the city's cultural heritage. Here you can wander the narrow streets winding their way up and down, left and right over the little hill the old town is built on, and experience the pulse of Stavanger. It

The Norwegian Petroleum Museum building is an exhibit itself, inspired by Norwegian bedrock, coastal landscape and offshore installations



is a bustling city centre with many cosy cafés and restaurants, and fun little shops.

### Action Outdoors

Among the locals, sports and the outdoors are intimately connected with quality of life. In the winter, Sirdal is a favourite destination for the Norwegian national sport, cross country skiing, whereas Rørdal has become one of the most popular freeride alpine skiing destinations in Norway, having been the host of Rørdal Freeride Challenge every year since 2001. In the summer, hiking and cycling are popular activities.

A typical tourist destination is Preikestolen, or Preachers Pulpit, a high cliff above Lysefjorden, which was formed during the last ice age. Water from the glacier froze in the crevices of the rock and large blocks of rock eventually broke off, leaving the 25m x 25m flat cliff top above a precipitous drop of 604m. If you take a closer look, there are still some cracks in the rock along the plateau, however there is no danger in the foreseeable future, and you can safely hike the 3.8 km up to Preikestolen to visit the rock. If you are brave (foolhardy?) enough you can even sit at the edge, dangling your feet over the cliff.

There are also multiple opportunities to hike, climb and even base jump in the mountains outside Stavanger. And if you have not yet caught enough action, Arctic surfing is another hot trend, with surfers, stand-up paddlers, windsurfers and kite surfers hitting the waves outside Jæren all year round. So, no chance of being bored in this northern oil city! ■

INGVILD CARSTENS

STAVANGER



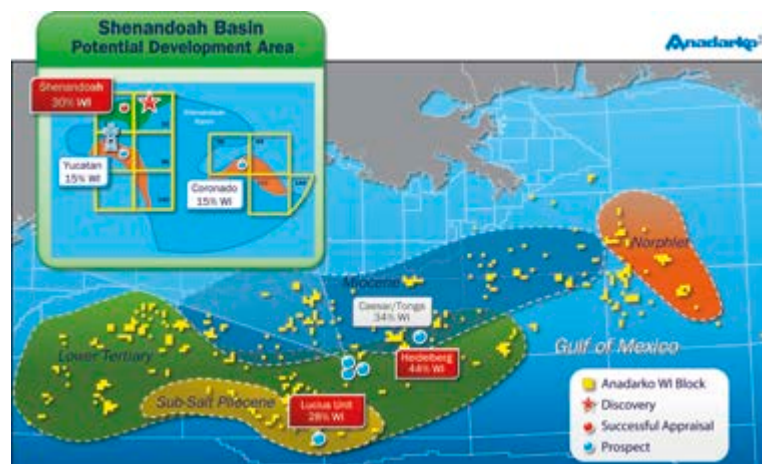
# Gulf of Mexico: Shenandoah Reserve Estimate Trebles

Anadarko managed to excite the industry with its revelations that its Shenandoah 2 appraisal well has discovered a 'potentially giant' oil field in the deep water of the Gulf of Mexico, a field that could hold 500 MMbo or more and which some analysts believe may open up a new area of Gulf oil production. Shenandoah 2, located in Walker Ridge Block 51, was drilled to a total depth of 9,572m in approximately 1,768m of water. It is about 1.7 km south-west from the 2009 Shenandoah 1 discovery that

encountered 91m of net Lower Tertiary pay. The latest well had over 305m of net oil pay suggesting 2P recoverable reserves of 500 MMb. Log and pressure data from Shenandoah 2 indicate excellent-quality reservoir and fluid properties, suggesting Anadarko could potentially recover a higher percentage of oil from the Shenandoah field than in other areas of the vast Lower Tertiary trend. The well was drilled to test the down-dip extent of the accumulation, and the targeted sands were full to base with

no oil-water contact.

The potential of the Shenandoah discovery, combined with very positive indicators of hydrocarbons in the nearby Coronado wildcat, provides a huge boost for the Lower Tertiary play, the Gulf's deepest, most challenging and most promising play, estimated to hold up to 15 Bbo. The Chevron-operated Coronado well is located in Walker Ridge Block 98 and was drilled to a total depth of 9,712m in 1,867m of water and encountered 122m of net oil pay. Shell's adjacent Yucatan prospect strategically positions Anadarko in a region "which has the potential to become one of the most prolific new areas in the deepwater Gulf of Mexico," according to Bob Daniels, Anadarko's vice president of deepwater and international exploration. ■



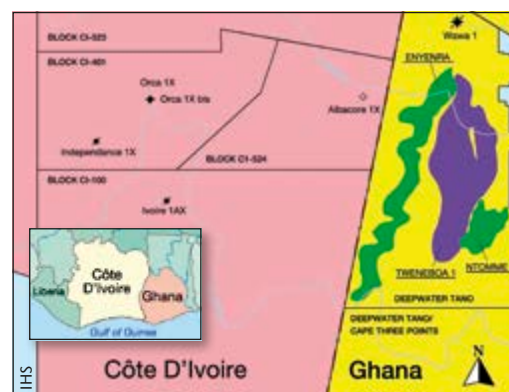
# Côte d'Ivoire: Total Find Ignites Deepwater Prospectivity

Côte d'Ivoire contributes only a minor part of the world's supply of oil and gas, but has still attracted some of the largest oil and gas companies as they look to generate growth and supply. Total has justified this interest as its Ivoire 1X wildcat, the first well to be drilled in deepwater Block CI-100, has confirmed the extension of the already proven active petroleum system in the prolific Tano Basin, home to several fields, including Jubilee in neighbouring Ghana.

Located in the west zone of Block CI-100, in 2,288m of water, the well reached a total depth of 5,044m and established approximately 28m of net oil pay in a series of around 100m of Cretaceous reservoirs. It is unclear as to whether the well was tested but Total has described the oil as light with a gravity of 35° API. Total operates the block with a 60% interest and is partnered by Yam's Petroleum (25%) and Petroci Holding (15%).

Ivoire 1X lies 11 km south-east of the 2011 Independence 1 oil discovery made by Lukoil/Vanco in neighbouring

Block CI-402. The CI-100 permit adjoins the maritime border with Ghana and Tullow's Deepwater Tano block where a near US\$ 5 billion proposal for the Tweneboa-Enyenra-Ntomme (TEN) field development is under consideration and the Deepwater Tano/Cape Three Points block where Hess has made six hydrocarbon discoveries. The discovery has also drawn attention to the maritime border dispute with Ghana, which gained momentum when Vanco discovered oil in the Dzata-1 deepwater well for Ghana. The Ivorians noted that the oil discovery was within their territorial waters and subsequently petitioned the United Nations in 2010 to complete the demarcation of the maritime boundary between the two countries to forestall any dispute. The disputed border also covers some parts of the Jubilee oil field which is said to be the largest discovery in West Africa in recent times. The Ivorian authorities would rather establish a common development zone



in the border area. If Ghana was going ahead unilaterally with the development of the TEN fields next to the current demarcation line, it is likely that Côte d'Ivoire would launch a legal action.

Côte d'Ivoire currently produces around 31,000 bopd and for years made little effort to develop its offshore potential. However, seeking to diversify its economy following a crippling decade-long political crisis, the government hopes to raise its oil output to around 200,000 bpd in five years thanks to recent discoveries and ongoing exploratory drilling. ■



## Malaysia: Significant Gas Find

Newfield Exploration has described its B14-1 gas discovery wildcat, the second of three obligation wells in block SK-310 offshore Sarawak, as the 'largest conventional exploratory success' in its history, news that saw its shares climb over 7%. Located in 76m of water and drilled to a total depth of 4,791m, the B14-1 well encountered 483m of net gas pay in a pinnacle reef structure from which the company estimates there are 1.5 to 3 Tcf of gas in place. Located some 80 km offshore, the find is nearly five kilometres from the company's 2010 B-15 discovery, where recoverable reserves are an estimated 265 Bcf and will be developed along with B14-1. Newfield has not commented on gas quality but it is known that the B-15 well had around 5% CO<sub>2</sub>, much lower than similar pinnacle reef finds in the area. The final commitment well, B-17, is due to be drilled in the third quarter of 2013.

This major discovery comes just a few months after the company revealed it had appointed Goldman Sachs Group to explore strategic alternatives for its international assets, which include offshore holdings in Malaysia and China. Newfield plans to focus on production onshore in North America in such areas as the Uinta, Cana Woodford, Williston and Eagle Ford formations.

Malaysia appears to be reaping the benefits of several fiscal initiatives that have recently been introduced to encourage exploration and development. The country has been described as the 'stand-out performer' in South East Asia's upstream sector in 2012 according to one group of industry analysts, with estimated discoveries of 1.2 Bboe for the year – 62% of the total discoveries in the region. ■



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# CABLE-FREE SEISMIC



# 15 Years of Hugo Chavez

*Comandante: Inside Hugo Chávez's Venezuela.*  
Rory Carroll, Canongate 2013.

"It isn't really a book about oil," said Rory Carroll, the author, smiling apologetically as he handed me my signed copy. And true – the ins and outs of the national oil company PDVSA are not detailed, nor is Venezuela's relationship with OPEC, nor the development of Venezuela's Orinoco Belt of tar sands. But the country now rivals Saudi Arabia in oil reserves and it is oil – and its mismanagement – that brought Chávez to power and oil that fuelled his 'Bolivarian revolution'. Although the book concentrates on the personality and management style of this 'bear of a man', it is inevitably – if unwittingly – a study of the resource curse, the economic and political explanation of why new oil-rich states become prone to conflict, corruption and economic devastation. Of course this 'paradox of plenty' pre-existed Chávez but given the bold promises and revolutionary fervour of his 15 years in office – as well as the 'gift' of a rare and prolonged upsurge in oil prices – its continuation in Venezuela is a particularly bitter blow.

It is because of that revolutionary idealism that Venezuela excites such unparalleled biting scorn. No other oil-rich state receives quite the same level of ridicule. The question for any author writing about Chávez is whether they manage to maintain balance between the zealous pro-Chávez left and outraged international observers. The answer in this case is a disappointing 'no'. The book reads as one man's unrelenting slide from a position of objectivity to one of head-in-hands frustration at Chávez's failures. Although a fascinating read that brings to life Chávez full booming personality, the reader is left with a queasy sense of over-indulgence.

## 2002: A Turning Point

According to Carroll, the attempted coup of 2002 was the turning point, the 'mood changer' in Venezuela. Chávez had come to power on a wave of anti-elitism, seeking 'a Third Way', neither capitalist nor socialist. His motivation, in common with many other Latin American states in the 1990s and 2000s, was a continuation of Simon Bolívar's 19th-century anti-imperialist revolution, an economic and social liberation. Chávez espoused both a potent mixture of nationalism and a genuine desire to spread wealth and ease hardship.

However, the effect of the 2002 coup was to push Chávez 'into the arms' of Castro and into direct conflict with

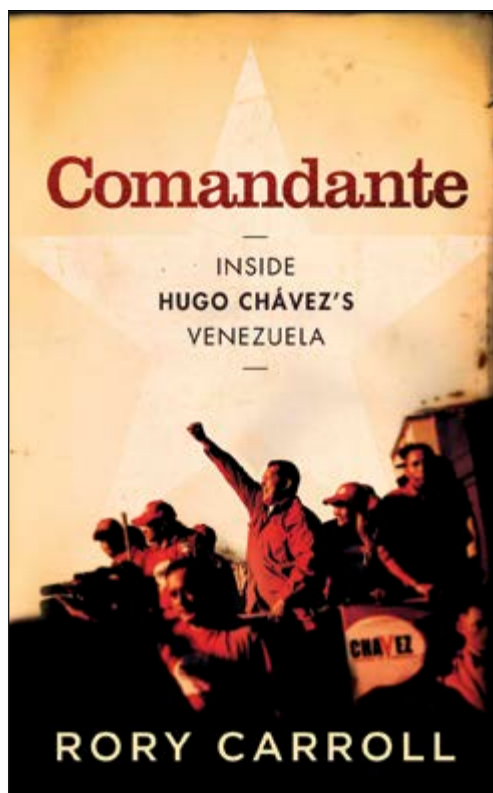
Venezuela's wealthy elite who, as Carroll describes, 'thought they were Venezuela' and exuded a 'sense of entitlement'. Whether the US 'pulled the strings' behind the coup remains unclear: Carroll states that there is 'little evidence', although he acknowledges US funding of anti-Chávez groups and their prior knowledge of the coup. Regardless, the effect was a deepening of US hostility, exacerbated by Chávez's agreement to export 95,000 bopd to Cuba in exchange for 20,000 doctors, teachers and engineers. Chávez had become the nightmare scenario of 'Fidel's heir with oil'.

In this atmosphere of increased division and external pressure, loyalty was everything. You feel Carroll's utter exasperation as he describes how a 'masterful politician' became a 'disastrous manager', making communication with the public – through Chávez's marathon 'Sunday shows' and almost daily interruptions of other public media – the highest priority. "The catch was that he never shut up," says Carroll. Chávez's word was de facto law and ministerial power was determined by 'access to the throne'. His media broadcasts became renowned for their unpredictable announcements but initiatives and reforms were not followed through. Bizarrely, given Chávez's original anti-corruption platform and his own 'monastic' life, he became tolerant of wide-spread pocket-lining, only denouncing corrupt ministers when it was

politically expedient to do so. Foreign loans simply evaporated.

## Wasted Opportunities

As the book progresses, the reader increasingly feels Carroll's end-of-tether frustration and it is hard not to agree with his conclusion that Chávez's legacy is one of wasted opportunities. Despite Chávez's apparent concern for the poor, the Avila slum dwellers stayed living in their mud-slide prone shacks, kidnappings and street crime became commonplace, and much heralded penal reforms proved a failure. Carroll is particularly critical of the lack of economic restructuring for long-term sustainability, notably Chávez's reliance on 'raids' on the Venezuelan state oil company PDVSA to fund his social programmes and the country's increased reliance on oil exports – from 80% to 96% within a decade. Chávez's choice of strategy during a period of severe drought that affected hydroelectric production is illustrative: he chose to cut power to industry rather than reduce domestic consumption,



for fear that his popularity might suffer. The absurdity of crowd-pleasing state subsidies is abundantly clear when you consider that in 2011 you could still fill an SUV for less than \$1.

But of course, that is the central dilemma of the 'resource curse': why does reliance on resource wealth, particularly oil, result in internal division and economic and political dysfunction? As the book moves from being a well balanced, informative analysis of Chávez's ascent and consolidation of power towards an excoriating attack on his failures, you feel the loss of the author's international perspective. His ridiculing of Chávez for abandoning nuclear energy after the Fukushima disaster, and for losing state investments in Lehman-issued derivatives exemplify the exceptionalism to which Venezuela is routinely treated. His acknowledgement that real incomes soared between 2003 and 2008, that half the population was lifted out of poverty, that communities were empowered and there was a halt to US meddling are muted, tucked into the narrative, and easily over-read by those more alert to Chávez's failures.

Carroll does give Chávez credit for not becoming a despot – there are no torture chambers in Venezuela, no death penalty, and elections are respected. Internal division never became Nigerian-style guns and sabotage and Chávez didn't amass a personal portfolio of assets, Middle Eastern style. Indeed, the final word belongs to the people of Venezuela who, in 2012, gave Chávez a 55% win with an 80% turnout. For all his many failures, it seems that Chávez has been hoisted on his own petard of revolutionary idealism – had he promised less, condemnation of the 'monkey in the palace' would have been more muted. Carroll's book, disappointingly, fails to put Chávez in his international context or give him sufficient credit for his achievements, and the reader is left with the tantalising thought of what might have happened if the 2002 coup had not occurred. However, it does provide one more, if oblique, study of the apparent inevitability of the resource curse. ■

NIKKI JONES



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# Why Share Data?

**Malcolm Fleming** is CEO of Common Data Access Ltd (CDA), which was established with the aim of sharing the costs and benefits associated with managing subsurface UK E&P data through collaboration. He talks to us about the importance of sharing data.

## *Why is sharing data important for the industry?*

Cost savings are the most obvious benefit from data sharing. When CDA was set up in 1993, for example, we discovered that at least 40 identical copies of most well reports and logs were being independently stored. It's not only the storage costs that are duplicated – but also the effort, work flows, applications and infrastructure needed to manage and store this data independently.

Another advantage of data sharing is the improved speed of access that comes with distribution of data through entitlement systems. In CDA and comparable systems, data is instantly available, simply by setting an entitlement flag. Moreover, when assets are bought and sold it is easy to reassign data ownership through entitlement, making transferred data immediately available to the new investors. If regulators are included in data sharing arrangements, then licensees can configure a business rule which enables them to comply with reporting obligations and to receive alerts where there is a risk of breach.

Through sharing, stakeholders collaborate to achieve the completeness, quality and consistency of a single 'gold standard' data collection. Sharing also brings consistency in terms of reference metadata and taxonomies. Indeed, this is a condition for sharing – items such as well and company names must be standardised before data can be shared. In CDA's case, this imperative has driven the wider adoption of several key nomenclature standards, which today can be found in the regulations.

One final, initially unforeseen, benefit is that sharing forces recognition and implementation of an entitlement model with standardised definitions which are aligned with commercial and legal rights to access and use data. These have hugely simplified the transfer of assets and have gone a long way towards eliminating inadvertent IPR breaches and the attendant risk of litigation.

## *How much progress has been made?*

Enormous progress has been made in mapping the relationship between legal rights and obligations and sharing arrangements. More work undoubtedly remains but there is a growing understanding of how the legal/commercial world and data management interact.

The models underlying entitlement systems have become increasingly sophisticated over time, now combining user properties (determined by the rights attributed to authenticated individual and organisational identities) with data properties (vintage, release status and data type, for example) through automated business rules which can be manually over-ridden on-line by data owners for specific items or for defined sets of data.

## *What is CDA?*

CDA is a wholly-owned, not-for-profit operating subsidiary of Oil & Gas

UK, founded in 1995 by industry to share subsurface geoscience data. CDA's website ([www.cdal.com](http://www.cdal.com)) offers shared data services to more than 75 organisations and a channel for regulatory reporting, and constitutes an important component of the UK's National Data Repository (NDR). CDA provides leadership for the UK data management community through seminars, an annual workshop event, guidelines for good practice and, most importantly, through a broad programme to professionalise data managers.

## *Do all countries share data?*

Most countries now see the value of sharing subsurface data but this is, of course, influenced by national interests and strategic positioning and some are consequently extremely cautious in this area. There is now a very active community of National Data Repositories with representatives from more than 35 countries sharing knowledge about the role of data in promoting inward investment. It's a fine balance, but more and more countries are now recognising the benefits available in terms of investment promotion that accompany data sharing.

## *Why do organisations not share data?*

Everyone wants others to share their data with them but they don't always see the obligation on their side of this contract for mutual benefit. This said, failure to share data usually reflects the challenge in finding it and understanding the rights and obligations that may be attached rather than any opposition to sharing per se.

## *What international data sharing developments would you like to see?*

I would like to see greater cooperation internationally around sharing solutions to common challenges such as the preservation of seismic field data, and attracting and educating new data managers.

## *How did you get involved in data management?*

I have been in the oil industry for my entire career, starting off as a cartographic draftsman with an oil company in 1972 – right at the start of the North Sea boom. Managing the growing volumes and complexity of data became an important part of my job and this is where I then developed my career, working outside the UK for more than 20 years before finally returning and accepting my current position with CDA in 1998. ■

*Malcolm has forty years of data management experience in the oil industry, having worked with NOCs, independent oil companies, service companies and consultancies. He is on the Executive Board of the National Data Repositories group.*



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# First Gas Hydrate Production Offshore Japan

Japan's test production is a breakthrough in the development of gas hydrate resources

In March 2013, Japan announced the first successful testing of gas production from deepwater methane hydrate deposits offshore Japan. Methane hydrates, which occur in the Polar regions and deepwater basins, are among the most abundant unconventional hydrocarbon resources in the world; therefore, Japan's test production has been hailed as a breakthrough in gas hydrate technology and resource development.

According to the United States Geological Survey, current estimates of methane hydrates range from 100,000 to 5,000,000 Tcf, and each cubic foot generates 164 cubic feet of natural gas. Put these numbers together, and methane hydrates are theoretically the largest hydrocarbon resources in the world, exceeding petroleum. However, their development poses technological and environmental challenges including the release of methane, a very strong greenhouse gas, into the atmosphere.

## Japan Needs Energy

Japan's attraction to gas hydrates is two-fold. First, the country heavily depends on the import of oil and gas from overseas, and the tragic Tohoku earthquake-tsunami and the Fukushima nuclear plant accidents in March 2011 placed a huge setback on Japan's nuclear energy programme and motivated the nation's policy makers to seek alternative sources to meet Japan's increasing energy demands. Secondly, the Japanese archipelago has abundant methane hydrate deposits offshore: about 40 Tcf according to some estimates.

In 2001, Japan began the Research Consortium for Methane Hydrate Resources, or MH21 for short, which is managed by Japan Oil, Gas and Metals Corporation (JOGMEC). During Phase I of the project, from 2001–2008, basic data were collected, exploratory seismic survey and drilling in the Nankai Trough were conducted, and Japan collaborated with the Geological Survey of Canada and other partners to run

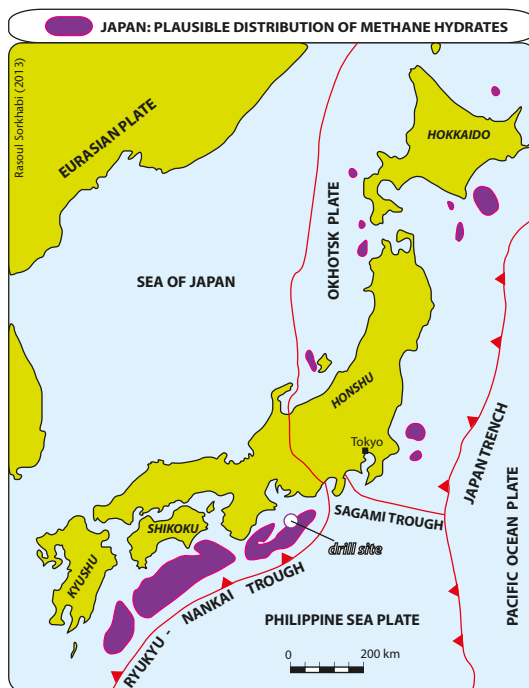


Plate tectonic map of Japan and expected distribution of methane hydrate sediments offshore Japan. Such deposits are usually detected by the bottom-simulating reflectors (BSRs) on seismic images. The BSRs occur in the Polar (permafrost) regions and in the deepwater (continental slopes and rises) where cold bottom water is prevalent.

Japanese and American researchers recovering 'pressure cores' (samples of methane hydrate sediments preserved at their formation pressures) from the Nankai Trough well site in January 2013, two months before Japan's successful test production.



test production at the Malik gas hydrate well, located on the Richard Islands in the Mackenzie Delta. The Malik well produced about 459,050 cf of natural gas in five and a half days. In Phase 2 (2009–2011), Japan joined the US Department of Energy and ConocoPhillips to do test production from methane hydrates in Alaska's North Slope, which was successfully conducted in May 2012. In this operation, at the Ignik Sikumi (Inupiat for 'Fire in the Ice') well, carbon dioxide and nitrogen were injected into the methane hydrate bed for 12 days to depressurise the reservoir and to replace methane with carbon dioxide. The well was then backflowed for 21 days, producing methane.

JOGMEC's development this year marks Phase III of MH21 (2012–2016), which targets the feasibility of commercial production of gas hydrates, considering its economic propositions, environmental impact and large-scale technological challenges. The well site was located 80 km south of Japan's Atsumi Peninsula, close to Nankai Trough, in a water depth of 1,000m and into a sedimentary layer 250–330m below sea floor. Gas was produced by depressurisation, and for about six days a total of 4,237,760 cfg was produced. The Chikyu drillship, designed for the Integrated Ocean Drilling Programme, was used for the drilling, and Japan Petroleum Exploration Co. was the operator.

The Nankai Trough is thus a hotspot to watch for future developments in gas-hydrate research and technological development.

For more information on gas hydrates, refer to the following articles published in GEO ExPro: 'Gas Hydrates: Not So Unconventional', by Thomas Smith, Vol. 6, No. 2, and the series 'Gas Hydrates: Rock Physics' by Lasse Amundsen and Martin Landrø, Parts I–III in Vol. 9, No 1–3.

For more information on Japan's MH21 Research Consortium visit their website at: <http://www.mh21japan.gr.jp/english>.

**RASOUL SORKHABI**

# Norway APA 2013 License Round

## Bjarmeland Platform Multi-Client 3D Data

Polarcus has acquired 1,300 sq. km of high density multi-client 3D data on the southern end of the Bjarmeland Platform in the Barents Sea, offshore Norway.

Until now this area has lacked the modern 3D data required to properly understand the regional geology and image potential leads. This new 3D seismic survey, located east of the Hammerfest Basin on the Nyslepp Fault Complex, addresses those shortcomings and offers companies the opportunity to assess prospects around two oil and gas discoveries from the 1980's. Final data products available now.

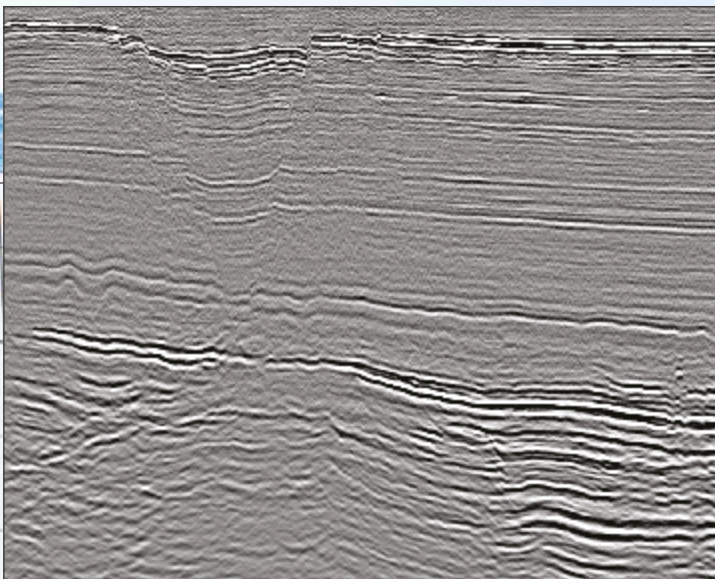
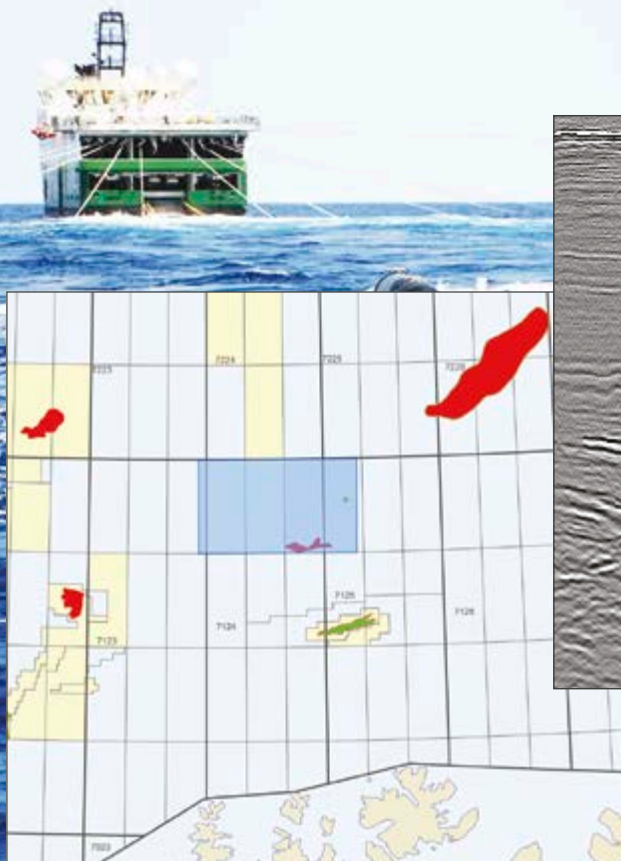
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## CONVERSION FACTORS

## Crude oil

1 m<sup>3</sup> = 6.29 barrels1 barrel = 0.159 m<sup>3</sup>

1 tonne = 7.49 barrels

## Natural gas

1 m<sup>3</sup> = 35.3 ft<sup>3</sup>1 ft<sup>3</sup> = 0.028 m<sup>3</sup>

## Energy

1000 m<sup>3</sup> gas = 1 m<sup>3</sup> o.e.1 tonne NGL = 1.9 m<sup>3</sup> o.e.

## Numbers

Million = 1 x 10<sup>6</sup>Billion = 1 x 10<sup>9</sup>Trillion = 1 x 10<sup>12</sup>

## Supergiant field

Recoverable reserves > 5 billion barrels (800 million Sm<sup>3</sup>) of oil equivalents

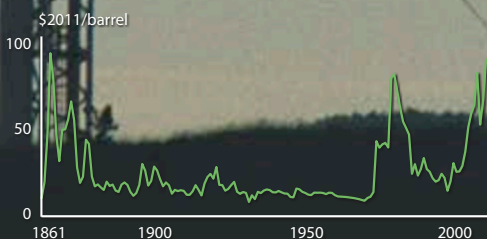
## Giant field

Recoverable reserves > 500 million barrels (80 million Sm<sup>3</sup>) of oil equivalents

## Major field

Recoverable reserves > 100 million barrels (16 million Sm<sup>3</sup>) of oil equivalents

## Historic oil price



# A 75-Year Anniversary

It all started near the beach in less than 5m of water. Through 75 years of intense exploration in the Gulf of Mexico, more than 50,000 wells have been sunk, and drilling is approaching the abyssal plain



Offshore oil and gas exploration in the Gulf of Mexico (GoM) began in 1938. The first well was drilled offshore Louisiana in less than 5m of water following seismic work. It also turned into the first producing property in the Gulf (the Creole field) with oil in three sands of Miocene age.

The first well drilled 'out of sight of land' was spudded in 1947. The Kermac No. 16 well was drilled 15 km offshore in almost 7m of water. It came in at 40 barrels per hour, and by 1984 it had produced a modest 1.4 MMbo.

The first GoM discovery in deepwater was made in 1975, while the first deepwater field to go on production was Shell's Cognac field in 1979 (100 MMb oil and condensate and 0.5 Tcf of gas in place). The first discovery (gas) in ultra-deepwater occurred in 1986 (the Mensa field).

The term 'deepwater' is used for water depths in excess of 1,000 ft, or 300m. Beyond this depth, the continental shelf slopes off rapidly into much deeper waters; 'ultra-deepwater' is used for depths greater than 5,000 ft or 1,500m. The abyssal plain in the GoM is at about 12,000 ft (3,700m). The well drilled in the deepest water was Chevron's Toledo prospect (Alaminos Canyon) in 3,050m, back in 2003.

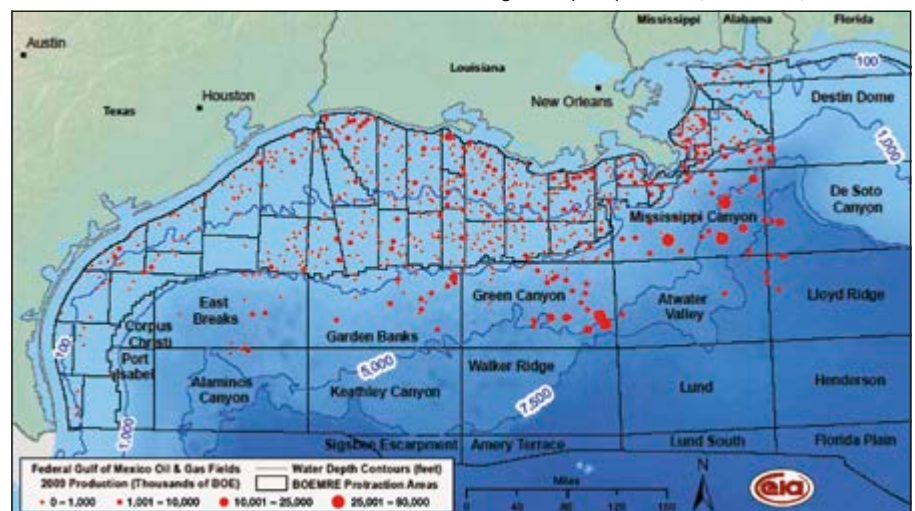
Typically, when exploring in deepwater and ultra-deepwater, some of the target formations are also found at extreme depth. The deepest well drilled to date is the Tiber well almost due south of Galveston, which reached a total vertical depth of 10,683m. Subtracting water depth, the operator BP was left with 9,425m (!) of sedimentary section. The well found oil in multiple Lower Tertiary reservoirs and has been reported as a giant discovery with reserves of several billion barrels. Such wells encounter extreme high pressure and high temperature (HP/HT) conditions, with formation pressures exceeding 20,000 psi and temperatures approaching 150° Celsius.

Despite these challenges, production from deepwater has increased rapidly since its commencement in the late 1980s. Deepwater production did however peak in 2004 and has been in decline ever since. Ultra-deepwater production, starting in 2004, has helped to offset the deep water production decline in a similar manner as deepwater production had previously offset shallow water production in the late 1990s.

Amongst the ten largest oil fields in the US, three are located in the Gulf of Mexico (Mars, Thunder Horse and Atlantis).

**HALFDAN CARSTENS**

*Gulf of Mexico offshore oil production accounts for about 25% (some 2 MMbopd) of total US oil production and about 7% of gas production. More than 3,500 platforms have been built for this purpose. Most leasing has taken place in the Western and Central Planning Areas of the Gulf, and each protraction area is divided into 900 to 1,000 individual lease blocks, generally 3 by 3 miles (ca. 2.5 km<sup>2</sup>).*





Mediterranean Sea

LEBANON

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### GeoStreamer® data ready for Lebanon License Round

The Lebanese Republic recently announced important dates for their 1st Offshore License Round.

In cooperation with the Ministry of Energy and Water in Lebanon, PGS has acquired more than 8,700 line-km of MC2D and 9,900 sq.km of MC3D seismic data, the most recent survey in February 2013.

All data will be available for the license round, for more information go to [www.lebanon-exploration.com](http://www.lebanon-exploration.com)

**Contact us to book a data review meeting at one of our offices in Oslo, London, Houston or Singapore.**

## Supporting your exploration success

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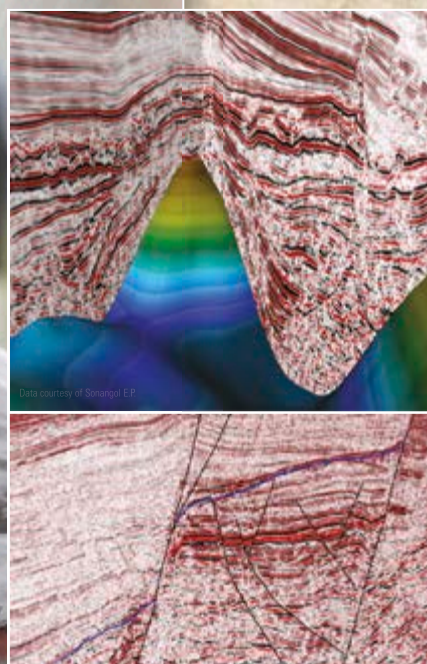


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