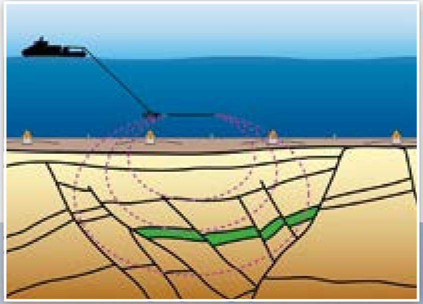
VOL. 12, NO. 1 – 2015

GEOExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED



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Improving Reservoir Characterisation

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EXPLORATION

Political Geology in the Arctic

GEOPROFILE

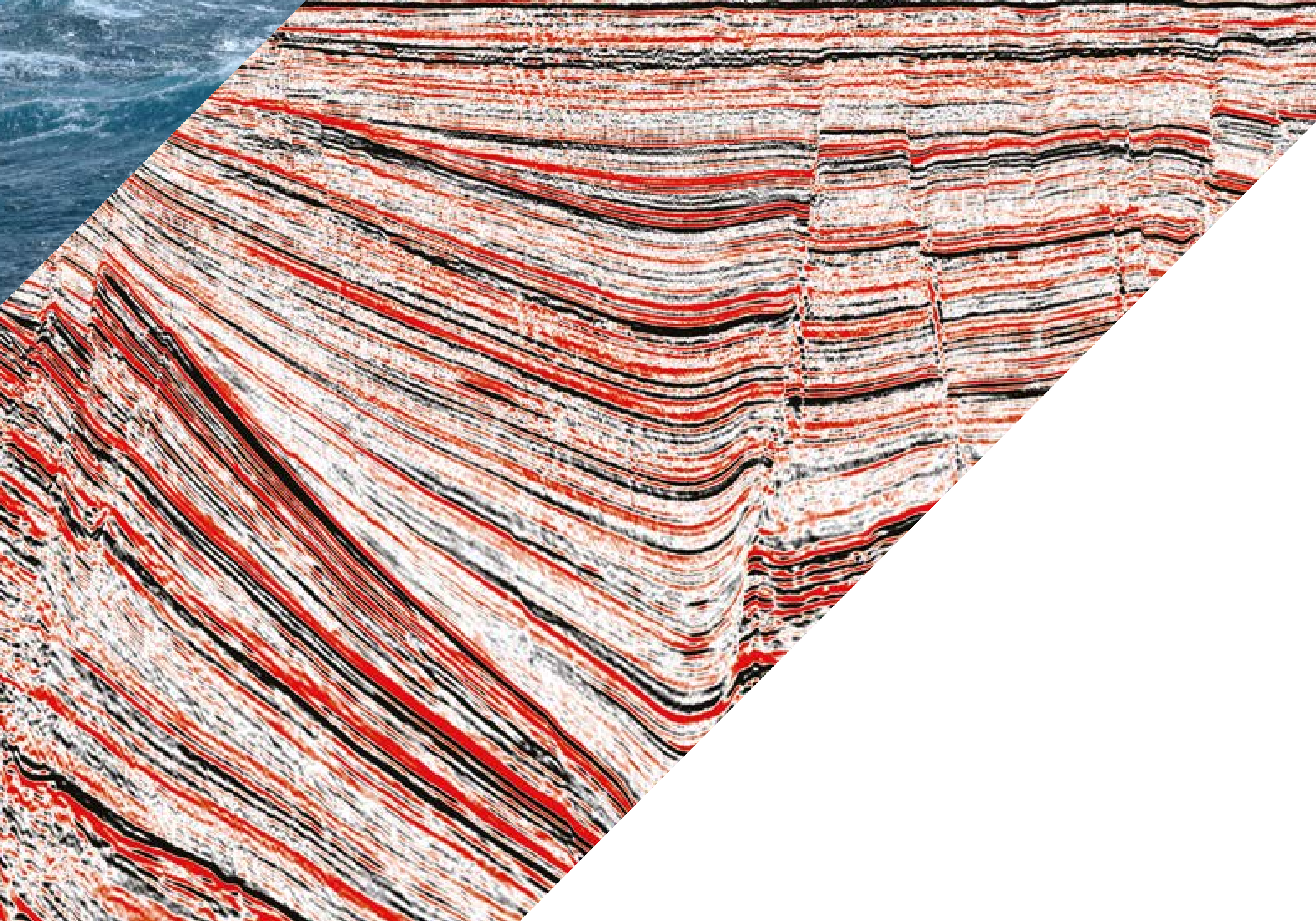
Prudhoe Bay and Beyond

INDUSTRY ISSUES

Turkey: Key Transit State

EXPLORATION

Deepwater Activity in South East Asia



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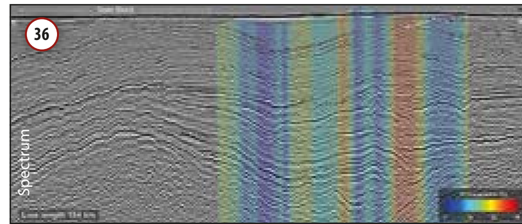

IP data and 2D broadband seismic used together can help de-risk areas like the Barents Sea.

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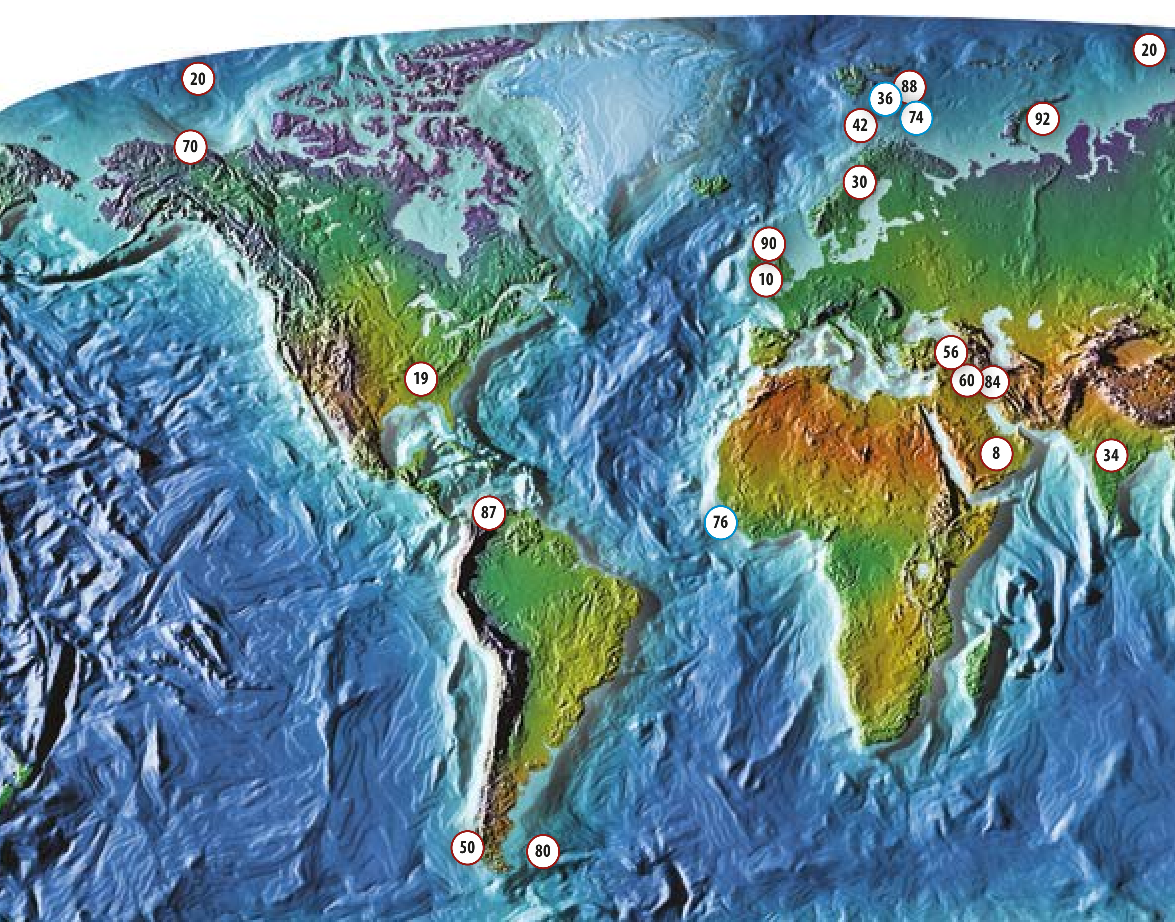
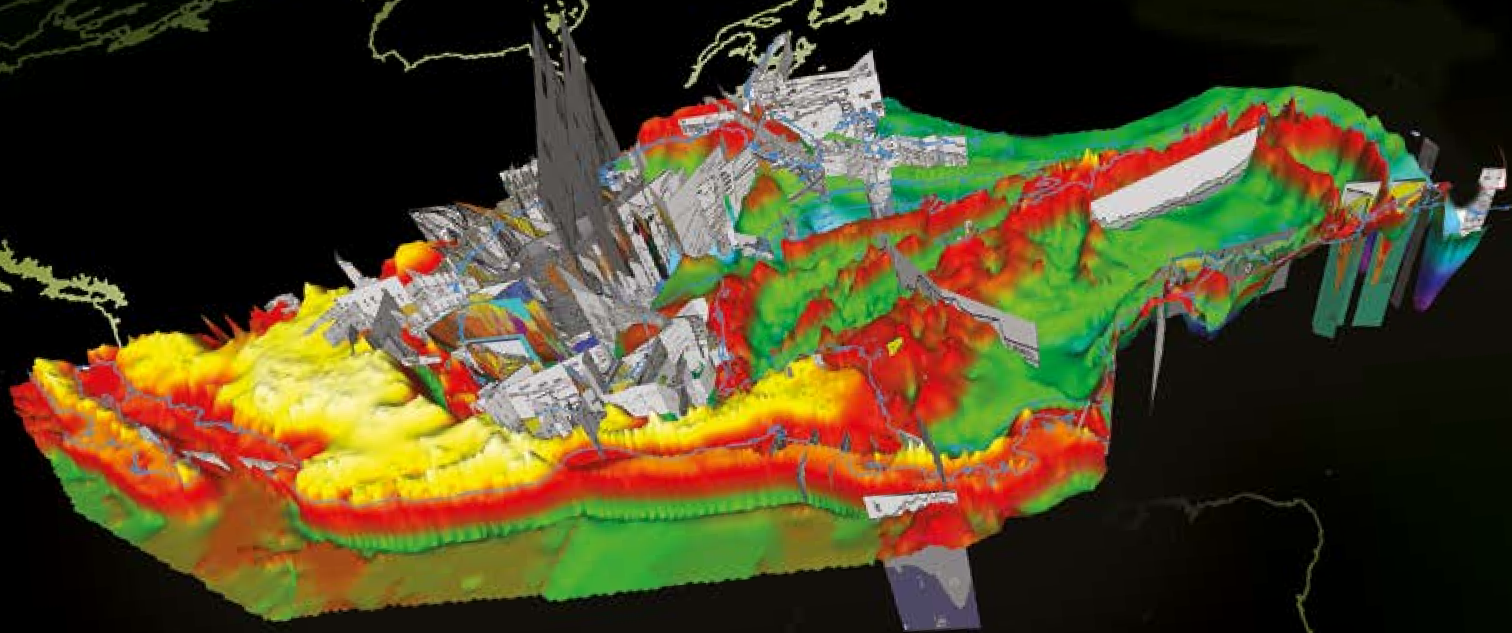
FEATURES

The magnificent Torres del Paine National Park is a geological jewel in the impressive scenery of Patagonia.



Joining up the exploration process



*Replica of original published data

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Exploiting the Arctic

The Arctic is the world's smallest ocean, and possibly the most resource-rich one. Beneath its icy waters lie not just conventional hydrocarbons – possibly 25% of the total remaining reserves – but unconventional ones such as gas hydrates, plus a huge range of minerals, including precious ones like platinum and palladium.

Who owns this massive bounty? As discussed in our cover article, this is a highly contentious subject, with the circum-arctic states all jostling for the best position in a sophisticated land grab. Serious Arctic exploration will perforce be limited until these territorial disputes are resolved.

There are so many issues involved. The geological chance of finding hydrocarbons in large quantities is good, but the risks involved in extracting them safely and economically without damaging the environment are immense. On top of this are the technical, political and economic challenges of getting the oil and gas to the energy-hungry markets many kilometres further south.

The new realities of the present low oil price world also have a bearing on this. What was potentially feasible at +$100 oil is laughable at $50. The well-known unpredictability of oil prices is particularly relevant, as exploiting Arctic resources takes much longer than in less environmentally challenging and sensitive areas: Snøvit in the Norwegian Barents Sea was discovered in 1981 and finally came on stream in 2007, for example. Cost will be the determining factor in the if, when and where of Arctic oil and gas production. Partnership models, such as the ExxonMobil/Rosneft collaboration which discovered the world's most northerly field last year, may well be the way ahead, sharing both the financial strain and the technological innovation. Collaboration, not competition – if politics permits.

The main objection from many quarters to exploiting the Arctic's resources is not the cost, nor the technological and logistical challenges, nor the ongoing territorial disputes. It is the possibility of damaging a unique, pristine environment. We have other sources of hydrocarbons, and of energy, so should we be exploiting the Arctic at all? ■

Jane Whaley
Editor in Chief

POLITICAL GEOLOGY OF THE ARCTIC

The Arctic is a spectrum of national interests, making it the crossing point of the geopolitical interests of both Arctic and non-Arctic states. Geology is key to addressing the questions of territorial limits.

Inset: Seismic alone can struggle to discriminate fluids and their saturations, but reservoir characterisation can be improved through integrating it with CSEM and well log data.

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A New Oil Order

Oil prices continue to drop sharply

OPEC's surprising change of strategy, formidable growth in US shale oil, and Russia producing at record highs have set a new oil order. The market is no longer controlled by a cartel adjusting production to balance the market and thereby indirectly supporting higher prices. Saudi Arabia's focus on protecting market share, the growing influence of US shale production and increasing volumes of Russian barrels have pushed us towards a more market-driven price development.

In addition, oil demand growth is weakened not only by the economic downturn in large oil-producing countries such as China, Japan and the EU, but also by the removal of fuel subsidies and increasing energy efficiency. And in the oil market's last stronghold, China, overcapacity, a slowdown in energy-intensive industries, tighter credit conditions and a move towards consumption-driven progress have restrained growth in industrial oil products.

How Far Can Oil Drop?

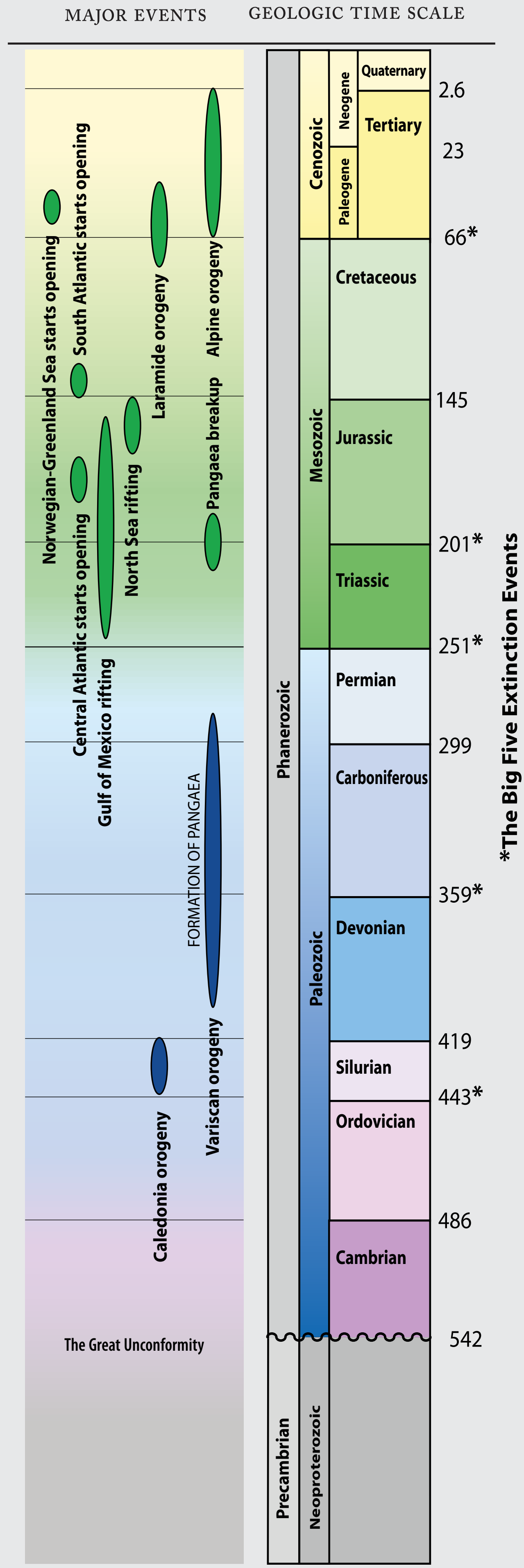
The question many are asking now is how far can oil prices drop? The honest answer is that nobody knows, as the fall in oil prices is extended by a flight-from-oil by financial players worried about OPEC's future strategy and the likelihood of large volumes of US shale production being squeezed out of the market. The investment-production-decline cycle is much shorter for conventional wells than for shale, making the latter marginal; according to Rystad Energy the breakeven oil price for the large US shale players such as Bakken and Eagle ranges from US$ 45 to 60/barrel. US rig counts and drilling permit numbers are dropping and uncertainties about future financing for small independent shale producers have increased, but it will still take time before we see a substantial decline in production, and oil from these wells will continue to flow into the market for several months.

Lower oil prices will also put production for many conventional oil producers and exporters under strain. Several non-OPEC countries such as Norway and Brazil have indicated they will cut spending plans in 2015 and Russia, burdened by sanctions and a sharp drop in the rouble, is expected to do the same.

OPEC's decision to maintain the production level of 30 MMbpd came as a big surprise. At the current oil prices countries like Angola, Algeria, Iran and Venezuela, which supported a production cut, are under severe stress. In contrast Saudi Arabia, Oman, Qatar and United Arab Emirates have large financial reserves to back up the cartel's decision to leave the production quota unchanged.

It is extremely difficult to forecast oil prices during a period of high oil price volatility, with uncertainty about OPEC's future strategy, the exact breaking point for US shale production, the true growth rate of the Chinese economy and the timing of financial players' return to the market. In the short term we expect prices to continue down. In the long term, however, prices cannot stay below the marginal cost of new production.

Thina Margrethe Saltvedt



The End of an Era?

In January the death was announced of 90-year-old King Abdullah of Saudi Arabia. During his nearly 20 years as regent and then monarch, he introduced some tentative reforms in this very conservative country, such as extending education and granting limited new rights for women, but basically continued the status quo, despite a rising tide of suppressed protest and overt terrorist attacks from within the country, and increasing political tension and sectarianism in the surrounding region.

So what can we expect from his successor, his half-brother, 79-year-old Prince Salman bin Abdulaziz Al Saud? So far, it looks like little change: on accession he vowed to continue the path set out by his father, King Abdulaziz, the founder of modern Saudi Arabia, and major adjustments seem unlikely under his rule, as he is believed not to be supportive even of his brother's very cautious reforms.

What effect will this change of leadership in the country which is the largest exporter of total petroleum liquids in the world have on the oil market, especially when considering that the new king once headed the country's petroleum committee? Oil prices briefly surged on the announcement of Abdullah's death, amid speculation that there could be a change in the country's policy of maintaining production despite rising non-OPEC production, but fell back again when the new king stated that he would retain Ali Naimi as oil minister, indicating that there would be no immediate change in strategy.

Changing Dynamics

In fact, it has been reported that the Kingdom is now pumping more than its OPEC quota, in what is assumed to be a bid to take back market share from non-OPEC producers like Russia and the US unconventional drillers. Many analysts expect the market to go low enough for marginal producers to drop out, but the interesting move will be when the Saudis or their OPEC partners decide it is time to cut production and let prices rise, and there is little indication of that at the moment.

The decision to keep producing despite the low price of oil means that, according to the IMF, Saudi Arabia and its fellow Gulf Arab producers are set to lose a collective $300 billion in oil export revenues this year, and while these wealthy states have large financial reserve buffers, the situation cannot continue indefinitely without a trickle-down effect on the region, both economically and politically.

As the US moves nearer to energy self-sufficiency thanks to unconventional production, an interesting factor in this situation is its position as major friend and supporter of Saudi Arabia. For years, America needed the Saudis and their oil, but the dynamics have changed. Given the upheavals and instability of many of the countries surrounding Saudi Arabia, the see-saw of reliance may be tipping the other way.

The game of 'who blinks first' between the wealthy OPEC Gulf states and the rest of the world's oil producers before market forces come into play could have some very interesting consequences.

Jane Whaley

The new king of Saudi Arabia, Salman bin Abdulaziz.

ABBREVIATIONS

Numbers
(US and scientific community)

M: thousand = 1×10^3
MM: million = 1×10^6
B: billion = 1×10^9
T: trillion = 1×10^{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^3 gas
MMscmg: million m^3 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:
www.glossary.oilfield.slb.com

Stories from Deep Time

How one man's passion for the fossils of 'an uninteresting rock' has resulted in a unique collection.

Steve Etches is a man with a passion – and a very crowded garage.

Born in the county of Dorset in southern England, not so many miles from the world-famous Jurassic coast, Steve found his first echinoid fossil at the age of five, but it was not until he had a family of his own that he began to think a little more about the treasure which lay beneath his feet.

"I had no formal academic training in geology – I owned a heating and plumbing company – but thought that fossil hunting would be a great family hobby," he explains. "But I got hooked far more than they did! Dorset is just so rich in fossils; I very soon started collecting."

Unrivalled Collection

Now a World Heritage Site, the Jurassic Coast extends for about 130 km, and has the greatest succession of exposed Jurassic rocks in the world. Geologists and palaeontologists have flooded to the area since the early nineteenth century. But Steve realised that there was one formation that did not get as much attention as the others – the Kimmeridge Clay, well known to the oil and gas industry as the richest source rock in the North Sea and approximately 530 metres thick in Dorset.

"The Kimmeridge Clay has been described as 'the most uninteresting rock for fossil collecting in the Jurassic', because more often than not, fossils that were found were crushed and distorted, therefore interest in that formation was not as great as other stratas of the Jurassic period," Steve says. "However, although some fossils have been flattened, and are therefore hard to collect, the fine clay often means the fossils are well preserved, some even with soft part preservation."

Over the last 35 years, Steve has amassed an unrivalled collection of over 2,000 Late Jurassic specimens, including the world's first ammonite eggs, the first pterosaur skull from the Kimmeridge clay of Britain, the largest collection of pterosaur remains, and a Kimmerigian fish collection, recognised by the Natural History Museum as being the most diverse. Steve is an excellent and painstaking fossil preparator, taking many hundreds of hours to clean some of the fossil specimens.

A Permanent Home

Having accumulated this amazing collection, Steve had a problem. "I set up a display in my garage, gradually overflowing into the living room, then the dining room. They needed a new home. The collection was attracting interest from the academic community. I love discussing the collection with them and have been lucky enough to work with some excellent geologists. But lack of space means that the collection is not currently housed together and viewings can only be made by appointment."

In 1998 PESGB led a field trip of their delegates to the Dorset coast, and as part of that visit they came to view the collection in Kimmeridge. From this visit PESGB were enthralled with the collection and keen to contribute funding to create a permanent home and museum for the fossils.

"Five years ago they gave me £60,000 to formulate plans, enabling us to set up a board of trustees and prepare a website, pamphlets and other material needed to raise the serious money required to build a purpose-built museum and education centre," continues Steve. "Much to our delight, we were awarded about £2.7 million by the Heritage Lottery Fund (HLF). With hard work from the Kimmeridge Trust (the charity set up to raise additional and ongoing funds for the collection) we have matched the HLF grant with funding from Trusts and private sponsors, including further support from PESGB, and the museum is about to become a reality. Building starts early this year and we hope to welcome the first visitors in early 2016."

The Etches Collection will be situated very appropriately in the village of Kimmeridge on the Dorset coast. As well as housing his amazing collection, which Steve has gifted to the museum, the Etches Collection will include educational and research areas, as well as a workshop where visitors can learn about the painstaking processes involved in cleaning and preserving fossil specimens.

A fitting home for such a unique and important collection, and a fine tribute to an amateur palaeontologist who has always sought to advance science and his own knowledge through his passion.

For more information, please email : info@theetchescollection.org

Jane Whaley

Jane Whaley

Steve Etches and one of his best discoveries – a fully articulated ichthyosaur, its final meal of fish and squid visible within the ribcage.

Environmentally Friendly Seismic Source

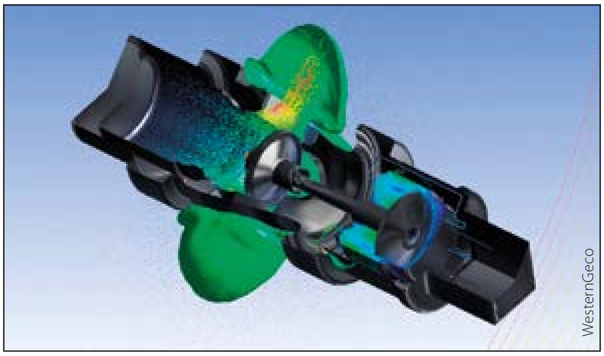
eSource is a tunable, flexible seismic source which reduces the high frequency emissions that can affect marine life.

Everyone working in the oil and gas industry is aware of the importance of ensuring minimal impact on the environment of the areas in which they are exploring, and the expansion of environmental regulations such as marine mammal studies means that reducing the effect of, for example, seismic sources on marine life is now an imperative. In fact, a third of all seismic acquisition revenue in the last six years was derived in the regions that are most sensitive to mammal regulations, including New Zealand, Brazil and Sakhalin.

Key elements of these environmental guidelines include visual observations and passive acoustic detection of marine mammals in the survey area. 'Soft-start' procedures are commonly used, gradually increasing sound pressure levels with the intent of warning animals of pending seismic operations and allowing sufficient time for them to leave the immediate vicinity. Research has shown that mammals such as porpoises have high frequency auditory bandwidths and are therefore potentially more sensitive to seismic disturbance.

With this in mind, Teledyne Bolt has been working for a number of years on the design of a new airgun which will minimise unwanted source noise. Previously, such sources were designed to focus on delivering high levels of energy by covering a wide range of frequencies, and the pulse signature of a traditional airgun source shows very high frequencies at the beginning of each pulse. This high frequency energy is believed to be the most disturbing to marine life – but is not particularly beneficial to seismic acquisition. The new eSource therefore limits unwanted high frequency emissions through a sophisticated mechanical filter, while maintaining the lower frequencies required for optimal seismic penetration and resolution.

The key principle behind eSource is the gradual release of air at a predetermined rate and as a function of time. By controlling the way the air is released, the spectral content of the pressure signal can be tuned.



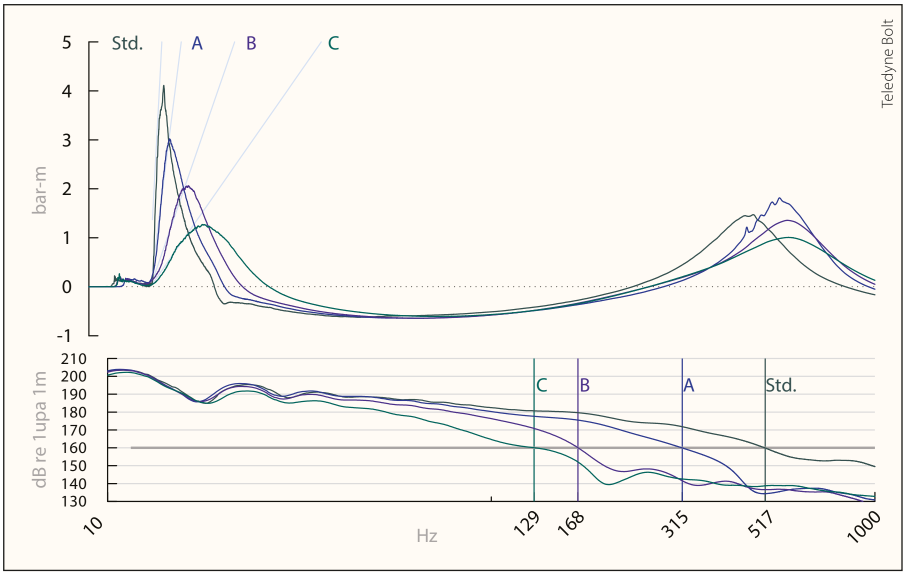
The eSource design was driven by extensive fluid modelling and verified with physical prototypes.

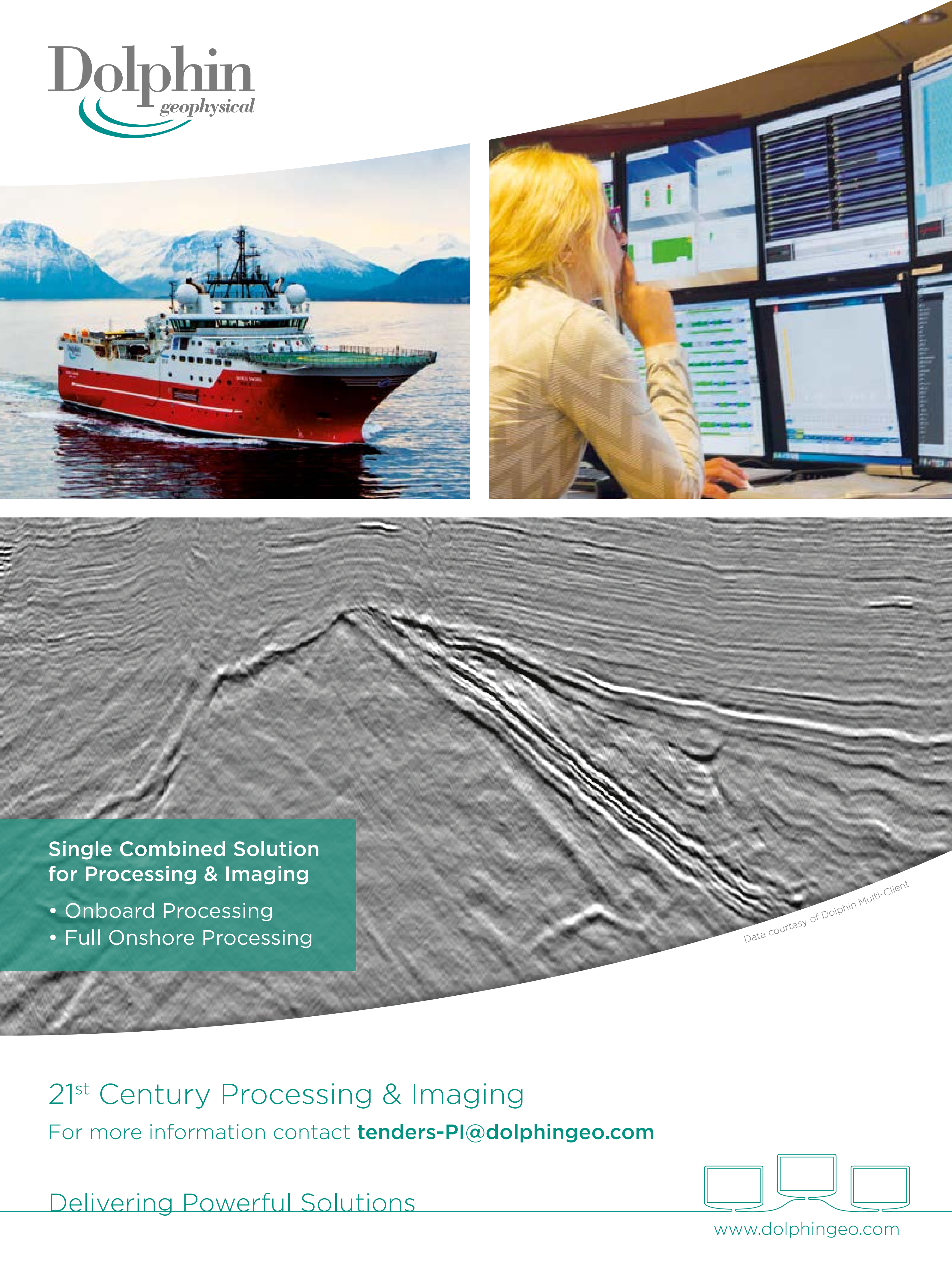
The new eSource is designed to be adaptable, so it can be used in different regulatory regimes and geological constraints, and is tunable in three levels ('A', 'B' and 'C' in image below), each having a different filtering of the high frequency emissions. Each setting is available in all major airgun volumes, with the e300 model covering 150 in^3 and smaller and the e500 model covering larger volumes. This is achieved through changing specific internal parts, a task which only takes about 20 minutes. The new source is fully compatible with existing infrastructure onboard the seismic vessels, including hangars, gun controllers, cluster assemblies and subarray interfaces, and efficiencies incorporated into the design mean that it is up to 15 kg lighter than standard Bolt sources.

Bolt partnered with Schlumberger to evolve the initial design of the new source, which has been in development since 2005. In 2012 the product underwent extensive field testing to prove reliability and performance, including optimal imaging results, before it was finally unveiled at the 2014 EAGE conference.

The result: the first bandwidth-controlled seismic source which is focused primarily on the environment, meaning that marine wildlife will be subjected to less sound in the vicinity of seismic operations. ■

A plot comparing the signatures of a 150 in^3 eSource and a standard airgun. The controlled flow of air can be seen in the first peak in the plot, the slope of which is directly related to the rate at which air is initially released from the airgun. The flatter the slope, the more attenuated the high frequency emissions become. Low frequency energy necessary for seismic exploration is preserved.

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Licence Opportunities That Could Shape 2015

KEN WHITE

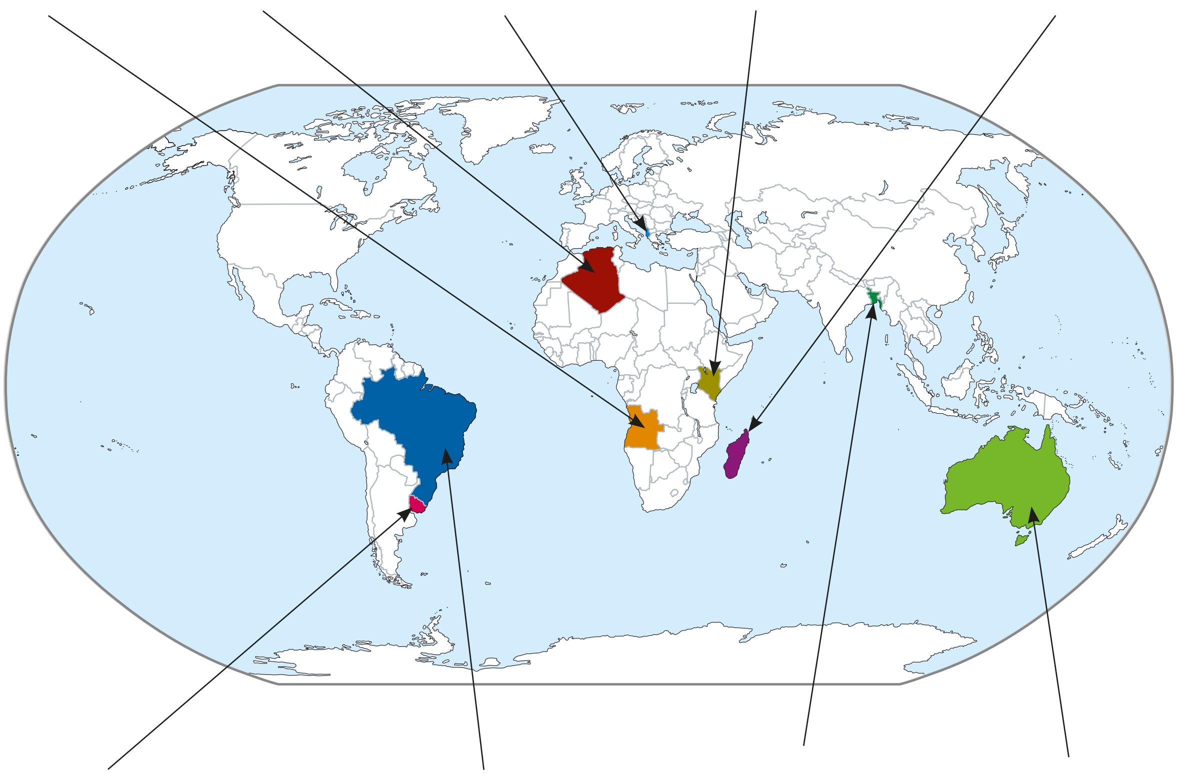
Angola
According to oil minister, Botelho de Vasconcelos, Sonangol plans to launch a licensing round for 12 undrilled deep and ultra-deep water blocks in 2015, including seven parcels in the Namibe Basin and five in the Lower Congo Basin. The minister also reaffirmed the country's intention to reach a 2 MMbopd production level in 2015 and keep this output for five years.

Algeria
Algeria will open a new round of bidding for investment in its oil and gas fields by the third quarter of 2015, and the government is considering improving terms for companies to attract more interest after the last round in September 2014 awarded just four out of 31 blocks on offer. The energy ministry is focusing on how to attract more investment from major international players, in particular the contractual framework of deals, rather than the legal terms.

Albania
The Ministry of Energy and Industry has announced tentative plans to launch a licensing round for some 12 onshore blocks and one offshore tract. The opening is not expected before the first quarter of 2015 and is subject to the release of new regulations for the upstream sector. The round will feature in the inaugural Albania Oil, Gas and Energy 2015 Summit to be held 17–18 March 2015 in Tirana.

Kenya
Cabinet Secretary for Energy and Petroleum Davis Chirchir said the country had 15 new blocks it was ready to open but parliament has first to approve its revised petroleum law. The law, updating a 1986 code, would list new guidelines on natural gas exploitation not adequately covered now, allow for the creation of a sovereign wealth fund to save some revenue, and specify how local communities will benefit. However, the timeline for approval has been slipping.

Madagascar
Madagascar plans to issue licences for three onshore and between 30 and 50 offshore exploration blocks in 2015 once parliament approves a new petroleum law. Madagascar is eyed by foreign companies for its minerals and its hydrocarbon prospects, but has struggled to court oil and mining giants since a coup in 2009, which also prompted international donors to cut off ties. Director General of Hydrocarbons at the Ministry of Hydrocarbons, Pascal Velonarivo, said that among the changes in the revised law would be separation of roles for the state-run OMNIS, which acts as both a regulator and oil company, plus revamping environmental regulation.



Uruguay
Uruguay plans to seek bids from international companies for four ultra-deepwater and seven shallow-water blocks in the Punta del Este-Atlantic Basin, on offer in the country's third oil and gas round scheduled for mid 2015. Uruguay has no oil production at present and no proven resources. Only two offshore wells have ever been drilled in the country's waters: Lobo 1 and Gaviotin 1, both abandoned by Chevron in 1976. Total is scheduled to drill its first deepwater wildcat in the latter part of 2015.

Brazil
The country's 13th licensing round is confirmed for June 2015. The tender will see the offer of offshore blocks in the eastern margin basins, from the Potiguar Basin south to the Pelotas Basin, with the exception of the pre-salt area. Onshore blocks and marginal fields are also to be proposed. The sale will be the first auction of concession rights since 2013 and only the third since 2008, when the government halted annual oil-rights auctions to re-write its oil law to boost control of new 'subsalt' resources.

Bangladesh
Following the resolution of the maritime border dispute with India, it is understood that the Bangladeshi government, represented by Petrobangla, is preparing for the Fifth Offshore Bid Round and is planning to offer 10 blocks along the Bangladesh-India maritime border.

Australia
The Department of Industry within the Australian government has released 28 proposed areas for the 2015 Offshore Petroleum Exploration Acreage Release, spanning across seven basins. Release areas will be finalised when the Minister for Industry, Hon. Ian Macfarlane, announces the commencement of the 2015 Acreage Release during the APPEA conference on 18 May 2015 in Melbourne, Victoria.

Energising Asia

Exchange your geoscience ideas at APGCE 2015.

Anticipation is building as we get closer to the month when the Asia Petroleum Geoscience Conference and Exhibition 2015 (APGCE 2015) is set to take place. Having established its stature as Asia's premier geoscience event, APGCE 2015, which is being held on 12–13 October, 2015, in the Kuala Lumpur Convention Centre, Kuala Lumpur, Malaysia, will be an event not to be missed.

The theme of APGCE 2015 is 'Energising Asia Through Geoscience Ideas and Solutions'. You can look forward to an expansion of the Technical Programme and be an integral part of the conference by submitting your abstracts by 15 March 2015. Other popular attractions to keep your networking momentum up this year include the exhibition, gala night, poster sessions and student programme, with the return of the student geo-quiz as well, to name just a few. The new prospect forum at the exhibition venue gives companies the opportunity to promote areas and blocks for sale, as well as open up for countries to invest, farm-in or farm-out acreages.

For more information visit www.apgce.com. ■

Africa Independents Forum

The 12th Africa Independents Forum gathers together key corporate independent players from across Africa and provides enhanced exposure to the wider oil and gas upstream industry plus key financial markets, equity financiers and investors drawn from around Europe and elsewhere. It focuses on new and fast-growing corporate players in Africa with acreage and assets across the continent and incorporates the PetroAfricanus Cocktail Reception and the Global Women In Africa Business Breakfast. It is an ideal opportunity to meet senior management, discuss new ventures, strategy and deal-flow, evaluate exploration potential and obtain an inside track on Africa's fast-emerging domestic oil and gas game.

The Forum, which will be held in London at the Waldorf Hilton Hotel on 26–28 May 2015, also includes the 8th African National Oil Companies Strategy Briefing (separately bookable), presented by Dr. Duncan Clarke (Chairman, Global Pacific & Partners). This provides an in-depth review and critical insights on Africa's NOCs, licensing agencies and governments, on frontier zones, open acreage, bid rounds, and potential, plus the geo-politics, risks and economic drivers shaping Africa's oil-gas game. ■

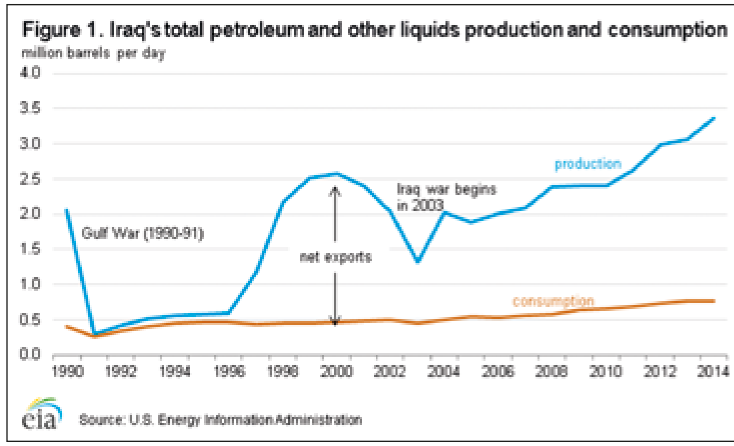
Dolphin's Seismic Hits the Target

After a number of years in the doldrums, two recent oil discoveries offshore Senegal have lifted interest in the country. Cairn Energy's FAN-1 and SNE-1 deepwater finds both discovered hydrocarbons in Cretaceous clastics, a reservoir area which was identified as having potential through multiclient data acquired in the North West Africa Atlantic Margin (NWAAM) 2D regional survey, a joint venture between Dolphin Geophysical Ltd and TGS.

An interpretation study based on this seismic noted the expected existence of stacked Cretaceous clastic deepwater turbidite fans, so the discovery by Cairn of significant quantities of oil in such reservoirs is a milestone in de-risking the petroleum system in the area. In addition, the recovery of a range of distinct different oil types indicates that multiple mature source kitchens exist. The 2D data clearly demonstrates these discoveries as well as further potential leads across the area.

The NWAAM survey, located offshore Mauritania, Senegal, The Gambia, AGC, Guinea Bissau and Guinea Conakry, consists of approximately 30,000 km of seismic, processed through to PSTM using the latest technology, as well as gravity and magnetic data. It covers and extends from the Mesozoic shelf to approximately 3,000m water depth, and provides new long offset regional multiclient data in an area with known hydrocarbon reservoirs and available open acreage. ■

Iraq Surges Despite Security Fears



With a substantial increase in production over the last two years, Iraq was the second-leading contributor to global oil supply growth in 2014, as over 300,000 bpd more than the previous year were delivered, giving an annual average of 3.4 MMbopd. It accounted for almost 60% of production growth in OPEC countries, although this growth was more than offset by production declines in other member countries. This was impressive growth in an environment dominated by the threats to security posed by ISIL, which disrupted production in northern Iraq and shut down the Baiji refinery; in fact, 95% of Iraq's total crude oil exports in 2014 came from the southern part of the country. In December, Iraq's central government and the Kurdistan Regional Government reached a deal on oil exports and revenues, which could facilitate significant increases in production and exports from northern fields in 2015.

With 144 Bbo of proved reserves (according to the *Oil and Gas Journal*), Iraq has the fifth largest proved crude oil reserves in the world, about 9% of the total reserves, and it is the second-largest crude oil producer in OPEC. ■

Geometric Freedom

FairfieldNodal recently announced that its ZLand® 3-component (3C) nodes are now available commercially. This new 3C model takes the company's established ZLand nodal technology to the next level, giving oil and gas explorationists Geometric Freedom™ to better define subsurface formations. Like the original ZLand, it is cablefree and features a completely self-contained geophone, recording system and battery. The nodes are faster, safer and easier to deploy; they can be placed in any configuration, even in the most challenging terrestrial environments or they can readily be buried out of harm's way; and they deliver high-quality seismic data without the need for the laborious troubleshooting and maintenance required of systems dependent on cabled connections.

The new model has the added ability to acquire multicomponent data, something many users believe is critical to their survey results in certain situations, and can easily be used in concert with the latest generation of ZLand 1C nodes, as well as the company's upcoming Z100® nodes designed for shallow water and transition zones, targeting specific areas where 3C data might be more beneficial. ■

Satellite Art

At the Prospex Exhibition in London last December an unusual picture on the wall of the *GEO ExPro* stand caught the attention of quite a few passing delegates. Was it a painting? Or a photo? What's it showing – and are you sure it's the right way up? Just a few of the questions generated.

'It' was actually a satellite image – and the much sought after prize in our Prospex raffle. It showed part of Australia seen from an altitude of over 700 km, expertly processed to create a piece of stunning contemporary art. With nine spectral bands to manipulate and utilising sophisticated image processing techniques, the artist employs his more than 15 years of experience in processing various types of satellite imagery to turn science into spectacular works of art. Each is a dramatic vision of our world, highlighting the wonderful variety of patterns and textures on the earth's surface.

The raffled image showed Lake Eyre in the deserts of central Australia, which was filled with playa salt, highlighted by the cyan and grey colours on the image. During the rainy season rivers from the north flow towards and break through the salt pan as highlighted by the moving currents, seen here as blue and dark blue.

Oonagh Werngren, 2014 PESGB Chairman, drew the raffle for this amazing picture, and Bela Marton from San Leon Energy was delighted to win it. We are still not quite sure how he got it home to Poland.

Which way up? Well, that's up to you, if you view it as an abstract piece of art – but the geoscientists will probably insist on north being at the top.

To see more images, visit palette-earth.com ■

Bob Sheriff

Readers of *GEO ExPro* magazine, along with many geoscientists worldwide, will be saddened to hear of the death of Robert (Bob) Sheriff in November last year, at the age of 92.

Bob, who was the subject of our GEO Profile feature in September last year (Vol. 11, No. 4), was the author of the seminal geophysics reference book, *The Encyclopedic Dictionary of Exploration Geophysics*, first published in 1973. He had a long career in the oil industry, living with his family throughout the world, from California and Trinidad to Australia and Texas. He also developed a second career as a much revered teacher and academic, becoming professor emeritus at the University of Houston, where he was not just a teacher, but also a mentor, friend and role model, especially for international students.

Bob and his wife were also great benefactors of the university, setting up a number of professorships and faculty chairs, as well as a scholarship through the SEG for international graduate students coming to study geophysics at Houston, which has so far assisted over 100 students.

He will be greatly missed. ■

Bob Sheriff teaching.

Bob and his wife Margaret.

Political Geology in the Arctic

Geology has been used to argue for the rearrangement of maritime borders of states, often to the prejudice of geology as a science. This is especially true in the Arctic, so what impact does this have on potential exploration in the area?

EUGENE PETROV, Geology Without Limits

There is an established notion that political geography is a socio-geographic science, which studies territorial differentiation through political phenomena and processes and which expresses the policies of states with respect to its borders and its interaction with other countries, primarily neighbouring ones. In recent years, one can see the appearance of a similar notion of political geology, particularly in the Arctic, where the science has become a tool for the justification and protection of political interests of states and the expansion of their borders, while taking no account of the geological processes themselves or their objective interpretation.

In this article we see, through the example of the Arctic, how geology is being transformed from an assemblage of sciences into a powerful tool for the rearrangement of maritime borders of states, often to the prejudice of the actual science.

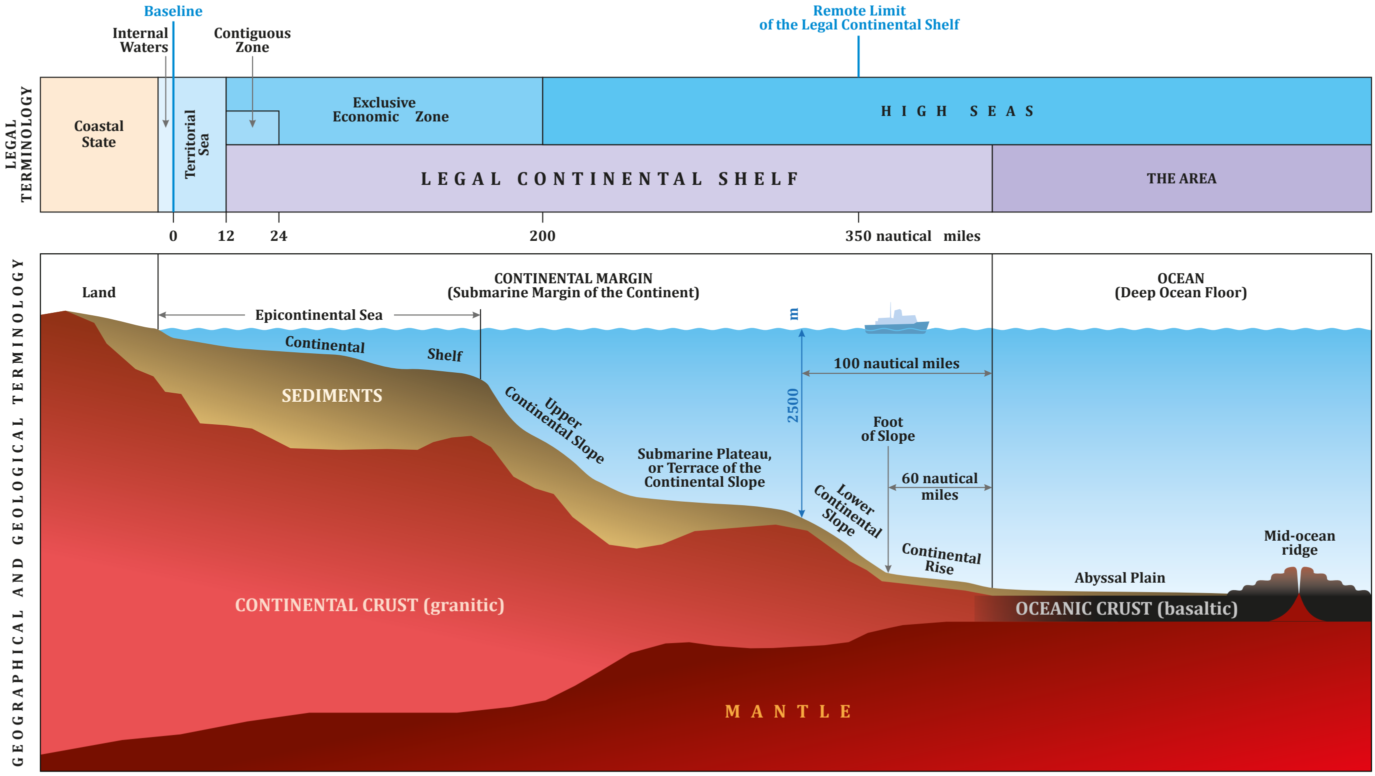
Why the Arctic?

The Arctic region was tinged with heroism in the 19th and early 20th centuries. Polar explorers were viewed as heroes overcoming unheard of icy dangers in a continuous chain of acts of bravery – although not many people understood what these polar explorers were engaged in and why they ventured their lives, except perhaps to demonstrate the limitless capabilities of the human organism. Thereafter, the Arctic was forgotten, left to a few people interested in such extreme environments, because there was nothing there of interest to the ordinary man.

But public and media interest in the Arctic is growing annually, partly fuelled by an awareness of the area's vast

Geological exploration in the Arctic can be performed only via governmental programmes. There are no oil companies able to withstand the environmental conditions and the cost of exploration.

Eugene Petrov



Maritime zones and rights under the 1982 UN Convention on the Law of the Sea

resources. The US Geological Survey estimates the Arctic could contain 1,670 Tcf of natural gas and 90 Bbo, or 30% of the world's undiscovered gas and 13% of its oil, plus deposits of precious and rare earth metals and massive fishery resources.

According to the UN Convention on the Law of the Sea of 1982 (UNCLOS), the circum-arctic states have the right to develop the mineral resources of the continental shelf which is a continuation of their territories within their respective exclusive economic zones. However, no oil or gas company would consider implementing a project until all legal or political risks are settled as the financial risk is too high.

The continental shelf is a term that refers to the ledges protruding from the continental land mass into the ocean. They are covered with relatively shallow water (approximately 150–200m), eventually passing into the ocean depths. Continental shelves occupy around 8% of the total area of ocean water, forming the extended boundaries of every continent and coastal plain. They were part of the continental land mass during glacial periods and are inundated during interglacial periods.

A Spectrum of National Interests

When referring to the huge resource potential of the Arctic, most experts consider that 97% of all known and potential natural resources in the Arctic are situated in the zone of sovereign rights and jurisdiction of the Arctic states (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and USA). However, few point out that this huge percentage is all found in the marginal seas of the Arctic Ocean, within the 200-mile economic zone. What lies beyond?

The Arctic comprises two main basins. The Paleogene Eurasian Basin consists of oceanic crust with about a kilometre of sedimentary cover, lying in 4–4.5 km water depths with extremely harsh ice conditions, making it both logistically and economically challenging. The Amerasian Basin is considered more promising; it comprises Cretaceous continental sediments that were subjected to strong extension as the Eurasian and the Canada Basins opened. Sedimentary cover varies between 1 km and 2 km, but with water depths up to 3 km and harsh ice conditions, it also offers challenges to exploration.

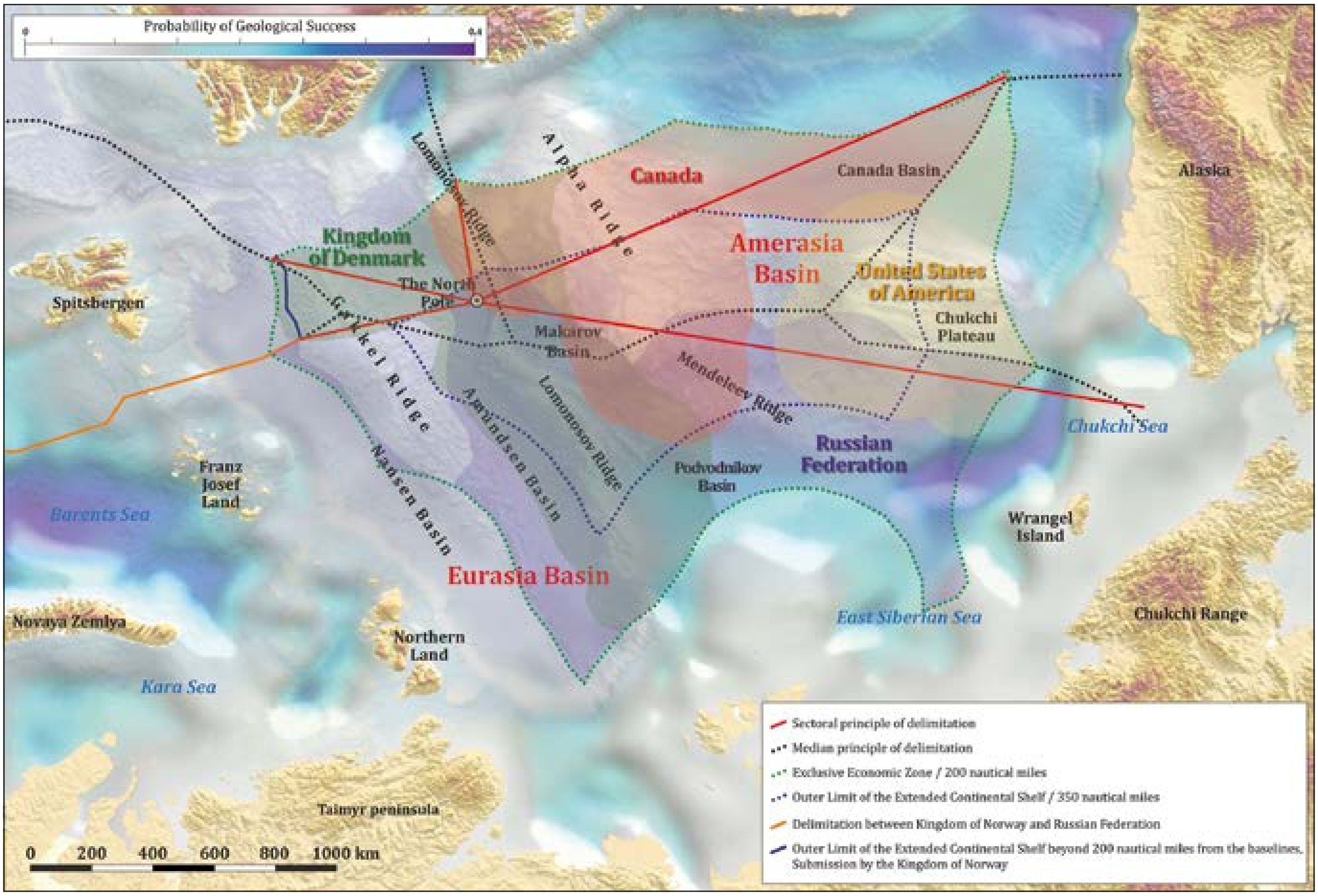
But what has geology to do in such an intricate tangle of political interests of countries? The delimitation of maritime boundaries in the Arctic must be officially solved at the international level. States must file an application to establish the outer limit of their continental shelf; then get positive recommendations from the UN Commission on the Limits of the Continental Shelf; define and agree principles of delimitation of maritime borders within the boundaries of each country's continental shelf; before finally signing interstate agreements on the delimitation of their maritime borders.

However, before any of that can be done, a geological substantiation of the continental shelf will have to be prepared, because that is at the root of outlining the limits of each state's continental shelf – coupled with the wish of each country to maximise its continental shelf in its national interest.

Establishing the Limits

So how is the limit of the continental shelf beyond the 200-mile zone established?

Under the Convention, submarine elevations and ridges can be attributed to the continental margin and hence to the 'juridical continental shelf' if their



Claims to Arctic waters can be based on a number of different premises.

continental origin and association to natural components of the underwater continental margin are proved. It stipulates that the continental margin does not include 'the deep ocean floor with its oceanic ridges or the subsoil thereof', a provision specially envisaged so as to exclude the possibility of including the mid-oceanic ridges in continental margins.

UNCLOS contains a number of formulae and limiting lines by which the edge of the continental margin shall be determined based on bathymetric and geological criteria. The former include the position of the foot of the continental slope, while the geological criteria include data on the structure and thickness of the sedimentary cover, the nature of the earth's crust and geological and geophysical evidences of the position of the continental rise. If no data on the sedimentary cover is available, the limit of the shelf may be delineated by straight lines not exceeding 60 nm (nautical miles) in length, drawn from the foot of the continental shelf (FCS). According to the Convention, a coastal state can use a combination of limiting and formula construction lines to increase the size of its continental shelf.

Article 76 of the Convention outlines limits beyond which the continental margin determined by these criteria cannot extend: either 350 nm from the coast, or 100 nm from the 2,500m isobath. For submarine ridges, only the 350 nm limit is applicable, with the exception of submarine elevations that are natural components of the continental margin.

Different Interpretations

So what do the limits of the continental shelf look like from the viewpoint of the different countries?

In December 2014, Denmark filed its application for establishing the outer limit of the continental shelf in the Arctic Ocean. When determining the limit of the shelf, it included in its continental shelf the Lomonosov Ridge, interpreting it as an integral part of the northern continental margin of Greenland both morphologically and geologically; the Podvodnikov Basin, limited by the 2,500m isobath and 100 nm from the Lomonosov Ridge; the Amundsen Basin, along the FCS + 60 nm formula line; and part of the mid-oceanic Gakkel Ridge, applying the 350 nm distance limit, classifying it as a submarine ridge, thus creating a precedent for the inclusion of oceanic ridges in claims.

Canada's continental shelf, in accordance with Article 76 of the Convention, may include part of the Canada Basin up to the 350 nm limiting line, depending on the thickness of the sedimentary cover, thereby emphasising the importance of geology; the Alpha Ridge, which is classified as a natural continuation of the continental shelf of Canada; and part of the Canada Basin and of the Podvodnikov Basin along the limiting line of 2,500m + 100 nm from the Alpha Ridge.

The continental shelf of the Russian Federation may include the

Lomonosov Ridge and the Podvodnikov Basin, as natural continuations of the continental margin of Eurasia, following morphological and geological criteria; the Mendeleev Rise, the Chukchi Basin and the Chukchi Plateau, using the same criteria as they were formed by extension of the earth's crust and volcanic activity in the course of formation of the Amerasian Basin; and parts of the Amundsen and Nansen Basins along formula lines depending on thickness of the sedimentary cover.

A possible limit of the USA's continental shelf may include the Chukchi Plateau, by morphological and geological criteria, as a natural continuation of the continental shelf of Alaska, again resulting from geological activity during the formation of the Amerasian Basin; and part of the Canada and Podvodnikov Basins along the limiting line of 2,500m + 100 nm from the Chukchi Plateau.

What do we understand from this? As can be seen from the map on page 22, a serious overlap exists in the interpretation by the countries of their continental shelves and, as a consequence, there are major disagreements in interpretations of the geological history of the evolution of the Arctic. Everything should depend on geological evidence and reasonableness – but as has often been said, "two geologists always have three absolutely different opinions…" It is worth noting that each of the countries interprets the same geological information to its own favour, often strongly distorting the objective reality.

Delimitating the Continental Shelf

After establishing the outer limit of the continental shelf it is necessary to delimit the continental shelf between countries under Article 83 of the Convention. In the Arctic, several approaches have historically been used.

One of these is the concept of the sectoral principle of delimitation of the Arctic territories among the five circumpolar states, which was worked out in the early 20th century in order to exclude the ice-covered areas of the Arctic Ocean from the then rules of the international law. Applying this principle to the sea floor of the Arctic Basin requires the agreement and unified position of all five states, but unofficial monitoring conducted in the 1990s showed that they prefer to establish the outer limit of the continental shelf in the Arctic using UNCLOS.

Norway, for example, which ratified UNCLOS in 1996, filed its application for establishing the outer limit of the continental shelf in the Arctic Ocean in 2002, having excluded the Gakkel Ridge. Denmark does not recognise the sectoral principle, advocating delimitation of the shelf along the median line – giving it ownership of the North Pole. In its application to determine the limits of the continental shelf, it included the Lomonosov Ridge, the Podvodnikov Basin and part of the Amundsen and Nansen Basins, up to Russia's 200-mile economic zone.

Canada took its first steps in securing its Arctic claim as long ago as 1909, but in 2005 it departed from the sectoral principle when determining its Arctic Ocean shelf by seeking to establish the outer limit of its continental shelf in the Arctic Ocean strictly under Article 76, leaving part of the Canada Basin classed as International Seabed.

The Russian Federation approved the sectoral principle of delimitation back in 1926, declaring that 'all lands and islands, both discovered and which may be discovered in the future' were the territory of the USSR. In 2001 it filed its first application, adhering to the sectoral principle, but the Commission was unable to confirm the outer limit of Russia's continental shelf and

Countries would like to delimit the Arctic, but the Arctic does not want to be quick about it.

Eugene Petrov

recommended the submission of additional bathymetric and geological data.

An alternative concept of delimitation is the principle of 'the median (equidistant) line'. In the 1950s and '60s this was the generally accepted method and was included in the Geneva Convention of 1958, but its application did not always satisfy contesting parties. In 1960 the International Court of Justice, considering the continental shelf of the North Sea, noted that the median line method was not a part of customary international law and proposed the principle of equity instead. This departure from using delimitation along the median line as the compulsory method for solving coastal state border issues was confirmed in decisions of the International Court of Justice delimiting the continental shelf between Tunisia and Libya in 1982 and the offshore areas between Canada and USA in 1984, among other examples. The median line as the norm was formally overthrown in UNCLOS in 1982, when the principle of equity was fixed as the best method of identifying the limit of the economic zone and the continental shelf.

Geology Versus Politics

The Arctic now is a spectrum of national interests covering state security, influence on transport routes and economics, making it the crossing point of the geopolitical interests of both Arctic and non-Arctic states.

So how will the relationship between political order and the geological structure of the Arctic change in the next ten years? We will see, and time will tell; but it would be good to find politics taking second place to geology, rather than the present situation where geological considerations are being overshadowed by politics, relinquishing the principles of scientific disciplines. ■

Sorting out the borders between countries is just one of the many issues inherent in Arctic exploration.

Improving Reservoir Characterisation

Reservoir characterisation can be improved through the integrated analysis of CSEM, seismic and well log data.

LUCY MACGREGOR, RSI Inc.

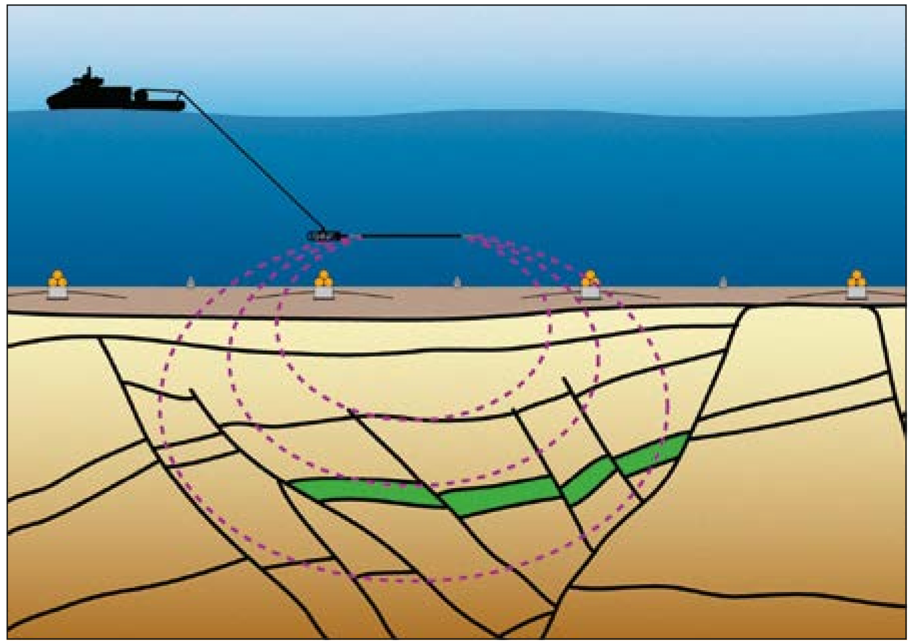


Figure 1: Schematic of a traditional CSEM acquisition system. A dipole source transmits a low frequency signal through the earth to an array of receivers that measure the electric and/or magnetic field. Analysing the received signal as the source moves through the receiver allows resistivity to be determined to about 2.5–3 km below mudline (depending on geology). More recently, alternative acquisition systems in which both the source and receiver are towed behind the vessel have been tested. These have the potential to improve acquisition efficiency, albeit at the expense of geometric coverage and potentially depth of penetration.

Determining reservoir geometry and properties from the surface is a challenging but important task. The seismic method is in most situations the geophysical tool of choice, providing high resolution images of structure and stratigraphy. Given high quality seismic data, and well log information for calibration, seismic data can be inverted to provide quantitative information on reservoir properties such as porosity and lithology. However, in many situations when taken alone seismic can struggle to discriminate fluids and their saturations.

Electrical resistivity is well known to respond strongly to changing fluid type and saturation, which is why the resistivity log is such an important component of any well log suite, and is an integral part of a petrophysical interpretation. The Controlled Source ElectroMagnetic (CSEM) method allows resistivity to be measured from the seafloor (Figure 1). Taken by itself, however, this measurement of resistivity can also be ambiguous. The structural resolution of the method is poor, and without further constraint the depth of features of interest may be uncertain. Nor can regions of high resistivity be uniquely linked to sub-seafloor hydrocarbon deposits: they could equally be caused by low porosity sands or by carbonates, salt bodies or volcanics, among other things.

However, when CSEM is combined with seismic reservoir characterisation approaches within a rock physics framework, many of these ambiguities can be resolved, and the complementary measurement of resistivity derived from CSEM can significantly improve the accuracy with which reservoir properties in general, and saturation in particular, can be determined.

Multi-Physics Challenges

Although there are many benefits to putting seismic, CSEM and well log datasets together, there are also a number of challenges.

The first challenge is one of physics. Seismic and CSEM methods probe the earth using very different physical processes. The resulting electric and elastic properties must be linked in a consistent fashion to the underlying rock and fluid properties. This requires a rock physics framework to be either numerically derived or empirically calibrated at well locations. In either case the models are subject to uncertainty, which in turn leads to uncertainty in the resulting interpretation.

The second challenge is one of scale. Seismic, CSEM and well log techniques sample the earth at very different scales, varying from a few centimetres in the case of well logs, to hundreds of metres for CSEM. For example, using seismic data it may be possible to resolve the individual sands within a stacked reservoir interval. However, CSEM methods are likely only to resolve the bulk properties of the interval and not the details of the fluid distribution in the individual sands within it. These different scales must be reconciled in an integrated interpretation or joint inversion approach. Again, a robust rock physics framework, calibrated to well logs, is required to reduce this uncertainty.

The final challenge is one of sensitivity. It is perhaps an obvious statement, but in order for an integration approach to be successful, both seismic and CSEM methods must be sensitive to the interval of interest and changes in properties within it. This is a key consideration in determining where multi-physics approaches can be applied. For example, a reservoir that can be imaged and constrained seismically may lie at too great a depth below mudline, or be embedded in too complex or resistive a background structure for CSEM methods to be effective. Similarly, low saturation gas clouds above a reservoir may render seismic ineffective, whilst having little or no effect on the CSEM response or interpretation. Establishing the common domain of sensitivity is a key first step in any multi-physics project.

What is Meant by Integration?

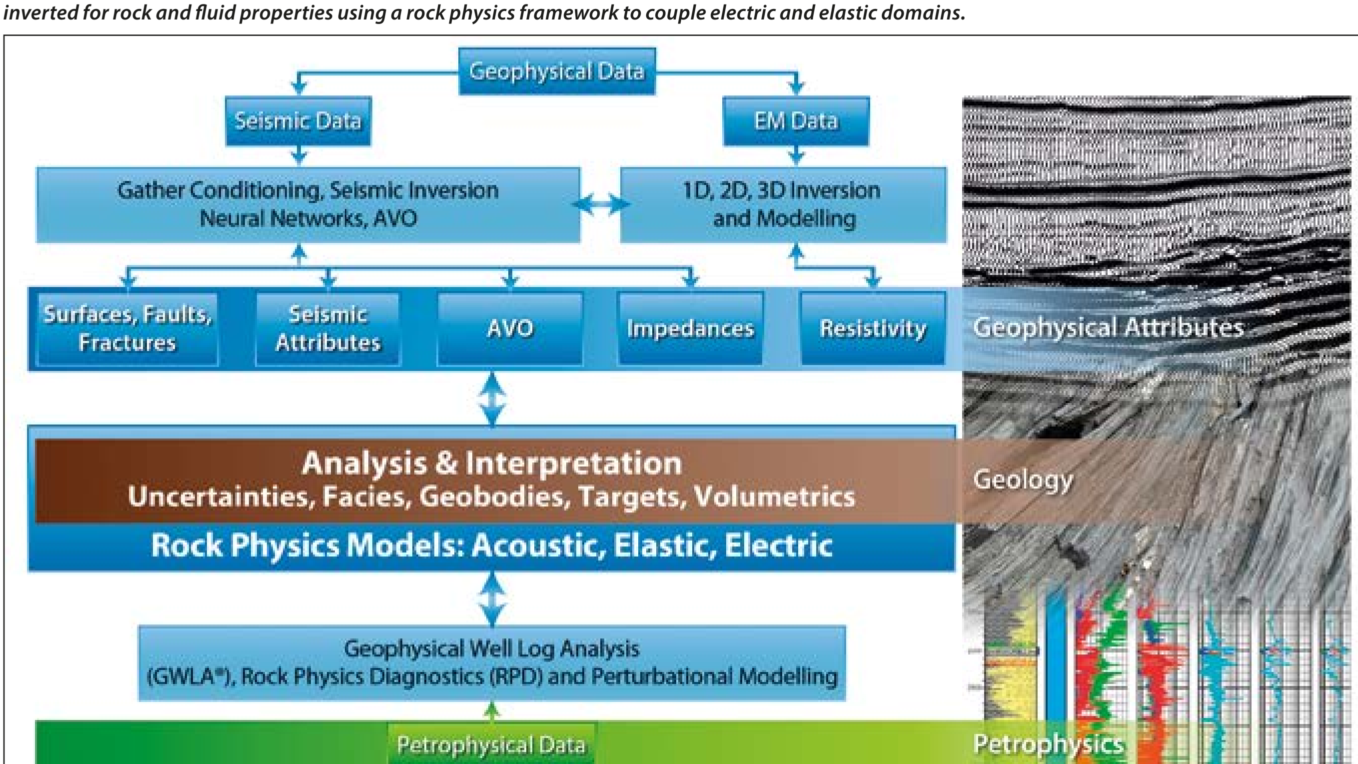
The terms 'multi-physics analysis' or 'integrated interpretation' can be used to cover a huge variety of different approaches and workflows, ranging from the purely qualitative to the quantitative.

Perhaps the simplest approach to combining CSEM and seismic data is co-rendering CSEM inversion results with seismic sections (in the depth domain). The correlation (or lack thereof) between seismic structures and CSEM-derived resistivity variations can be used to draw inferences on the geology under study. This is a powerful first-look tool, but must be treated with care. Resistivity sections from unconstrained inversions suffer from the inherent low vertical resolution of the CSEM method when interpreted alone, and the depth to features of interest may be uncertain or incorrect. If co-rendered and interpreted without care alongside seismic this could lead to erroneous geological conclusions. This limitation can to some extent be mitigated by using seismic-derived structural constraints in the inversion of CSEM data to improve the vertical resolution; however, care must still be exercised. Perhaps the most important pitfall is in interpreting the cause of resistivity variations observed. A zone of high resistivity could as easily be caused by a lithological variation as by a change in hydrocarbon charge. Correlation between structural closures or fluvial stratigraphy and zones of high resistivity can perhaps provide confidence in an interpretation of hydrocarbon presence, but this is not infallible and the underlying question remains: what is the cause of the resistivity variation?

Integrated interpretation approaches start to address this question, by using rock physics relationships to quantitatively interpret the observed variations in seismic and CSEM-derived attributes in terms of the underlying rock and fluid properties. This is a two-stage process, and is illustrated in Figure 2. First, seismic data are inverted to provide acoustic and/or elastic impedance, and derived properties such as Poisson's ratio. Similarly CSEM data are inverted, usually with structural constraints from seismic included, to provide a measure of resistivity and resistivity anisotropy. Second, these physical properties are then coupled through rock physics relations and jointly interpreted to provide an understanding of variations in rock and fluid properties.

Joint inversion approaches seek to do both steps at once by inverting directly for a model that satisfies simultaneously both seismic and CSEM datasets. A number of approaches to this problem have been suggested, all of which require electric and elastic domains to be coupled. There are broadly two approaches to achieving this coupling. In the first category are methods where the coupling between electric and elastic properties is primarily structural, constraining variations in resistivity to be spatially coincident with variations in elastic properties. Such methods are useful in cases where the variations in properties are known to be coincident, or where a direct relationship between electric and elastic properties is uncertain or difficult to obtain. An alternative approach uses rock physics models to relate the elastic

Figure 2: Integrated interpretation is a two-stage process. In the first step data (seismic and CSEM) are inverted for physical attributes (for example, impedances or derived attributes in the case of seismic, and anisotropic resistivity in the case of CSEM). In the second step these physical attributes are inverted for rock and fluid properties using a rock physics framework to couple electric and elastic domains.



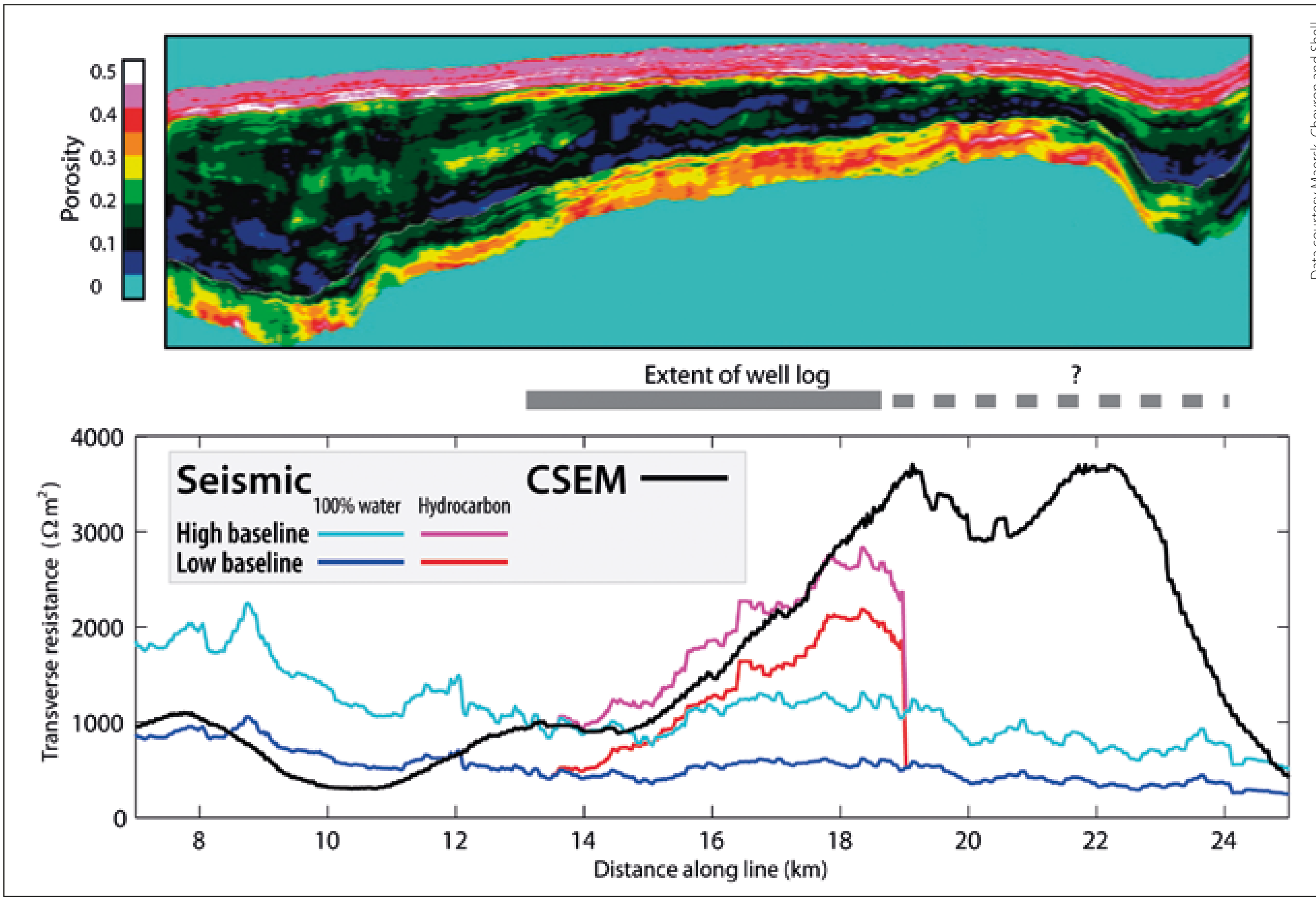


Figure 3: Seismically derived porosity is shown in the upper panel. However, seismic alone cannot distinguish hydrocarbon from water saturated chalk. CSEM derived transverse resistance is shown below. High resistivity (black curve) could be caused by either hydrocarbon fluids, or by areas of low porosity chalk. This ambiguity is resolved by transforming the seismic porosity into an equivalent seismically derived transverse resistance for the water saturated case (blue curves). These account for variations in porosity and so the remaining difference between CSEM and seismic derived curves can be attributed to hydrocarbon saturation. This is confirmed in this example using well log data (red/pink curves).

and electric properties of the earth directly to underlying lithology and fluid properties. This is a good approach in many situations, but uncertainties in these rock physics relationships and the possibility that they vary away from well control (for example with lateral lithology variations) can increase the uncertainty in the inversion result.

The Fluid Content of Chalk

An example of the benefits of an integrated interpretation approach is shown in Figure 3. In this example the challenge is to determine the fluid content of a chalk reservoir in the North Sea. In this case seismic data can be used to accurately map the porosity variations in the chalk, but when taken alone have little sensitivity to the fluid content. In contrast CSEM data provided a measurement of resistivity within the chalk, and indeed identified a high resistivity zone. The cause of this is, however, uncertain when only resistivity is considered: is it the result of hydrocarbon fluids saturating an area of high porosity, or simply an area of low porosity chalk ?

Taking the two measurements together resolves this ambiguity. Once the porosity variations in the chalk are constrained with seismic data and accounted for in the resistivity map, any remaining resistivity variations have a high probability of being related to changes in fluid properties, and in this case a confirmed hydrocarbon reservoir. Linking the seismic and electric domains through well log calibrated rock physics models further allows quantification of reservoir properties, in this case hydrocarbon column height.

Benefits of a Multi-Physics Approach

The demands of reservoir characterisation often go well beyond a simple requirement for an image of structure, impedance or resistivity. In order to fully understand the characteristics of a field, quantitative estimates of properties such as porosity, clay content, fluid type and saturation are required. However, such estimates can be fraught with uncertainty when only a single data type is considered. Seismic data remains the backbone of geophysical analysis and reservoir characterisation, but the advent of CSEM methods, measuring seafloor resistivity, brings the possibility of integrating multi-physics data within the characterisation workflow. Such approaches are of course not infallible, nor are they universally applicable. They must also be tailored to the problem of interest. However, when carefully applied, integrated interpretation approaches have the potential to significantly improve the robustness of reservoir characterisation projects. ■

Why Norway?

For more than ten years, Norway has attracted small- and intermediate-sized companies because of favourable geological and fiscal conditions. An uplift in the tax system may now reduce the majors' interest in the Barents Sea.

HALFDAN CARSTENS

Jan Norstrøm, Vice President Technology, outside Rystad Energy's head office, which is located on Aker Brygge in the centre of Oslo. The red building in the background is the City Hall.

"A discovery on the Norwegian continental shelf (NCS) can potentially be more valuable than in many other countries," says Jan Norstrøm, Vice President Technology at Rystad Energy.

The reason is that, contrary to common belief, the fiscal regime is quite favourable in Norway.

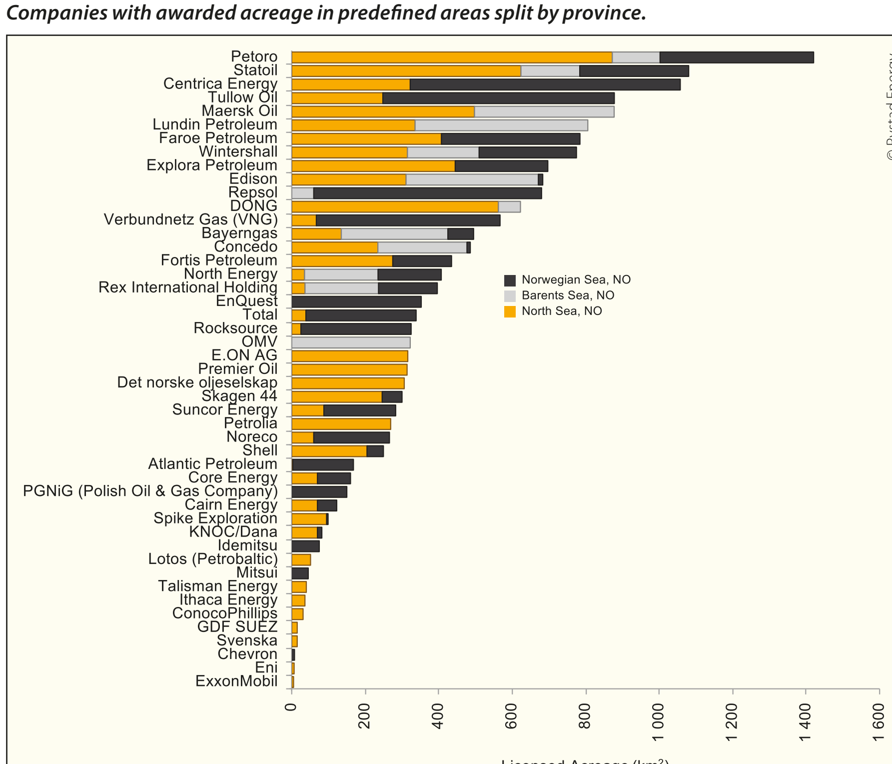
However, a recent tax hike took the industry by surprise and will make things more difficult for the development of small and marginal fields. This is also an important reason why the NCS was placed on a watch list by the petroleum industry. In the long run, "it may be regarded as less attractive if this kind of political decision-making continues", according to Norwegian Oil and Gas.

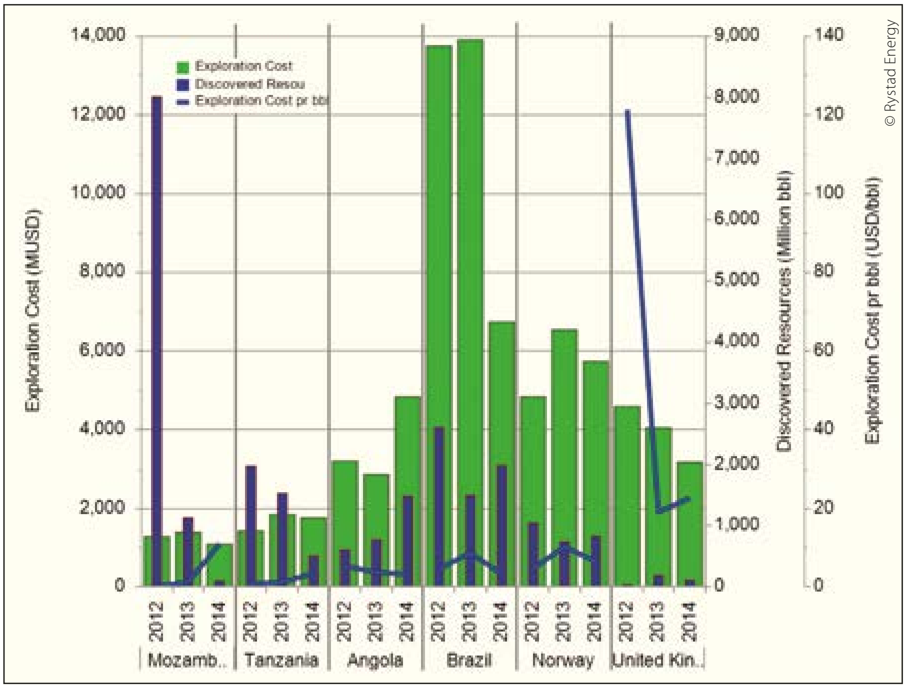
"Nonetheless, the exploration terms remain good and coupled with frontier acreage as well as many large discoveries, quite a few oil companies still look upon Norway as a place to be. In the Barents Sea, for example, an area with only a few commercial discoveries and quite a few disappointments, more than 40 companies – Shell, BP, ConocoPhillips, Total and Eni included – are actively exploring," says Norstrøm, inspecting one of many diagrams that he spits out of the computer. In the latest licensing round, ExxonMobil was also amongst the applicants.

Scrutinising the World

Rystad Energy is an independent consulting company offering business intelligence data to a growing number of players in the oil industry. Oil companies, service companies, investors, investment banks and governments are all returning customers. The main product is a set of global databases specifically tailored to analysing the E&P and oilfield service industry.

Companies with awarded acreage in predefined areas split by province.





Exploration cost, discovered resources and discovery cost for six selected countries.

"The consistency of the data provided is a result of systematic research, 24 hours a day, in several time zones," says Norstrøm.

The analyses include E&P company reporting (over 1,000 companies are tracked), investor presentations, press releases, governmental sources, public institutions and academic sources including, for example, IEA, OPEC, USGS and the Norwegian Petroleum Directorate's extensive reporting. Based on these sources Rystad Energy makes more than 1,000 data updates daily. The result is an impressive database that provides instant, colourful graphs of whatever statistics you might imagine.

As a result, maths specialist Norstrøm can, in less than a second, tell you how many wells have been drilled in the Gulf of Mexico deepwater since the Deepwater Horizon explosion and blowout some four years ago (the answer is more than 350 exploration wells). In addition, he can tell you which companies have been involved, to what depth the wells have been drilled, and a lot of additional information.

Tough Comparison for the UK

Norstrøm pulls out one graph that is of particular interest when it comes to illustrating how attractive Norway is in a worldwide setting.

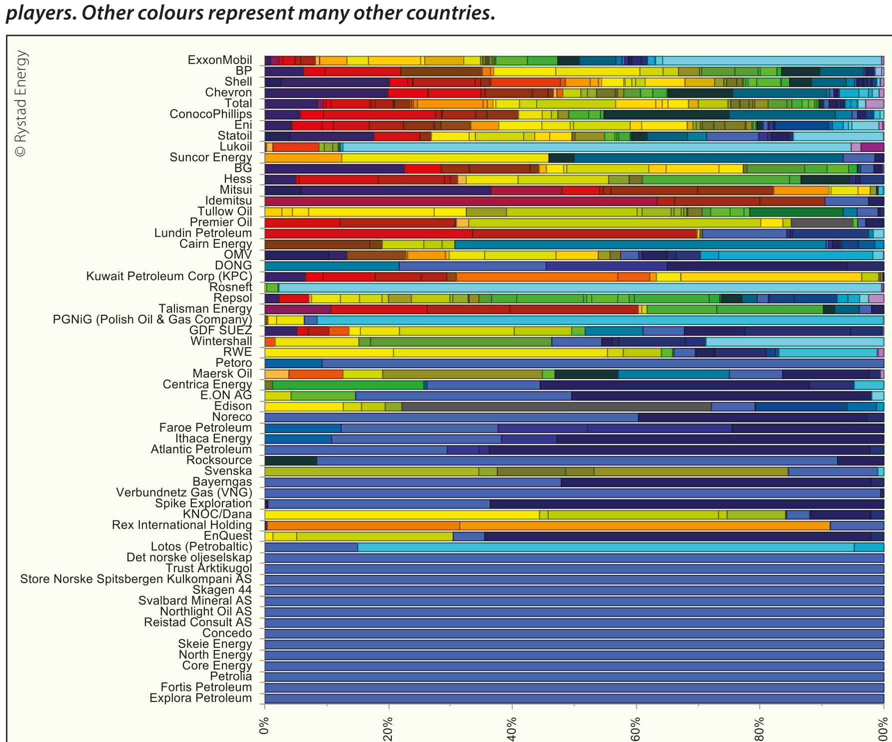
The graph compares exploration costs in six countries. Thanks to several recent giant gas discoveries, average exploration costs since 2012 in East Africa – Mozambique and Tanzania in particular – are less than two dollars per barrel; for Mozambique, just 40 cents, and one dollar, 25 cents for Tanzania. Brazil used to have very good exploration costs, also less than two dollars per barrel, thanks to a number of giant oil discoveries, many in the Santos Basin. However, over the last three years the new finds have not delivered the same volumes, so costs have been averaging around $ 5/Boe since 2012. Angola comes out with a slightly better exploration cost, at around $ 3.8/Boe.

"Norway compares favourably with these countries. Our estimate for the last three years, which includes 1.8 Bboe oil and 657 MMboe gas discoveries, totalling 2,400 MMboe of discovered resources, gives an exploration cost slightly in excess of six to seven dollars per barrel," says Norstrøm. "Based on recent successes like the discovery of Johan Castberg, Wisting and Gohta in frontier areas, but also additions to old fields like the Gullfaks Lista formation, this may not be surprising."

Norstrøm explains that Norway's tax regime, with 78% cashback, is an important reason behind the low exploration cost as it encourages companies to drill more exploration wells. This, in combination with good exploration results, makes the country attractive.

"However, on the other side of the North Sea border, the perspective is quite gloomy. In the UK, discovered resources are very small, with only some

Companies active in Norway vs. other country exposure. Royal blue shows the Norwegian-only players. Other colours represent many other countries.



300 MMboe having been proved the last three years, resulting in an exploration cost which is sky high compared to Norway, at around 40 dollars per barrel," Norstrøm says.

Ever Increasing Number

Based on the statistics above, it is not surprising that Norway is still attractive for explorationists.

"The primary reason is of course that there is still frontier acreage that needs many more wells, and that there are numerous prospects in the mature areas that continuously offer positive surprises. The last ones that left some geologists with eyes wide open was Pil and Bue, offshore mid-Norway, which may contain up to 175 MMboe recoverable," says Norstrøm.

Two other factors have been crucial in maintaining high activity on the NCS.

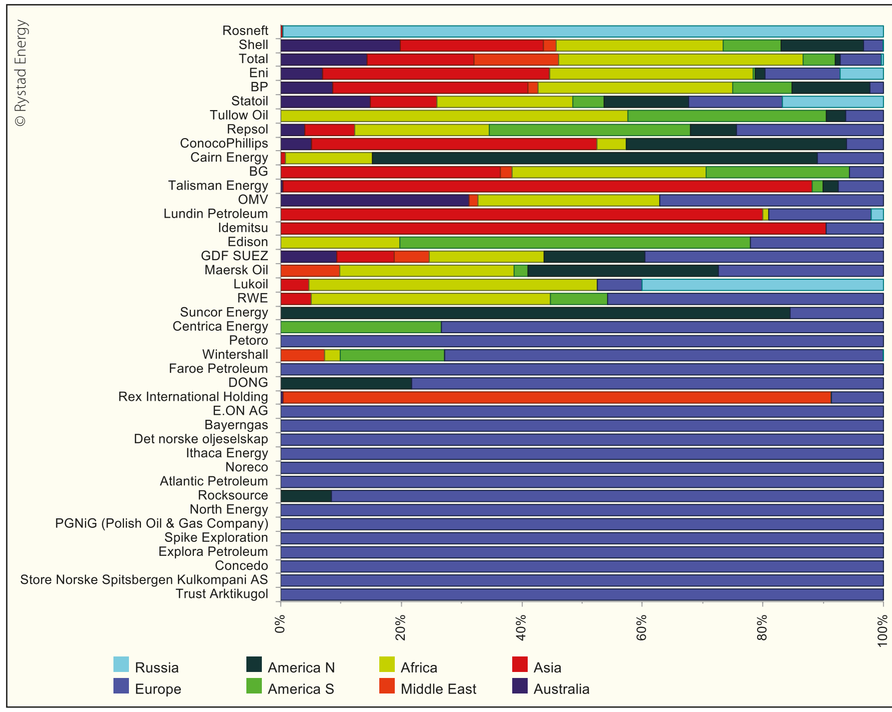
"The APA [Awards in Predefined Areas] system with acreage being offered every year within the mature areas, and the unique tax regime that allows companies to deduct exploration expenses without any producing assets, have both acted as a fly paper for small- and intermediate-sized companies, while many new companies have been established based on the revised tax system," explains Norstrøm.

"According to our last count, 68 companies are 'pre-qualified' as either partners or operators, and 58 companies are currently active on the NCS, according to NPD. Out of these, 13 have offshore exploration acreage only in Norway, like Det Norske and North Energy. In addition, 20 out of the 68 companies have an offshore portfolio only consisting of Western European blocks where Norway is in focus."

Making Things More Complicated

"Norway is a good place to be for small- and intermediate-sized companies that are not dependent on making giant discoveries. For some of them, a modest discovery can easily be a company-maker, as we have seen with Rocksource, a partner in both Pil and Bue."

We can therefore expect continued interest in the mature areas. There are enough players that need to make new discoveries in order to thrive, while for some it is a question of surviving. Without a decent find, they can rapidly become cash-strapped; there are already examples of companies looking for more money to compensate for the lack of exploration success.



Acreage percentage split into regions for oil companies active in the Barents Sea.

In the Barents Sea, the situation is different. There is still a need to attract the majors, but they are not happy about changes in the tax regime that are particularly negative for small discoveries. This is exemplified by the Johan Castberg discovery, which has been delayed by at least one year. According to Statoil, preliminary volume estimates are in the range of 400–600 MMbo but there are still uncertainties related to this as well as the investment level, so Statoil still considers the find marginal.

"The Norwegian government has recently proposed reduced uplift in the petroleum tax system, which reduces the attractiveness of future projects, particularly marginal fields and fields which require new infrastructure. This has made it necessary to review the Johan Castberg project," says Øystein Michelsen, Statoil's executive vice president for development and production in Norway.

"There is therefore a risk that the majors will withdraw, or put Norway on hold, as the Barents Sea is competing with acreage in other countries with potentially more attractive terms and better prospectivity," says Norstrøm.

"Some 20 companies that are actively exploring the Barents Sea have acreage in other parts of the world. This applies not only to Shell, Total, Eni and BP, which have less than 5% of their licensed acreage in this area, but also to Statoil, which only has 20% of its exploration rights in North West Europe.

"We need to keep in mind that Norway in general and the Barents Sea in particular only represent a fraction of the acreage that the supermajors and majors control," concludes Norstrøm.

More to Come

In APA 2014 a total of 47 companies applied fo r acreage in the mature areas. This is close to last year's record of 50 companies, proving that both Norwegian and international companies still find Norway very attractive.

"The most important reason is, of course, that Norway still has attractive acreage. There is a strong belief amongst experienced geologists that a lot more oil and gas is to be found. According to the Norwegian Petroleum Directorate, 19 Bboe have not yet been identified," says an optimistic Jan Norstrøm. ■

The Pore Pressure Expert

Ajesh John is a Lead Operations Geologist for Cairn India, and is a pore pressure specialist. He explains how his role fits into the E&P cycle, and suggests what makes a good pore pressure expert.

Pore pressure models play a crucial role in the E&P workflow, from the early exploration phase to the final stage of field production. Pore pressure models and predictions are important in well planning and safe completion and also play a crucial role in field development and in reservoir management. Since most well design is based on pressure and temperature models, a wrong prediction can incur either a costly well or a hazardous situation, depending whether the model had over- or under-predicted the pressures. In a nutshell, pore pressure controls two of the major pillars of drilling activities – cost and safety.

As nothing works in isolation in this industry, the pore pressure expert works in conjunction with many factors to produce the perfect plan, so the team is a collaborative effort with input from all departments – interpretation geologist, geophysicist, petrophysicist, drilling engineers, reservoir engineers etc. – to produce the most realistic and reliable results.

Imagination with Conviction

A comprehensive pore pressure model will be the result of the collaboration of offset well data and analogue calibration; a basic understanding of well behaviour in relation to different geological settings controls the accuracy of pressure predictions. Since many exploration wells will need real time decisions based on the well behaviour and pressure models, it is much easier if an operations geologist with a pore pressure background is in command.

I started my career as a wellsite geologist where I came to understand the importance of pore pressure in a well, and gradually moved into pore pressure modelling. Over time, I have developed a core wellbore behaviour interpretation skill which is one of the main pillars of pore pressure modelling, particularly real time pressure prediction and well calibration. Since most pressure predictions are from petrophysical logs and seismic velocities, understanding rock properties and their relation to log and seismic response is vital in predicting the right kind of pressures.

Because I have this background I feel more confident, as it makes decision-making more accurate and helps me to manage operations with minimum errors and clear, effective communications with other departments. The basic understanding acquired through my years as a wellsite and then operations geologist have helped me blend the theoretical aspects to the 'well' reality. In many ways pore pressure modelling and its visualisation equates to imagination with a conviction. Like any model, a pore pressure model is not always accurate, but needs to be verified and upgraded with real time results to take the well forward and confidence is vitally important.

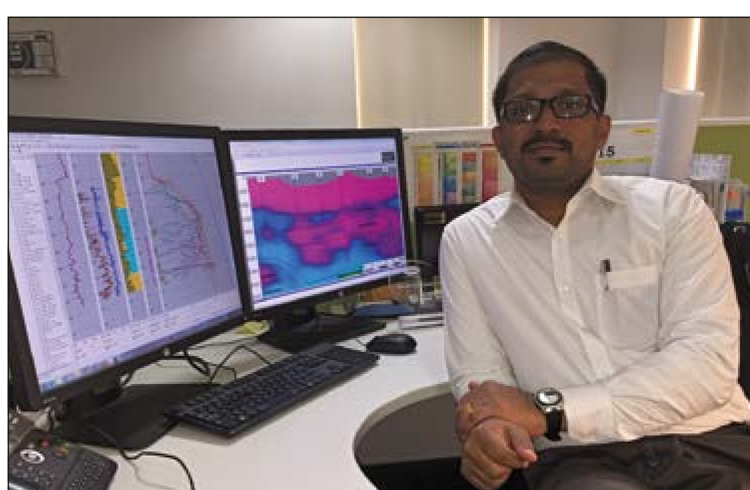
As a pore pressure specialist has to deal with multiple regimes and facets to come up with a reasonable model defining a well's pressure attributes, there is no 'essential background' or training, but theoretical knowledge, technical expertise and extensive practical experience are all needed.

A geoscience background is essential to understand the subsurface geological processes while geophysical understanding allows the specialist to analyse the attributes/proxies which will be the backbone of the workflow. In addition, a thorough understanding of well bore behaviour analysis and calibration is needed, as is comprehension of geomechanics to help resolve complicated wellbore stability issues. The success of the pore pressure geologist greatly depends on the integration of all these disciplines with a holistic approach.

Responsibility and Excitement

The most interesting part about this job is the responsibility and excitement involved in the prediction. It involves a lot of imagination, knowledge of regional concepts and methodologies, good integration of the multidisciplines – and you actually get to see the impact and results of your models during drilling. Being an operations geologist, handling the pore pressure modelling makes me more responsible in terms of the predictions, as I am very aware of the negative or positive impacts of a predicted model. At the same time it gives me immense confidence to deliver my responsibilities efficiently knowing the pressure trends well in advance.

It is unrealistic to define the pore pressure specialist in isolation. He/she has to deal with and incorporate inputs from various groups or departments before reaching a valid conclusion, so the ability to convincingly discuss with different groups to obtain the required set of information on time as well as giving out a practically accepted model on time is important. A pore pressure specialist should have a lot of imagination and visualisation skills to correlate between different attributes, properties and events to pressure models. He/she has to be rational, safety-oriented, optimistic and should have good decision-making capabilities. If there is any ambiguity or confusion related to the pressure model, the pore pressure specialist has to handle many hot discussions with a cool and composed head; to be honest, a great deal of patience is required. ■



De-risking the Barents Sea

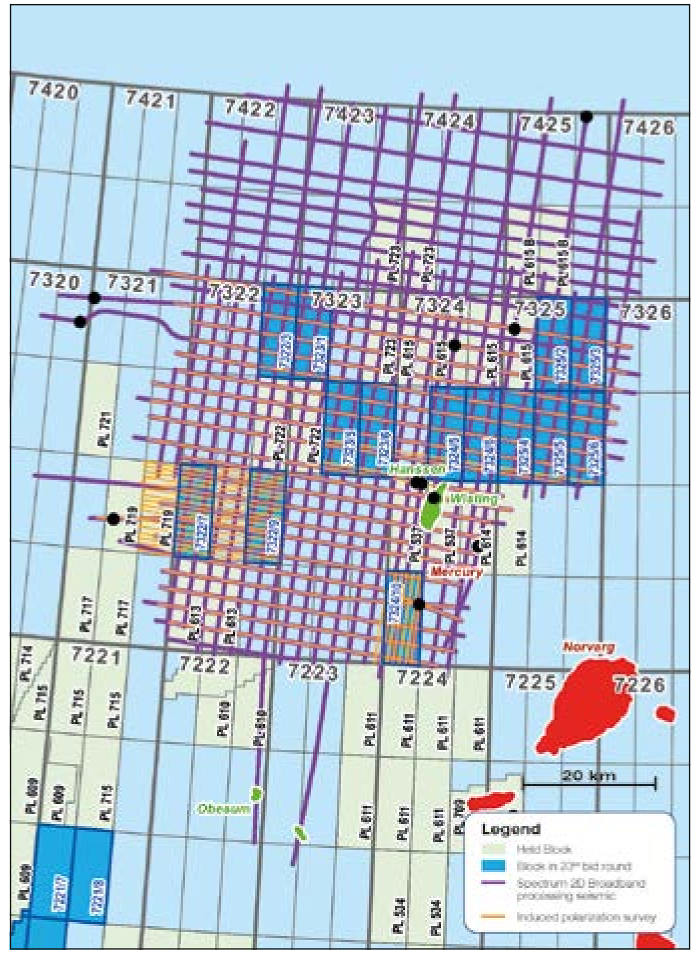
Induced polarisation and broadband seismic used together can help de-risk exploration in the Hoop area of the Barents Sea

2D seismic data is the key geophysical tool utilised in frontier hydrocarbon exploration to map new prospects. However, as part of the de-risking process, other geophysical technologies such as seismic inversion, CSEM and induced polarisation (IP) measurements, traditionally used in mineral exploration, have recently proven to be very valuable and reliable hydrocarbon indicators and therefore key factors when considering the estimation of Geological Chance of Success.

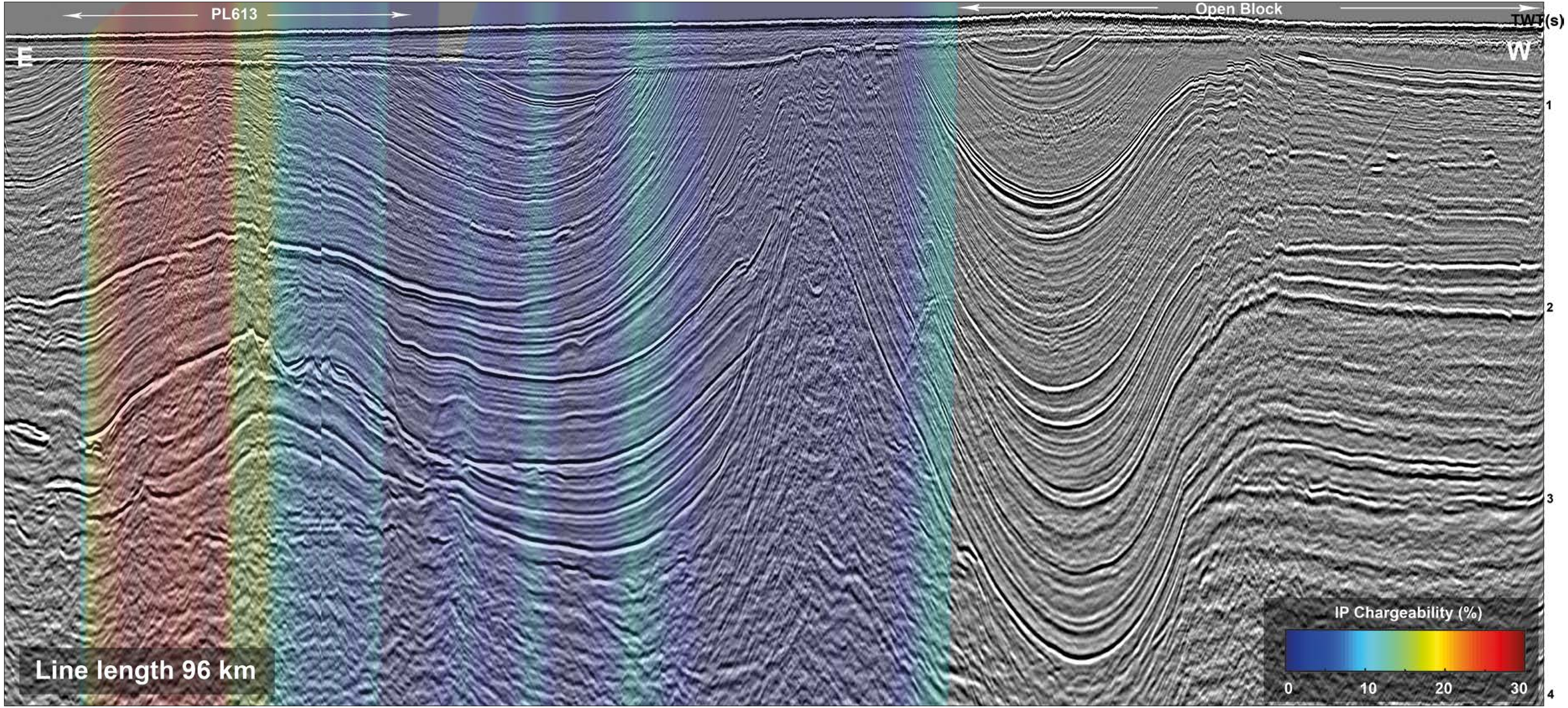
ORG GEOPHYSICAL

Spectrum

Figure 1: Survey map with licences and blocks in the 23rd licensing round.



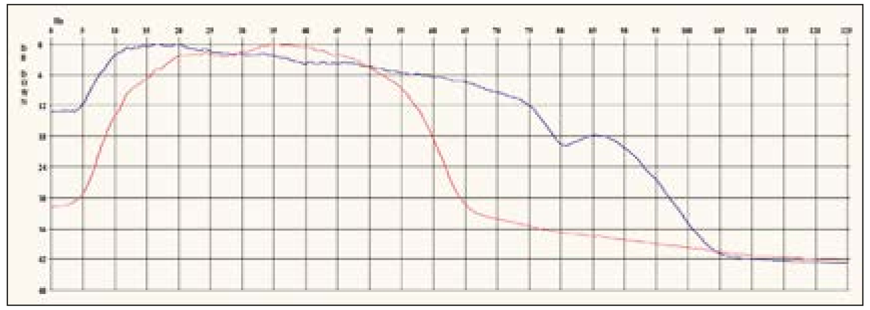
This IP anomaly overlying an east-west oriented 2D broadband processed PSTM stack section can be seen to indicate a high IP anomaly associated with a 4-way closure in PL613.



Increasing the Chance of Success

Used together, IP data and 2D broadband seismic can be very useful de-risking tools to help assess the Geological Chance of Success.

KIM GUNN MAVER, ANONGPORN INTAWONG, HOWARD NICHOLLS, Spectrum and **ANDREA KLUBICKA**, ORG Geophysical



Frequency analysis of conventionally processed PSTM stack (2013 – in red) against broadband processed PSTM stack (2014 – in blue).

In the Hoop area of the Barents Sea, 14 blocks are included in the Norwegian 23rd licensing round, which was announced in January 2015. Induced polarisation (IP) measurements along with 2D broadband processed seismic, which has been pre-stack inverted, have been acquired tying all wells in the area, as seen on the map on page 36. The data can be used for an interpretation of all recently announced blocks in the round, including the prospective Jurassic sequence with the recent Wisting discovery, the Triassic and to some extent the Permian/Carboniferous, largely de-risking any identified leads and/or prospects.

Data Acquisition and Processing

The 2D conventionally acquired seismic has been processed using broadband seismic technology through a de-ghosting and de-bubbling processing sequence, which ensures a high resolution image compared to conventional processing, adding 5 Hz to the low frequencies and 10–15 Hz to the high frequencies. This helps to facilitate a more detailed stratigraphic interpretation. A frequency comparison between conventional and broadband processing is illustrated above.

Acquiring the seismic with 8 km streamer makes the data suitable for pre-stack inversion which, tied to well log data, can be used to derive rock properties over key parts of the geological section for a more detailed interpretation of reservoir parameters.

Coinciding with selected 2D broadband seismic sections, IP has been acquired using an electric transmitter, with the resultant induced polarised field measured using towed streamer receivers. The main mechanism behind IP is micro-seepage from hydrocarbon reservoirs causing a chemical reaction in the rocks above the reservoir, creating a disseminated pyrite body (see *GEO ExPro*, Vol. 11, No. 3). These alteration zones display anomalous electrical polarisation properties (higher chargeability than the surroundings), which can be measured and which point to deeper lying hydrocarbon accumulations.

Geological Chance of Success

For prospect mapping and evaluation the Geological Chance of Success should be assessed, which consists of assigning fraction probabilities to the following parameters:

structure × **reservoir** × **charge** × **retention**
= **Geological Chance of Success**

Each geophysical method can add certainty to the four parameters and ideally independent and complementary measurements will increase (or decrease, depending on the results) the individual fraction probabilities and therefore the overall Geological Chance of Success.

Seismic data is a strong indicator of **structure**, especially with the enhanced bandwidth due to broadband processing. It can also be an indicator, though weaker, of **charge** through gas chimneys as well as of **retention** through flat spots, velocity pushdown, and frequency and amplitude brightening/dimming. Whereas seismic data is not a strong indicator of **reservoir** parameters, pre-stack inversion calibrated to well log data is a strong indicator of, and can provide, **reservoir** porosity and thickness information but also some indication of **structure**. Vp/Vs inversion results may also be an indicator of **retention**, as fluids can be detected in the reservoir, and of **charge**, in case hydrocarbons can be predicted.

By contrast, IP data is a strong indicator of **structure** as the anomaly in general coincides with the field outline and indirectly points to the presence of a reservoir. It is an indicator of charge, as hydrocarbons often contain sulphur, which is one of the constituents involved in the generation of pyrite. Finally, IP does not provide any information on **retention**, as all hydrocarbons may have leaked out and through this process produced the IP anomaly.

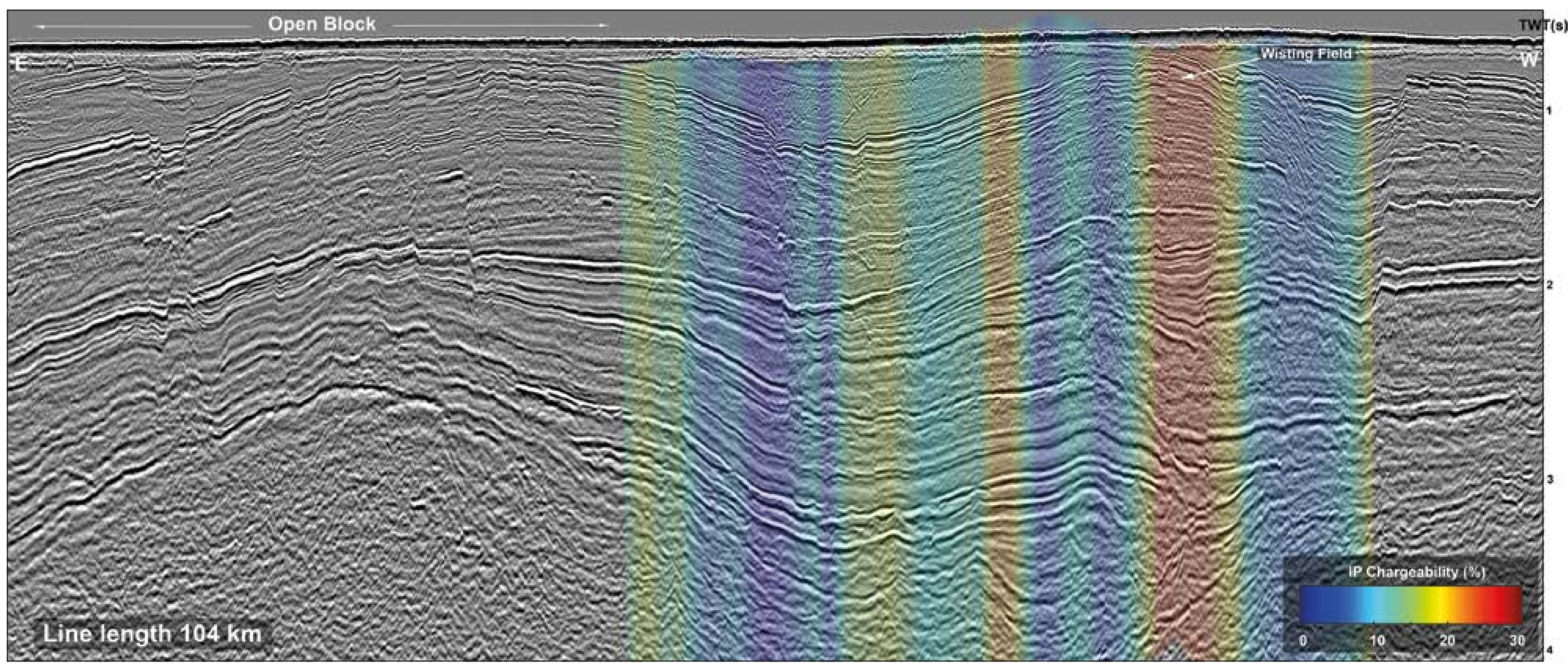
IP has been used for the past 13 years for hydrocarbon exploration and de-risking, with 40,000 km of data acquired both onshore and offshore and more than 200 wells tied with a prediction rate of approximately 90% (predicting a discovery or dry well correctly). On the Norwegian Continental Shelf alone, more than 4,000 km of data have been acquired, both pre- and post-drilling, in the period between 2012 and 2014. The outcome of pre-drilling IP data acquired over 13 well locations shows 11 correct predictions (both dry and discoveries). Complementing seismic data and derived products, IP measurements are proving to be very valuable, providing significant input to the estimation of Geological Chance of Success.

Hoop Area

2D broadband seismic and IP data intersect the wells in the Hoop area, including recent wells such as Wisting, Apollo and Atlantis (see map on page 36). This makes it possible to evaluate the acquired data and assess the reliability of IP measurements in predicting the possible presence of underlying hydrocarbon accumulations. The IP results on a selected east-west line show a chargeability anomaly which correlates well with the Wisting discovery and the general width of the field outline, as can be seen on the figure below.

Other prospects in the Hoop area may be identified, as illustrated on the 2D broadband processed seismic and IP results, acquired as an east-west line across licence PL613, which display a very strong IP anomaly. The seismic shows an associated 4-way closure which is clearly identified and thus pointing to the outline of a possible underlying hydrocarbon accumulation (main foldout on pages 36–38). Weaker and more localised IP anomalies further east on the line could be associated with faulting and sub-cropping units with possible hydrocarbon migration into the overburden.

Together, IP data and 2D broadband seismic could be very useful de-risking tools used during the 23rd licensing round to either help increase the Geological Chance of Success, when an IP anomaly is present, or lower it when it is not present. In both instances the Geological Chance of Success will be more reliable, ensuring both the right ranking between prospects as well as the right CAPEX investment. ■



IP data overlaid on an east-west oriented 2D broadband processing PSTM stack section demonstrates a high IP anomaly across the Wisting Field in PL537.

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- Badge Collection
- Registration and Evening Icebreaker

Wednesday 15th April Conference

- Registration and Opening Session
- Session 1: Asia-Pacific E&P; State of Play
- Session 2: Myanmar
- Session 3: Bangladesh-India-Indonesia (W)
- Session 4: Indonesia (E)
- Special Session: Counter-cyclic Strategy for Australasia
- Quiz Night

Thursday 16th April Conference

- Session 5: Asia-Pacific Overview & NZ
- Session 6: Philippines -PNG
- Session 7: Vietnam-MTJDA-Malaysia CO3's
- Farmout Forum
- Evening Entertainment

Friday 17th April Conference

- Session 8: Australia
- Session 9: Malaysia Fields
- Session 10: Malaysia Exploration Studies
- Closing Session
- Asia-Pacific Scout Check
- APSC and Seapex Cocktail evening

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New Perspectives on the Barents Sea

The recent opening of the south-east Barents Sea to oil and gas exploration has provided an opportunity to deploy the latest technologies such as full tensor gravity gradiometry to improve efficiency and reduce time to first oil.

Dr. STEPHEN RIPPINGTON and CHRIS ANDERSON, ARKeX Ltd.

The south-east Barents Sea was unexplored for many years prior to the territorial settlement between Norway and Russia in 2011. Since then, the region has been the focus of intense activity. The drive to apply new technology comes from the remoteness and cost of operating in the Arctic, and from the inherent geological complexity of this frontier area (Doré et al. 1999, Pease 2011).

Under Norwegian administration the area was included in the 23rd Concession Round. During 2013 and 2014, ARKeX Ltd acquired a multi-client Full Tensor Gravity Gradiometry (FTG) survey over a 42,000 km^2 area of the south-east Barents Sea, which was designed to complement an extensive 2D seismic programme offered by the Norwegian Petroleum Directorate (NPD) and four newly acquired 3D seismic surveys in the region.

The interpretation of the FTG survey addresses some of the key issues presented by the complexity of the geology on a regional scale. It helps identify and map structural trends associated with three major orogenic episodes: the north-west-trending Precambrian Timanian Orogen, the north- and north-east-trending middle Paleozoic Caledonian Orogen, and

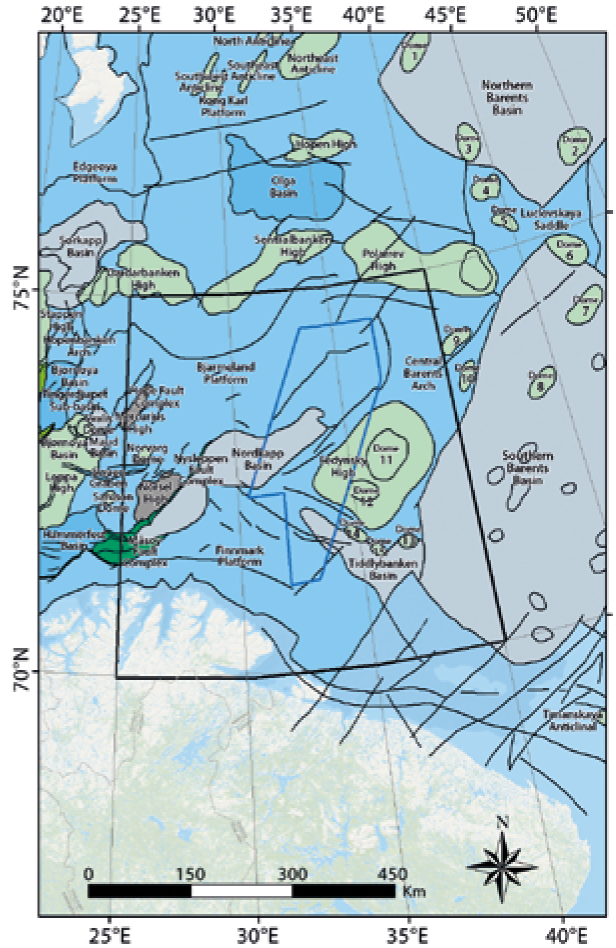
Chris Gorman (Field Geophysicist, ARKeX)

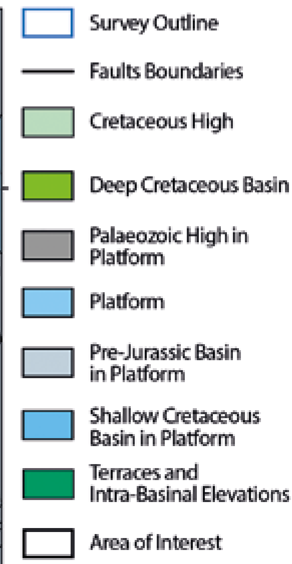
The Barents Sea – a challenging location for exploration.

the north-trending Permo-Triassic Uralian Orogen (Pease, 2011). Mapping the basement structures in the south-east Barents Sea is an important step to a better understanding of the structural and kinematic development of overlying, potentially hydrocarbon-bearing basins. This is particularly important in areas like the Nordkapp Basin where salt is present, as the timing of salt mobilisation and the geometry of the resulting salt diapirs may be tectonically controlled.

Of additional interest are the opportunities and risks associated with inversion, uplift and erosion in the Cenozoic. Erosion removed between 1,400 and 1,600m of Cretaceous and Paleogene strata from the south-east Barents Shelf, resulting in a major change of pressure, volume and temperature conditions in potential reservoir and seal rocks at the Triassic-Jurassic level (Henriksen et al., 2011). FTG technology allows the measurement and mapping of small variations in the bulk density of sections of the Triassic and Jurassic succession, providing a new tool for investigating the effects of Cenozoic inversion, uplift and erosion in this region.

In this article we present a preliminary insight into broadband gravity measurements afforded by the FTG method and its integration with seismic data. The main focus is on structural interpretation and salt morphology, which when considered as a whole provide additional information regarding the tectonic evolution of the area.



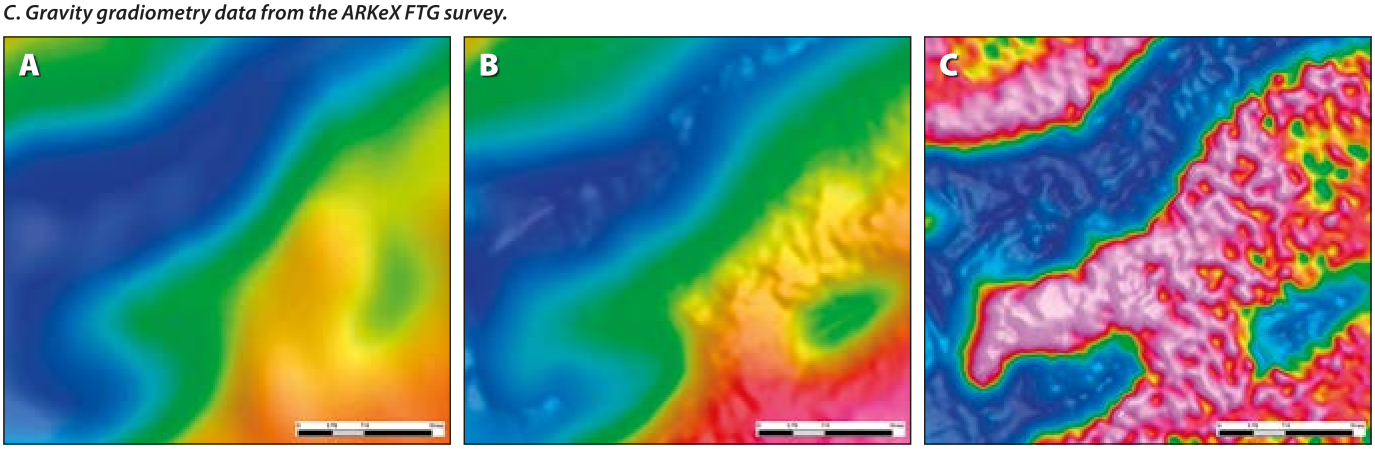


Location of the FTG survey and the expanded area of interest for the ARKeX multi-client study of the south-east Barents Sea. The base map shows the tectonic elements of the Barents Shelf (from the Norwegian Petroleum Directorate).

Applying Gravity Gradiometry

The ability to directly measure the gravity gradient tensor effectively isolates the signal coming from the varying density of the Earth's subsurface from the accelerations experienced by the measurement platform (vessel or aircraft). The fact that the full tensor is measured further enhances the signal to noise ratio and reduces smearing of 'out of plane' signal. The Lockheed Martin Full Tensor Gravity Gradiometer is also fitted with an additional set of instruments (the Gravity Measurement Assembly or GMA) to measure gravity, as well as the gravity gradient, so that longer wavelength information is not compromised. A good way to think of the FTG measurement compared to that of a conventional gravity meter is to regard the data available from FTG surveys as 'broadband gravity'. The noise isolation increases the higher frequency response resulting in much better lateral resolution, and the GMA takes care of the low frequency end. These data capture both the long wavelength components of the gravity field that are

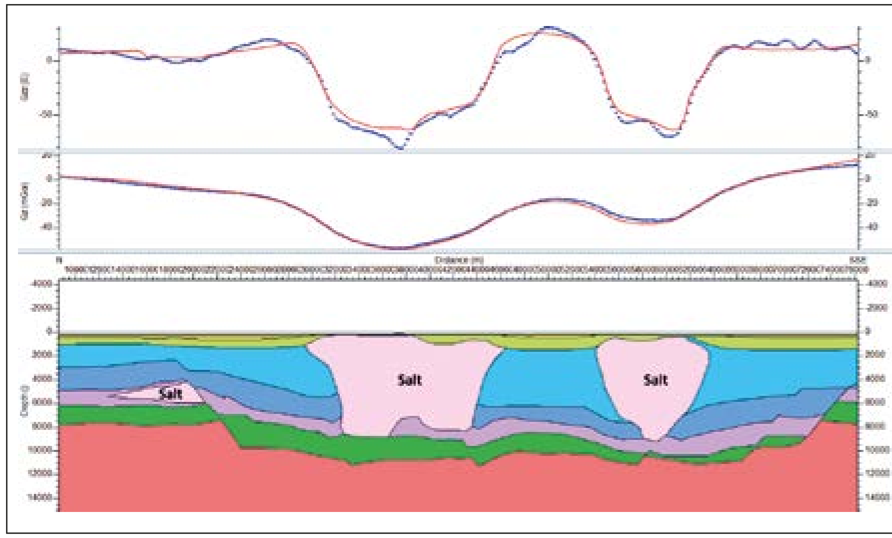
Gravity datasets over part of the Nordkapp Basin. A. Satellite gravity data (Sandwell et al., 2014). B. Gravity data derived from the ARKeX FTG survey. C. Gravity gradiometry data from the ARKeX FTG survey.



driven by deep structure and the shorter wavelengths which result from mid-crustal and near surface structure.

To provide a regional context to the FTG data and to capture the longer wavelength features provided by a wider survey area, the area of interest for this study was expanded to include the region between 24° E and 39° E and 70° N and 75° N. The FTG data are interpreted in conjunction with satellite gravity and EMAG2 magnetic data (Sandwell and Smith 2009, Maus et al. 2009) and published seismic data and maps to deduce the structure of the expanded study area in a GIS-based map.

The maps that are readily obtained both for the vertical gravity gradient (Gzz) and also for acceleration due to gravity (Gz) show a striking array of geological features with improved definition, positional accuracy and resolution over and above that which could be achieved with a conventional gravity meter. Whilst it is possible to build a geological model based solely on the interpretation of these data, there is a significant opportunity to extract greater value from an integrated interpretation where 2D or 3D seismic sections are available. Simultaneous interpretation of the seismic and gravity data has been used to identify major basement-involved faults on the seismic data; these faults were then interpolated along strike, away from the seismic lines using the gravity data. This is a relatively simple way to ensure a more robust interpretation of how faults link along-strike.



An example of a 2D/2.5D density model across the Nordkapp Basin. The model satisfies seismic, gravity and gradiometry data. The amplitude of the gradiometry anomalies requires a significant volume of salt in the diapirs. The gradient of the anomaly profile, in conjunction with a top salt interpretation from seismic, helps to define likely salt flank geometries.

Density Contrasts

The gravity gradiometry data is particularly sensitive to large, shallow density contrasts, like those formed by shallow salt diapirs in contact with denser host rocks. Top salt and maximum salt distribution were interpreted from the seismic and gravity gradiometry data and used to make a new salt map of the region. In addition to mapping salt diapirs, the gravity gradiometry data have proven sensitive enough to map grounded salt pillows trapped in the Permian succession at 4–6 km depth on the flanks of the Nordkapp Basin. To further investigate the geometry of the flanks of the salt diapirs, and the structure of the basins in which they reside, 2D/2.5D density models were produced to satisfy the gravity, gravity gradiometry and seismic data (see figure above). The FTG data also show that the Nordkapp Basin contains several significant salt diapirs. The anomaly amplitude profile across the diapirs requires that the Nordkapp Basin contains thick columns of salt (in excess of 6 km thick), which can be mapped along strike over tens of kilometres.

There are two clearly evident structural trends exhibiting north-west and north-east directional alignment respectively. This may reflect the varying influence of Caledonian and Timanian structures and their influence on the architecture of overlying basins.

Short wavelength (1–5 km) gravity gradient anomalies may be related to the variable geology of the seabed, and to subtle changes in the bulk density of the Triassic and Jurassic succession. These density changes correspond to faults that bound mildly deformed domains in which either compressional strain (increased density) or tensile strain (decreased density) is dominant. This deformation occurred through multiple phases of Mesozoic halokinesis and Cenozoic inversion, uplift and erosion.

Integrated Regional Interpretation

Broadband gravity data from a new FTG survey are used to produce a regional structural interpretation of the south-east Barents Sea, which can be integrated with other geophysical and geological datasets to produce robust interpretations from the regional to prospect scale. The long wavelength component of the gravimetry and gravity gradiometry data are used to map out basement-involved fault zones, by interpolation between seismic lines. Variations in the orientation of the principal basins in the region are attributed to variations in the basement structural grain that they have inherited. Short wavelength anomalies in the gravity gradiometry data are attributed to a combination of seabed density variations and deformation zones at the Triassic-Jurassic level, caused by a combination of halokinesis and tectonic inversion, uplift and erosion (unburdening). Using 2D/2.5 D modelling of the gravity gradiometry data in conjunction with seismic interpretation to investigate the distribution and morphology of salt bodies shows that diapirs in the Nordkapp Basin comprise thick, laterally extensive columns of salt.

The south-east Barents FTG survey is a multi-client dataset, and as such has presented ARKeX with the opportunity to provide a qualitative interpretation package for delivery with the data. The interpretation has suggested a number of key features and events that improve understanding of the structural evolution of this complex region.

References available on www.geoexpro.com ■

South East Asia:
Deepwater Activity in an Environment of Oversupply

DYLAN MAIR and EVONNE TAN, IHS Energy

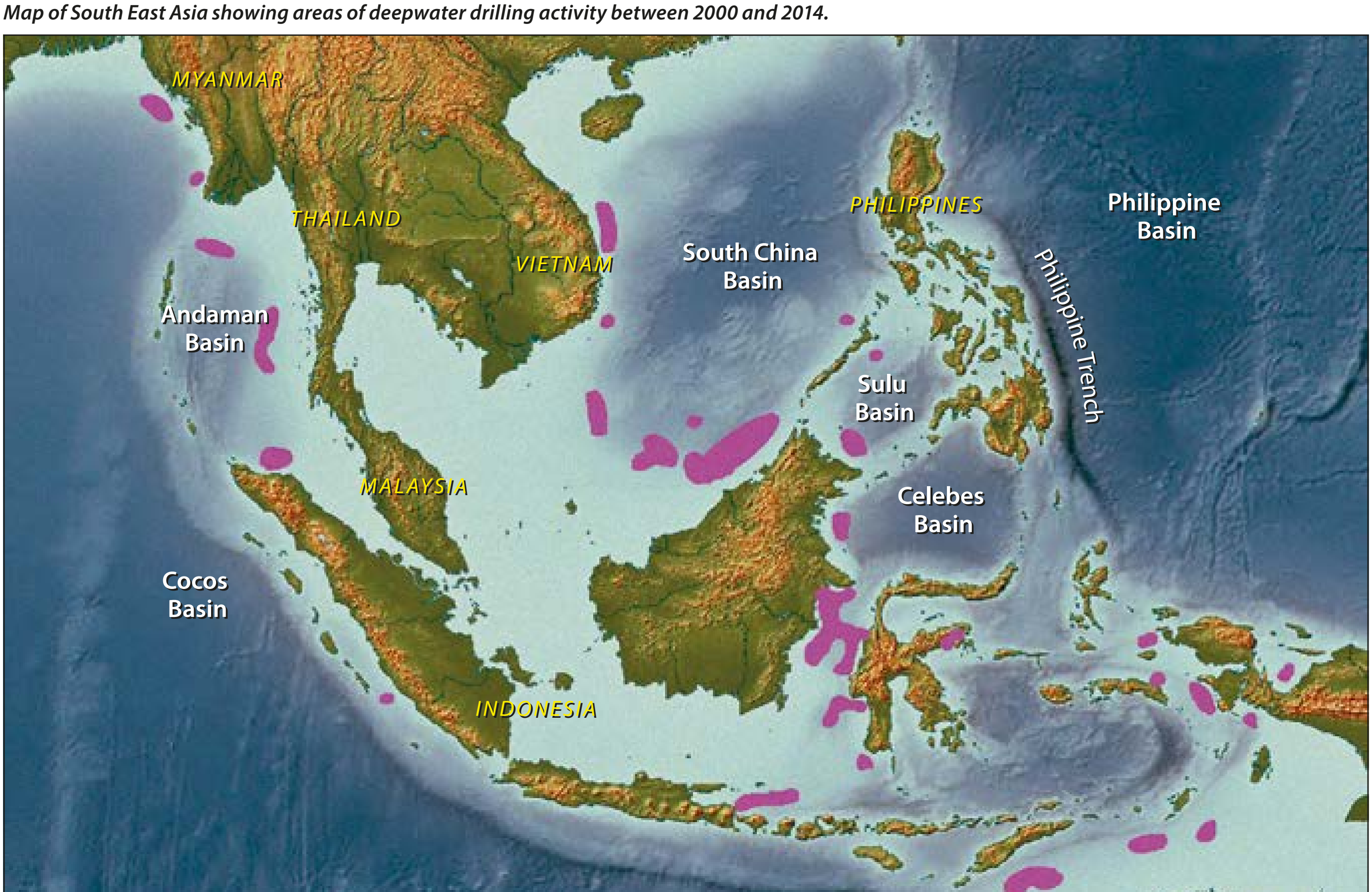
High oil prices and maturing onshore and shallow water plays have already driven explorers in Asia Pacific to target deeper waters and high pressure, high temperature plays. Meanwhile, concurrent exploitation of unconventional resources in North America, driven by technology advancement, has led to unprecedented production growth over the past three years. Amidst myriad events, which included the slowdown in China's economy growth, increase in production from Libya and OPEC's decision not to cut production, Brent prices fell below $50 per barrel in January 2015. The sharp decline in oil prices has compelled E&P companies worldwide to cut costs and reassess their portfolios. This article investigates the impact of current oil prices on deepwater projects in South East Asia, and reaches four conclusions:

- In the short-term, deepwater exploration is expected to be delayed; companies will prioritise commitment wells and target higher probability (usually near-field) prospects. On the other hand, short-term production should remain on target and development of sanctioned projects is expected to proceed.
- In the longer-term, deepwater reserve replacement could potentially be affected by near-term exploration delays. When combined with possible delays in project sanctioning over the next one to two years, there is less certainty on the long-term deepwater production outlook for South East Asia.
- Capital spending could be redirected to mergers and acquisitions as companies take advantage of low oil prices to consolidate and optimise positions in core operating areas.
- South East Asian governments are expected to play a more active role in encouraging deepwater E&P through additional fiscal incentives and prioritising diplomatic resolution of disputed acreage, with the aim of replenishing reserves for energy and fiscal security.

Deepwater Activity in South East Asia

From 2000 to 2014, deepwater new field wildcats (NFWs) accounted for 13% of total NFWs drilled in the region. Deepwater contributed an additional 11 Bboe of discovered resources, representing 38% of total reserves discovered in the region.

Map of South East Asia showing areas of deepwater drilling activity between 2000 and 2014.



Deepwater development in South East Asia has historically been driven primarily by the international E&P companies. The largest deepwater operators in the region are Chevron, Murphy and Shell, each operating more than ten fields. Domestic national oil companies (NOCs) such as PETRONAS and Pertamina established their deepwater positions through initially holding non-operated stakes. However, as the NOCs refine their deepwater operational capabilities, they will become less reliant on international partners to drive deepwater development in their domestic basins. Over the past four years PETRONAS has drilled 17 operated deepwater NFWs in the region. Meanwhile, in Indonesia Pertamina has been pushing for an operator stake in the TOTAL-operated Mahakam Offshore PSC, which is due to expire in 2017.

Despite relatively higher finding and development (F&D) costs compared to onshore and shallow water plays, deepwater is still attractive to companies in pursuit of reserves replacement due to the potential to find larger-sized fields. However, deepwater drilling with higher initial capital risk is expected to face high risk of delays in an environment of weak and volatile oil prices as E&P companies review their portfolios to reduce operational and capital spending.

Short-Term Impact on Deepwater Activity

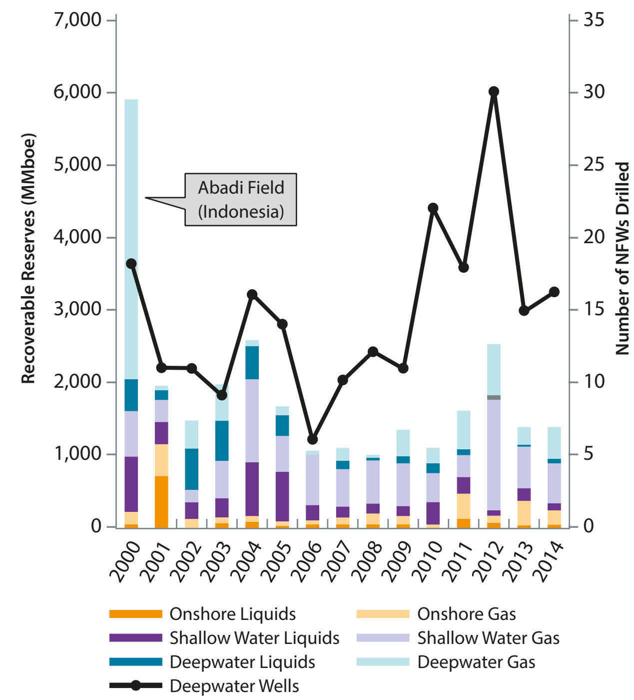
Major E&P companies across the globe have announced significant spending cuts in response to the recent collapse in oil prices. Shell announced a spending cut of $15 billion over the next three years, Chevron a cut of $5 billion for 2015 and PETRONAS has stated there will be reductions in 2015 capital spending of between 15 and 20%. Murphy plans to cut 33% of capital spending but will, however, be maintaining its current focus on global deepwater assets.

The impact of spending cuts on producing projects or projects already sanctioned, especially those expected to come onstream in the next year or two, are expected to be limited in light of existing contracts and commitments. As a result, the short-term production outlook for South East Asia is expected to remain relatively unchanged. Malaysia is forecast to be the largest contributor of short-term production growth, underpinned by the Kebabangan Gas Project, which came onstream in late 2014. The project is operated by KPOC, a joint operated company comprised of PETRONAS, Shell and ConocoPhillips.

On the exploration front, E&P companies will be forced to reevaluate exploration opportunities set within their portfolio in light of spending cuts. Subsequently, testing of deepwater prospects has a greater chance of being delayed due to associated higher costs and lower estimated possibility of economic success. E&P companies will likely target higher probability (near-field) drilling prospects when fulfilling their exploration commitments.

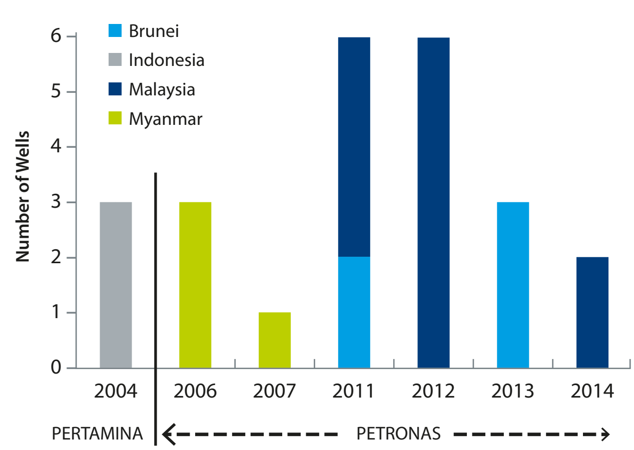
Rig utilisation in South East Asia has already been in decline since late 2013 due to oversupply. Potential deferrals of exploration drilling and project sanctioning are going to add further downward pressure on rig demand. Reduction in drilling rig rates and services and the easing of tight labour pressures are expected to result in the decline of upstream capital cost over the next two years.

Discovered Reserves in South East Asia



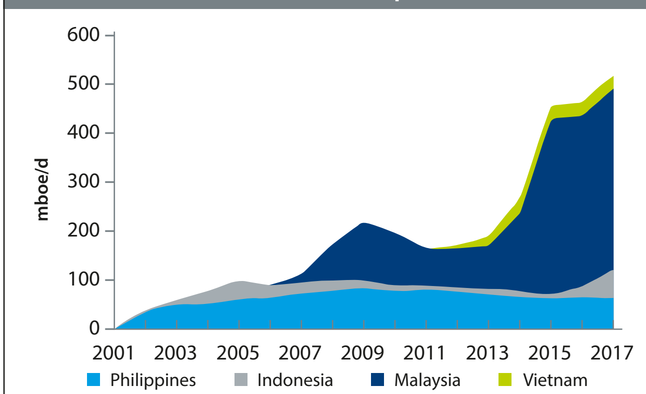
Source: IHS © 2015 IHS

NOCs-operated Deepwater NFWs in South East Asia



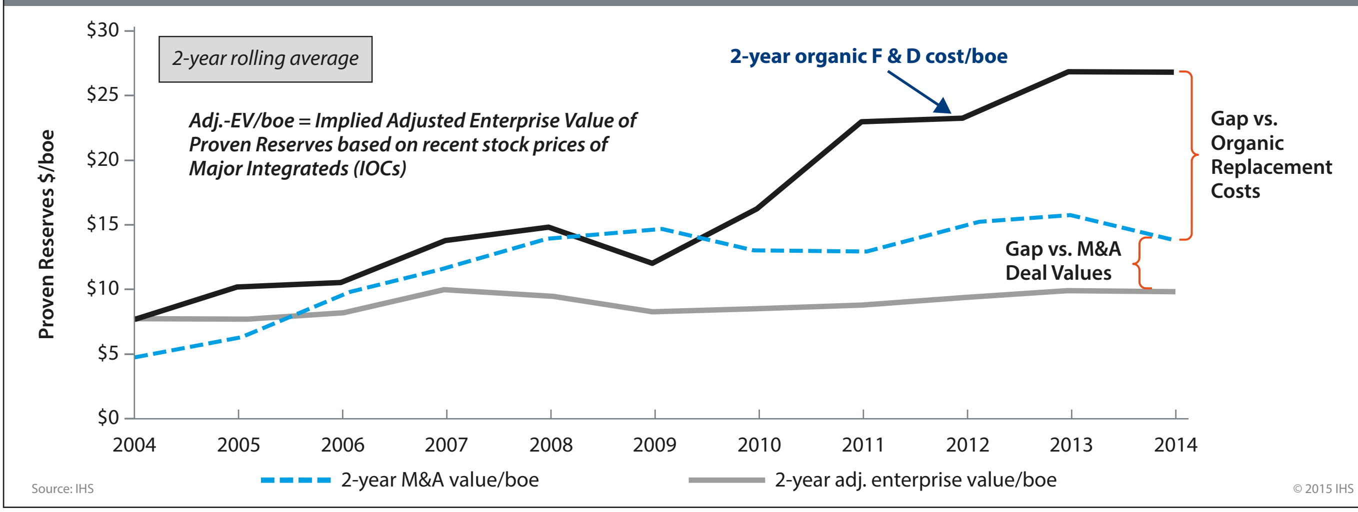
Source: IHS © 2015 IHS

South East Asia Short-term Deepwater Production



Source: IHS © 2015 IHS

Organic Replacement vs. M&A



Long-Term Impact on Deepwater Activity

In the long-term, production volumes at risk from low oil prices will depend on how far down prices go and for how long they remain at that level. IHS estimates an average operating cost of US$15 pboe for deepwater projects in South East Asia, which requires a drastic and sustained drop in oil prices possibly below US$35 pbo to render the operating costs of these projects uneconomical.

As major international E&P companies reassess their global portfolio in an effort to manage cost and cash flow in the near-term, deepwater projects are at high risk of delayed sanction – projects in Brazil, West Africa, and the US Gulf of Mexico are among those at risk. While deepwater project economics might appear feasible due to the expected recovery of oil prices in the long run and the long lead time of six to ten years from final investment decision (FID) to first production, in a volatile price environment companies will seek to conserve cash to support core operations and avoid committing to capital-intensive projects. In August 2014, Chevron delayed taking FID on the Gendalo-Gehem project. In addition, low oil prices could further exacerbate FID deferments for the 2.5 MMtpa Abadi FLNG project and the second phase of the Indonesia Deepwater Development project, which were still pending FID prior to the onset of low oil prices. All three projects are located in Indonesia.

Delays to exploration drilling over the next year or two could potentially foster a decline in deepwater reserves replacement in South East Asia. This will have a further impact on the longer term production outlook for the region.

Competitive Landscape and M&A

The deepwater competitive landscape in South East Asia is not expected to undergo significant changes as companies invested in the region, such as Chevron, Murphy, Eni and TOTAL, are financially able to withstand low oil prices for sustained periods. Operations in the region are material and core to many of these companies. NOCs, such as PETRONAS, Pertamina, CNOOC and Sinopec, are also likely to retain their equity stakes in current contracts to maintain position in the region.

While it is unlikely that there will be significant M&As in the region targeting deepwater assets, the number of upstream M&A transactions for global assets might see an uptake as the cost/boe to acquire becomes more attractive than cost/boe to explore. Companies could take advantage of low valuations to acquire assets from distressed companies that are of strategic fit to their portfolio. The potential shift to growing inorganically could result in the delay of greenfield deepwater exploration.

A Role for Governments?

South East Asian governments have been relentless in their efforts to promote deepwater exploration in the region. In December 2014, the Indonesian government implemented a Land and Building Tax exemption for 22 onshore/offshore exploration blocks. The tax relief scheme will be granted to exploration licence holders for a period of six years. Moreover, Indonesia will also issue extensions for the 42 blocks estimated to expire between 2015 and 2019 and the government has announced plans to simplify business process for obtaining licences. All these were efforts undertaken to stimulate exploration activities in the country.

Yet, the economics of deepwater projects in the region remain challenging given the high cost environment, lack of technical expertise, and export route barriers. The prolonged contested maritime territorial claims and China's recent aggressive move in the South China Sea further complicate deepwater exploration. However, the recent drop in oil price may put a downward pressure on cost, thereby improving deepwater project economics. Capital cost for deepwater projects is less elastic compared to shallow water projects to price changes, therefore it may take one or two years to respond, given the typical longer term commitment on deepwater projects.

Despite the low oil price, NOCs are expected to remain committed to deepwater plays, especially in their domestic basins. Going forward, South East Asian governments could potentially play a more active role in encouraging deepwater E&P through additional fiscal incentives and prioritising diplomatic resolutions on disputed acreage, with the aim of replenishing reserves for energy and fiscal security. With the right touch, it is possible to sustain deepwater exploration within a prolonged low oil price regime. ■

Torres del Paine
The Patagonian Diamond

Patagonia plays host to numerous geological marvels, including the famous Torres del Paine granite intrusion – a stunning spot in a fantastic wilderness.

OLIVIER GALLAND and CAROLINE SASSIER

The screams of a group of Guanacos suddenly catch our attention. We look around us and embrace the wilderness of the southern Patagonian landscape. Anchored to the saddle, the feet pushing automatically on the pedals, we are slowly cycling from Puerto Natales on the dusty road that meanders through the southern Andean foothills. Ahead of us, fabulous, majestically snow-covered peaks stick out above the horizon and dominate the Argentine Pampas: the Cordillera del Paine is attracting us like a magnet; it is one of the highlights of our nine-month journey (see box, page 54).

At dusk, after a seemingly endless day of cycling, we reach the gate of the Torres del Paine National Park. A red fox crosses the dirt road and looks at us before disappearing. Condors glide high over the hills without any wing beats. The Cordillera del Paine is impressive, with dramatic cliffs rising almost three kilometres above the foothills. But the most striking feature is the colour of the mountain: the cliffs exhibit a prominent white band, almost a kilometre thick, extending across the peaks of the massif.

History of the National Park

The landscape and the geographic situation make the Cordillera del Paine an emblematic feature of the area. Located at the transition between the Andes and the Patagonian steppes, it dominates its surroundings, and it can be seen for large distances from the east, yet is easily accessible for tourists. The Cordillera del Paine also stands at the

The Cordillera del Paine, from the southern gate of the Torres del Paine National Park; the large white granite intrusion is clearly seen in the mountains.

Olivier Galland, Géoroute

gate of the Southern Patagonian ice field, the third largest ice cap in the world.

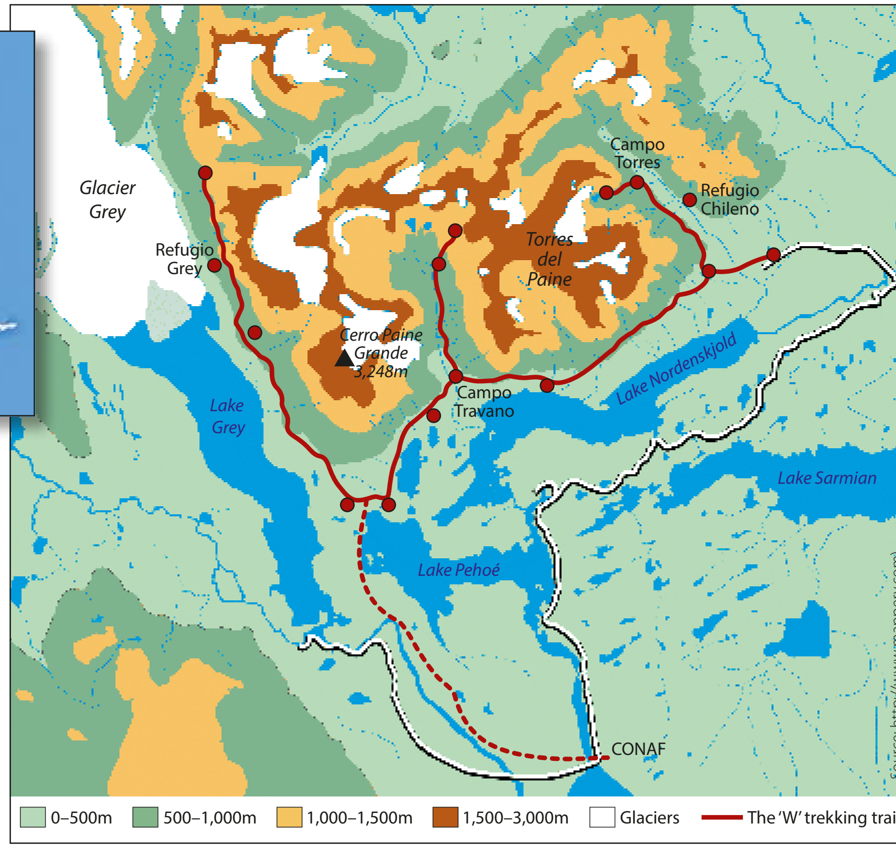
Archaeological remnants show that this remote 'end of the world' region was permanently inhabited by indigenous tribes as far back as the sixth millennium BC, although Europeans only explored the Cordillera del Paine for the first time in the 1870s. Since then, German and British colonists have occupied the surroundings, founding large sheep and cattle farms. Because of the rough climatic conditions, this farming considerably impacted the fragile, wild ecosystems of the area.

The Chilean government became increasingly aware of the unique value of this wildness and created the Torres del Paine National Park in 1959. It was designated a World Reserve of Biosphere by UNESCO in 1978. The Park's wilderness and breath-taking scenery attract growing numbers of tourists from all over the world: in 2010, almost 150,000 visitors enjoyed the marvels of the park, with tourism becoming the mainstay of the economy of Puerto Natales and the entire region.

Detailed view of the Cuernos del Paine. Note the 'frozen' sinking dark blocks of Cretaceous sediments from the upper contact of the laccolith (white) on the lower right peak.

Geology: Sea, Magma and Ice

The Cordillera del Paine is dissected into several mountain groups. The westernmost Paine Grande is the highest of the range at 2,884m. The most prominent peaks are those of the Cuernos del Paine (Paine's horns), which are separated from the Paine Grande by the deep glacial Vallé Francés. Nestling in the heart of the range, the gigantic natural cathedrals of the Torres del Paine are the most famous highlight of the massif.



Map of the Cordillera del Paine and the 'W' trekking itinerary.

As mentioned, the most striking feature is the two-toned colouration of the mountains. A prominent white band is sandwiched between dark rocks, the contact between them being extremely sharp, as though cut with a knife. The dark rocks are Cretaceous turbidites and layered sandstones with local occurrence of conglomerates, deposited in the Magallanes Basin. The white rocks are the result of a widespread (10 km by 20 km, up to 2,000m thick) magmatic intrusion emplaced during the Upper Miocene (12.5 Ma). Although the intrusion looks homogeneous, it consists of a suite of igneous materials resulting from successive magmatic pulses of mafic to felsic composition. The dominant magma body is a granite laccolith (a sub-horizontal intrusion with uplifted overburden). The Torres del Paine intrusion is one of a suite of granite intrusions in Patagonia, the most famous of which is the dramatic Fitz Roy-Cerro Torre Peaks, a few hundred kilometres to the north on the Argentine side.

The laccolith is clearly visible at the Cuernos del Paine, where both the bottom (lower contact) and roof (upper contact) of the laccolith are perfectly exposed. In the cliffs here the visitors can even observe some 'frozen' falling dark blocks of the laccolith's roof embedded in the white granite. The thickness of the laccolith means that the sedimentary host rock has been heated and metamorphosed, so that primary sedimentary layering is no longer visible in the vicinity of the intrusion.

However, these amazing geological features would have never been exposed without the combined contributions of Andean tectonics and glacial erosion. Originally deposited at the bottom of the sea, the sediments now crown nearly 3,000m-high peaks, the associated uplift being the result of the Andean orogeny. Evidence of the orogeny are prominent in the landscape, including stunning folds and faults. Finally, glacial erosion carved the deep valleys that dissect the Paine laccolith during the last glaciations. The retreat of the glaciers offered us this unique and wonderful heritage. In 2014, the current glacier retreat even uncovered a world-class dinosaur graveyard contained in the Cretaceous sediments, including 46 specimens of nearly complete skeletons of icthyosaurus.

A prominent syncline (we called it the Geo-Smiley!) on the southern shore of the spectacularly turquoise Lake Nordenskjöld.

The Trek: 'W' Versus 'O'

There are two main trekking options at Torres del Paine. The first and most popular is the four-day so-called 'W' itinerary, restricted to the southern flank of the range. The itinerary explores three valleys, each of them being one branch of a 'W', as seen on the map (left). The 'W' is usually crowded with tourists from all over the world. The other alternative, less popular but much wilder and more remote, is the six-to-ten-day so-called 'O' circuit, which extends the 'W' and makes the full loop around the Cordillera del Paine.

The 'W' trek starts from the administration huts of CONAF, the National Forest Corporation, which manages all Chilean national parks. The first day leads to the western branch of the 'W' along Lake Grey, and ends up at the Refugio Grey, facing the fabulous Glacier Grey. This retreating glacier is one of large glacial tongues flowing down the Southern Patagonian ice field. Blocks of ice constantly collapse from this impressive glacier into the grey-coloured lake, and the resulting icebergs are pushed away by the ferocious Patagonian winds and punctuate the surface of the lake.

The second day of the hike brought us to the gate of the Vallé Francés, the central branch of the 'W'. The track follows the shore of the deep blue Lake Pehoé, at the very foot of the Cerro Paine Grande. From the campground 'Campo Italiano', the view of the laccolith is stunning. An almost 1 km-high white granitic cliff dominates the campground, and the contacts with the dark sedimentary host rock are spectacular.

The track of the third day follows the shores of the astonishingly turquoise Lake Nordenskjöld. The extreme winds often lift up misty spray from the wavy surface of the waters. On the southern shore of the lake, a beautiful syncline smiles to the trekkers; whether it encourages them or makes fun of them depends on their physical condition! The hiking day ends along the eastern branch of the 'W', either at the Refugio Chileno or higher in Campo Torres.

The fourth day starts in the early morning darkness, to access the foot of the Towers at dawn. If you are lucky enough to wake to clear skies, the early rising sun lights up the towers, creating an unforgettable scene of the three gigantic natural cathedrals glowing red in the sunlight.

A Dream Destination?

'In southern Patagonia, there are no poisonous snakes, spiders, or dangerous predators… but there is wind!' This is an excellent summary provided by the owner of the Erratic Rock hostel at Puerto Natales. For the locals, a 100-km/h wind is just a standard breeze, so the winds can make trekking quite an adventure. Imagine an engine roaring nearby for a whole day: this is what we experienced for days in this part of the world. Several times during our trek, the ferocious Patagonian winds pushed us over. On our last morning, a sudden gust blew our breakfast all over the surrounding countryside!

Obviously, such conditions discourage the practice of unconventional outdoor activities. At Refugio Grey, we met a self-called 'professional air-diver', or base-jumper, who was researching the possibility of base-jumping the Paine's Towers.

Overview of Cordillera del Paine from the shore of Lake Pehoé.

When we asked about the result of his investigations, he instantaneously concluded: 'Are you crazy? I don't want to die!'

Obviously, the winds had a considerable impact on our cycling too: if the head wind did not kick us out of the road, we sometime managed to cycle at 4 km/h on a perfectly flat, tarred road! But conversely, we had to brake when tail winds pushed the bikes to 50 km/h; and incredibly we climbed uphill slopes freewheeling at 15 km/h.

Importantly, the Patagonian winds considerably enhance fire hazards. The Torres del Paine National Park unfortunately experienced several dramatic fires in 1985, 2005 and 2011–12 induced by careless tourists. The 2011–12 fire destroyed about 176 km^2 of the reserve, including 36 km^2 of native forest, and the park was closed for over a month. The economic consequences for the region were enormous. These dramatic events show that the protection of such a wonderful geological marvel is a collective responsibility.

Acknowledgments
The Andean Geotrail project was endorsed by the International Year of Planet Earth. The authors acknowledge financial support from the Guilde Européenne du Raid, the Conseil Régional Rhônes Alpes, the Conseil Municipal de Bourg-en-Bresse, the French Ministère de la Jeunesse et des Sports, and material support from Decathlon and Physics of Geological Processes. ■

The Andean Geotrail

The authors are earth scientists at the University of Oslo. The photographs in this article were shot during the Andean Geotrail project, a nine-month cycling expedition along the Andean Cordillera, from the southernmost city of Ushuaia, Argentina, to Lima, Peru. The 10,000-km expedition was the foundation of an outreach project, the aim of which was to promote earth sciences through a human adventure in a spectacular geological environment. The authors visited more than 30 remarkable geological localities along the itinerary to highlight the aesthetic and useful aspects of earth sciences. Torres del Paine National Park was one of the main highlights of the expedition.

More information on http://www.georouteandine.fr/English

Right: Map of the itinerary of the nine-month journey of the Andean Geotrail, listing the geological localities visited and described during the project.

Below: The authors on the Salar de Uyuni, Bolivia.

Turkey
A Key Transit State in Crisis

Turkey is slipping into authoritarianism and conflict. How stable is the West's key ally and oil supply route?

NIKKI JONES

Everything appeared to be going so well. In power since his landslide victory in 2002, Recep Tayyip Erdoğan has overseen a political and economic transformation. Military coups and unstable coalitions have been relegated to the past and there has been relative harmony as the government has engaged in a nine-year peace process with Kurdish insurgents, the PKK.

Living standards have improved from a low base as GDP growth has fluctuated around a healthy three per cent. Rapid industrialisation has been accompanied by a construction boom that has transformed most cities.

Energy Transit

Acting as an energy transit route for the West has been a significant part of Turkey's economic and strategic policy. Turkey has always controlled the Bosphorus choke point, which now carries almost 3 MMbopd, but over the last ten years it has developed its transit status further with a network of pipelines. Most critical are the Kirkuk-Ceyhan and Baku-Tiblisi-Ceyhan (BTC) pipelines that bring Caspian and Iraqi oil to the world's shipping lanes: they allow Turkey to earn substantial transit fees and have brought growth and revenues to state-owned companies TPAO and BOTAS.

In 2006 the South Caucasus gas pipeline (SCP) was opened, bringing Shah Deniz gas to both Turkey and Georgia. There have been protracted negotiations to extend the SCP to Turkey's western border, to secure direct transit through Turkey to Eastern and Central Europe. A technical feasibility study for the Trans Anatolian Gas Pipeline (TANAP) was concluded in 2012 and the project is expected to be complete by 2019. Agreement on the pipeline has been cemented by the EU putting its weight behind the Trans Adriatic Pipeline (TAP) which

The crowded Bosphorus carries almost 3 MMbopd between Europe and Asia.

will link with TANAP, taking gas from the Dardanelles through Greece and Albania, and under-sea to Italy.

Thus Turkey has become a key component in Europe's energy strategy – offering the possibility of reduced dependence on Russian gas (approximately 30% of all European consumption and almost 100% in Eastern Europe), or at the very least increasing countries' bargaining power vis-à-vis Gazprom. Events in Ukraine have helped focus Western leaders on this objective.

Increasingly Putin-like

But it appears to be all going wrong. Since 2008 Erdoğan has been showing alarming Putin-like authoritarianism. In 2005 the West turned a blind eye to a new law making it a criminal offence to insult the Turkish nation, but in recent years it has become impossible to ignore the increased attempts to stifle free speech, including moves to outlaw YouTube and Twitter. The protests at Gezi Park in 2013 focused the world's attention on Erdoğan's heavy-handed repression of dissent and in December 2014, there were raids of newspaper offices and high-profile detentions.

The public criticisms of Erdoğan have been fuelled by his attempts to manipulate the constitution in order to move from the role of Prime Minister to an enhanced Presidential role, the dropping of corruption charges against close ministers and their children, and the building of a $615m 1,000-roomed palace – plus a planned 250-roomed presidential suite.

At heart there lies an internal battle between Erdoğan and his former close confidant, Abdullah Gül, who in turn is supported by the 'civil Islam' group led by exiled Fetullah Gülen. Having jointly seen off the final military challenge in 2007, the divisions between the two Islamic traditions have emerged. In very general terms, the Gülenists are a centrist social movement, pro EU membership, economic modernisation and freedom of religion, opposed to active involvement in politics and particularly opposed to Iranian-style theocracy. Gülenist political activity is largely passive support for moderate opposition parties. However, with their focus on schools, media and business, Erdoğan now sees a 'parallel state' that threatens his overthrow.

In contrast, Erdoğan is becoming increasingly Islamist and anti-West. State-run religious schools have increased in number to almost a million, and Erdoğan has called for the re-introduction of the Ottoman script, a direct challenge to the legacy of the state's founder, Atatürk. He has called for women to return to traditional roles and have at least four children, for abortion to be outlawed and for the death penalty to be re-introduced. Erdoğan has recently stated that Muslims discovered America before Christians. He is widely seen as authoritarian, arrogant, and increasingly inept.

A Reliable Ally?

Given Europe's dependence on Turkey as a transit route and key ally, Western leaders must be wondering whether they are in bed with another Putin. Although not an expansionist state, Turkey's stability and reliable-supplier status are in question.

The critical division with the West – and with Turkey's own Kurdish population – is the war with ISIL in northern Iraq and Syria. Erdoğan's reluctance to get involved has led to a widespread perception that Turkey is prepared to see Kurds massacred – Turkish troops at first stayed passive while ISIL surrounded the Syrian border town of Kobani, within sight of the Turkish border, and the passage of Iraqi Kurdish fighters through Turkish territory was initially refused. This led to widespread demonstrations last October that left 31 people dead.

Similarly, the West has accused Erdoğan of doing nothing to stop the flow of jihadists crossing the Turkish border to join ISIL, many of them coming from Europe. The government has responded with strong criticism of

European states.

For Erdoğan, ISIL dominates the anti-Assad forces and therefore is a potential ally in the bid to bring down Syria's president, Turkey's number one enemy. The last thing Erdoğan wants to see is a Syrian Kurdish autonomous zone, similar to that in northern Iraq, which will only exacerbate Turkish Kurds' demands for similar status. Arming the Syrian Kurds' militia, the PYD, will effectively re-arm Turkey's PKK, according to Erdoğan. He is reported to have made highly inflammatory statements that there is no difference between the PKK and ISIL.

Turkey argues that the West and Middle Eastern countries' concern for Syria should be translated into more support for the 1.6m refugees that Turkey has been forced to absorb, largely unaided.

The big question for the West is where this leaves the peace process and how restive the Kurdish population (15–25% of Turkey's 75 million) will be. Abdullah Öcalan, their leader imprisoned on an island in the Straits of Marmara since 1999, has called for calm. Indeed, to a Western observer, the demands for civil and language rights and a confederalist constitution (not separatism) have always appeared moderate – even if PKK violence has not. It is noteworthy that the Gülenists have always opposed the peace process, preferring a unitary state.

New Project with Russia

Adding to the confusion in the relationship between the West and Turkey, a new complication arose late 2014. In December, Erdoğan and Putin jointly announced that Blue Stream, which has brought Russian gas across the Black Sea to Ankara since 2003, is to be extended to a planned new distribution hub at the Greek border. If it goes ahead, Blue Stream will bring an extra 1.73 Tcf of Russian gas to Europe annually, plus another 494 Bcfg specifically for Turkey – all bypassing Ukraine.

Since Europe has, for political reasons, recently scuppered Russia's plans for a direct pipeline to Bulgaria, known as South Stream, it is unclear why it should look favourably on a route that achieves the same goal but now includes Turkey as a transit state. It is possible that Blue Stream's extension will bring Turkey into direct conflict with the EU; moreover, the prospect of a closer relationship between Putin and Erdoğan will be sounding alarm bells in Brussels and Washington.

Erdoğan, Vladimir Putin and Silvio Berlusconi at the opening of the Blue Stream gas pipeline in November 2005. In December last year Erdoğan and Putin announced a further extension of the planned pipeline, bringing Russian gas to Europe via Turkey.

The Future

Having pursued a successful 'good neighbour' foreign policy in its early years, Turkey now appears to be at logger-heads with most of its neighbours. Despite Erdoğan's willingness to do deals with Putin, they remain divided over Syria, the treatment of Crimean Tatars and Russia's support for Greek Cyprus (where most of Russia's wealthy bank). Iraq, Syria and Egypt are in turmoil; relations with Israel were downgraded in 2010 following the massacre of Turks on a Gazan food convoy; and Europe has strongly criticised Turkey's 2014 surveys of Cypriot waters as both illegal and provocative.

At home, Erdoğan appears increasingly embattled, and peace with the Kurdish population appears to have become a more distant prospect. The economic miracle has slowed and the IMF is warning that $200bn of investment is needed to sustain current levels.

Critically for the West, Turkey's role as a transit state could be at risk. In the past, the PKK has targeted pipelines, frequently the Kirkuk-Ceyhan line and possibly BTC in 2008, when over 30,000 barrels were spilled and a fire burned for a week.

2015 is likely to be an uncomfortable year for Turkey, particularly since it is the centenary of the controversial Armenian 'genocide', an anniversary that is likely to stir up more animosity with neighbours and allies. Tensions run deep within Turkish society across many fault-lines. With an educated and generally West-looking majority, Turkey will remain an ally – but it looks like a rocky road ahead. ■

Syrian refugees in Suruc, Turkey. Only 200,000 Syrians are being accommodated in camps; Turkey has had to absorb 1.4 million into its cities with little help from the Middle East or Europe.

River of Oil

Early Oil Exploration in Iraq

Knowledgeable but squabbling geologists; summary dismissals; camel transport; 'lagoonal' oil; and 40m-high gushers. All in a day's work for the first oil explorers in Iraq.

MICHAEL QUENTIN MORTON

In 1925, the science of petroleum geology was still evolving, the geology of the Middle East was yet to be unravelled and great oil discoveries lay in the future. The only maps of Iraq available were those drawn by Edwin Pascoe and others of the Indian Geological Survey on their reconnaissances. And yet there were some intriguing clues to the presence of oil: folds that might contain oil traps, an abundance of seepages, an oilfield at Naft Khaneh and primitive wells at Qaiyara.

The Turkish Petroleum Company (TPC), the forerunner of the Iraq Petroleum Company (see 'Once Upon a Red Line', *GEO ExPro* iPad edition, June 2013), had obtained an oil concession for Iraq and now geologists from its multinational shareholders arrived to conduct a full geological survey, including those from US oil companies that were expected to join TPC in due course. With 18 experienced members, the survey party certainly lacked little in the way of geological experience and knowledge of other parts of the world.

Indeed, T.F. 'Jock' Williamson, a British geologist seconded to the survey from the Anglo-Persian Oil Company (APOC), thought that, between them, the geologists must have visited most of the countries of the world. He described those who gathered together in the autumn of 1925 in these terms:

"One man was at the head waters of the River Amazon among the head shrinkers when he was recalled to come to Iraq; another came from Argentina, another from Mexico, still another had been in Romania, one in Indo-China, several in Venezuela and the East Indies."

Unravelling Iraq

In the autumn of 1925, they all met up at Fathah on the River Tigris, about halfway between Baghdad and Mosul. It was an unprepossessing place, reminiscent of World War I. Trenches and gun emplacements – the last vestiges of a doomed Turkish defence – still scarred the hills and banks of the river. Here the geology was clearly visible, and the low level of the water in the Tigris revealed many oil seepages on the riverbed.

The geologists travelled in vehicles packed with provisions and equipment and used fly camps for surveys across northern Iraq. In rocky terrain, they rode on camels, horses and mules. They covered between 30,000 and 40,000 kilometres during the first eight months of the survey, ranging from the borders of Persia to Kurdistan and as far west as Rutbah.

During World War I, German and Turkish engineers extracted up to 10,000 gallons (about 240 barrels) of oil a day from Qaiyara, where primitive bitumen wells operated.

Library of Congress

From the start, there were worrying signs that all might not be well with the survey party. The APOC geologists followed a particular theory known as the 'lagoonal theory of oil' propounded by Professor Hugo de Böckh, a Hungarian geologist who was a geological adviser to APOC. The Arabian Peninsula was considered a poor oil prospect since there was no evidence of 'lagoonal' rock structures on that side of the Persian Gulf, and Iraq was the subject of his stringent views.

An experienced Alpine geologist, with an enthusiasm that could be infectious, de Böckh was well respected by his younger subordinates and certainly possessed the necessary intellectual ability to lead the survey. Yet he was also overpowering and determined in his views. In adhering to the lagoonal theory – that large quantities of oil might exist in certain rock formations derived from ancient lagoons – he risked alienating the other geologists on the survey. Concerns soon began to grow among the senior geologists, who were unhappy that de Böckh's approach was too rigid for the project at hand. In their view, it required a more open debate between them, but this was not permitted.

Map of northern Iraq showing the principal places mentioned in the text.

Hammers at Dawn

It fell to geologists Arthur Noble and Eugene W. Shaw to take up their differences with de Böckh. Noble had been seconded from Shell while Shaw led the American contingent. One bone of contention was the fact that de Böckh had arranged for APOC geologists to lead the various field parties. This was particularly disturbing for the older geologists because the Anglo-Persian geologists tended to lack their wider experience in the field. In the event, de Böckh himself managed the senior geologists, with the exception of Noble and Shaw who were allowed to survey Kirkuk and its surroundings.

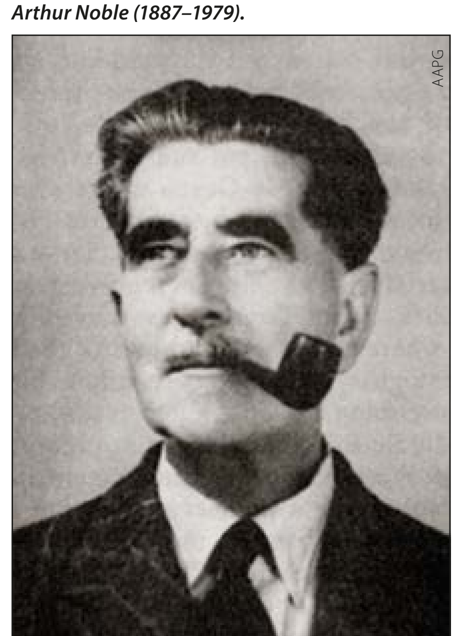
In less formal settings, the field parties enjoyed lively debates. A transport manager recounted how the geologists would discuss geology at the camp dinner table each night – before, during and after the meal. "Being the only layman of the party it was all double-dutch to me," he admitted. On one occasion, when there was a particularly heated debate, one of the geologists turned to him in the hope that he might break the tension. He plunged in, using all the geological terms he could muster, in a random order, and soon had them in stitches. But not for long – within five minutes, the geologists were back to arguing as furiously as ever.

Away from these moments, several concerns gnawed away at Shaw's conscience: the mapping of the terrain, the planning of the expedition and the placing of a senior geologist in a subordinate position. Although incidental to the main survey,

T.F. ('Jock') Williamson, one of the geologists on the 1925–6 survey of Iraq. He went on to take part in expeditions across the Middle East, including Oman and the Persian Gulf region.

Hugo de Böckh in Persia, November 1924.

Arthur Noble (1887–1979).



Pulkhana, No. 1 well, Iraq; official opening by King Faisal, 5 April 1927.

these issues were the symptoms of a deeper malaise. Shaw and Noble approached de Böckh about them, but they met the full force of his obduracy. De Böckh would not accept their advice or views on any subject, and they were left very disappointed. After the meeting, they wrote to TPC management in London and secured changes to the leadership of the field parties, but there was a price to pay. When they returned they found themselves banished to a vast area west of the Euphrates – the geologist's equivalent of being sent to the Eastern Front.

Finally, when it came to selecting sites for drilling, they found that de Böckh had already reached his own conclusions about the location of the oil reservoir and was not willing to discuss the matter further, rating Kirkuk only as a second rate prospect. To add insult to injury, Noble and Shaw were dismissed. It was only after a senior member of the TPC board intervened that peace was restored.

A Near Disaster

With hindsight, the drilling programme agreed by the TPC board was not ideal. The objective was to reach the main limestone underlying a rock formation known as the Lower Fars and with this in mind a number of wells were spudded in during the spring of 1927: Pulkhana, Injana and Khashm al-Ahmar. But it was the well at Baba Gurgur, near the oil and gas seepages known as the 'Eternal Fires', that would prove to be the most challenging of all.

Baba Gurgur No.1 produced oil shows at comparatively shallow depths in the Lower Fars but, since the well was only a short distance from the famous seepages, this was not entirely unexpected. Drilling continued at a slow rate, about 6m per day. Staff at field headquarters in Tuz Khurmatu settled down to a routine of daily reports and a dry, dusty summer. But on 23 September, the chief geologist of the company, Louis ('Chick') Fowle, suddenly realised that Baba Gurgur was making rapid progress – contrary to expectation, the drill bit had penetrated the main limestone at a depth of 463m. As the drillers had only cased the well to a depth of 180m, it was necessary to suspend the drilling and cement the remaining 330m of 'open' hole. While the cement was drying, the crew changed from rotary to percussion drilling.

On 14 October at 3 a.m., gas and oil suddenly erupted from the well, rising to a height of over 40m. Ever since the days of Spindletop, the first strike had been every driller's dream. In 1901, when American prospectors had penetrated the Spindletop oilfield in Texas, crude oil spurted to the surface and gushed out of the top of the derrick like a fountain, drenching men, equipment and the landscape in a thick black treacle. It was an image imprinted on every oilman's mind; and now, at Baba Gurgur, they had found a new icon.

In Kirkuk, townspeople gathered to watch: "The roof-tops of houses were packed with women and children gazing in the direction of Baba where a black cloud hung like an upturned umbrella," observed one eyewitness. "Most of the men rushed to the scene on foot and in horse-drawn carriages to get a better view." It was a miracle that, with all that oil and gas in the air, nothing ignited.

But this was a disaster in the making. A river of oil was now flowing westwards along a wadi, winding for miles through the deserted countryside. The company drafted in some 2,000 men to build dams lower down the wadi to contain the deluge.

Louis Fowle with Kurdish guards at Chemchemal in 1927.

Workers tried to approach the rig to block the gusher, but it was only when the company brought in an aero engine to blow the oily clouds away from one side of the derrick that they could stop the flow. By then over 95,000 barrels of oil a day had spilled out into the desert.

The famous gusher at Baba Gurgur with a river of oil in the foreground.

Kirkuk Revealed

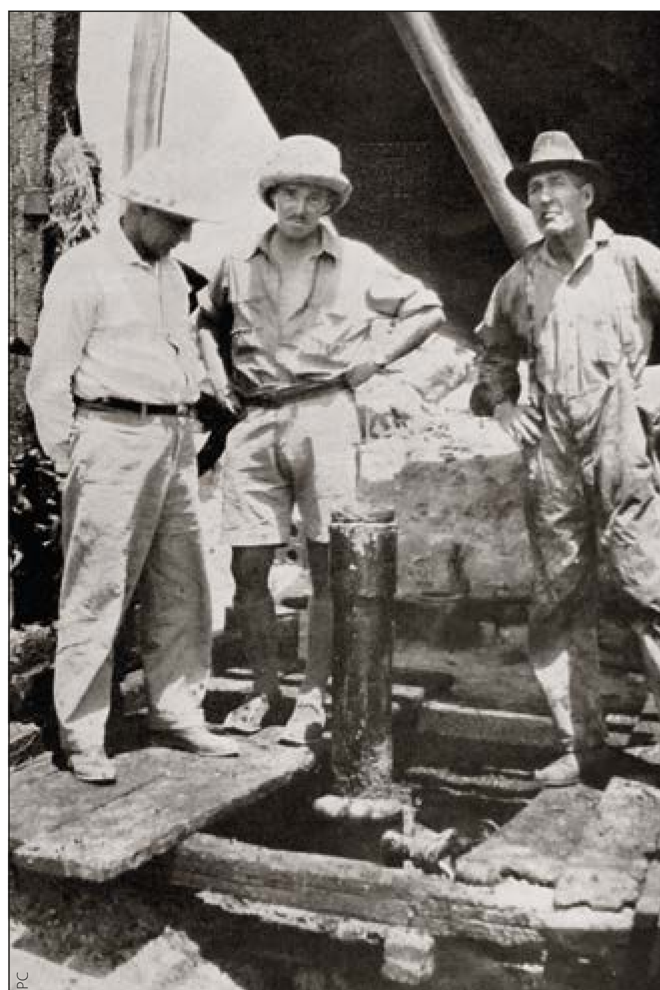
Some 30km along the Kirkuk structure, Tarjil No. 1 was a deeper well that encountered the oil-bearing rock at 760m compared with only 300m at Baba Gurgur. When this well encountered technical problems, Louis Fowle advised letting it stand for a while. The drillers, anxious to drill a certain amount of 'footage' each day, were unwilling to suspend operations. A new well site was located and, with a view to moving the derrick there, the drillers plugged the first well with mud and began dismantling the equipment.

Fowle disagreed, however. After intense discussion, he persuaded them to restore the original well and clean out the mud. "This took some weeks," wrote Fowle, "meanwhile unpopularity had to be endured." A subsequent oil strike vindicated his decision and, by the end of 1929, the geologists could say with confidence that there was a continuous oilfield some 50 kilometres in length stretching from Tarjil to the Lesser Zab.

This was also a time for innovation. Drilling was a lengthy process, and there was great pressure on the company to obtain data about underground conditions quickly. In the late summer of 1928, a party of eleven German geophysicists from Messrs Siesmos Gmbh arrived to undertake a series of seismic surveys. They used the relatively new technique of refraction whereby they detonated large charges of explosive and recorded the ensuing sound waves to compile a subsurface 'map'. The procedure caused great alarm among the townspeople of Kirkuk when they first heard the explosions and, in the event, the surveys produced mixed results.

Within three years of the drama at Baba Gurgur, the outline of the Kirkuk oilfield was established, but a new question loomed: what to do with all this oil? The next stage, the construction of an oil pipeline to the Mediterranean coast, would prove a mighty task. ■

A tool pusher, geologist and driller around a small flow of high grade oil from a shallow well at Kor Mor in 1928.

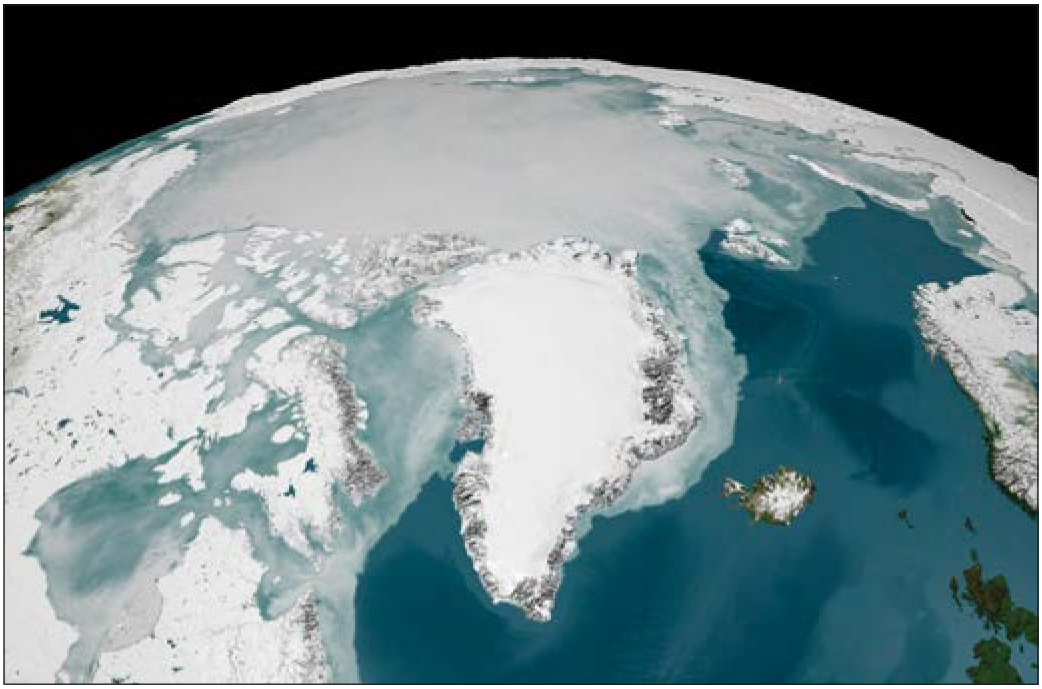


An IPC party surveying the route for the Mediterranean pipeline, 1931.

Gas Hydrates

PART VI: Hydrates in the Arctic

MARTIN LANDRØ, NTNU Trondheim
JÜRGEN MIENERT, UIT
LASSE AMUNDSEN, Statoil



'You can know the name of a bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird... So let's look at the bird and see what it's doing – that's what counts.'

Richard P. Feynman, Nobel prize laureate in physics, 1965.

Methane hydrate is formed in abundance in deep permafrost and shallow offshore regions, but little documentation exists regarding resource accumulations in Arctic areas and its evolution through time and space. Today's sub-seabed methane hydrate reservoirs remain elusive targets for both unconventional energy and as a natural methane emitter influencing ocean environments and ecosystems.

CAGE Specialist Community

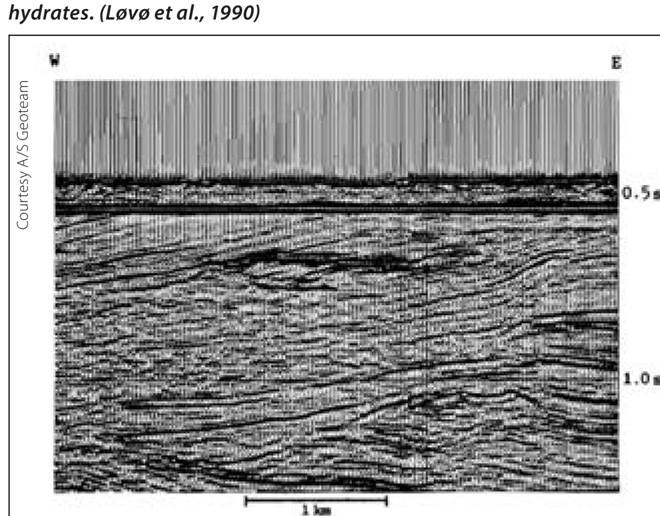
At the world's northernmost university, in Tromsø, Norway, the establishment in 2013 of a Centre of Excellence – called the Centre of Arctic Gas Hydrate, Environment and Climate (CAGE) – signalled the start of one of the world's foremost specialist communities in basic research on gas hydrate. It is funded by the Norwegian Research Council over a period of ten years.

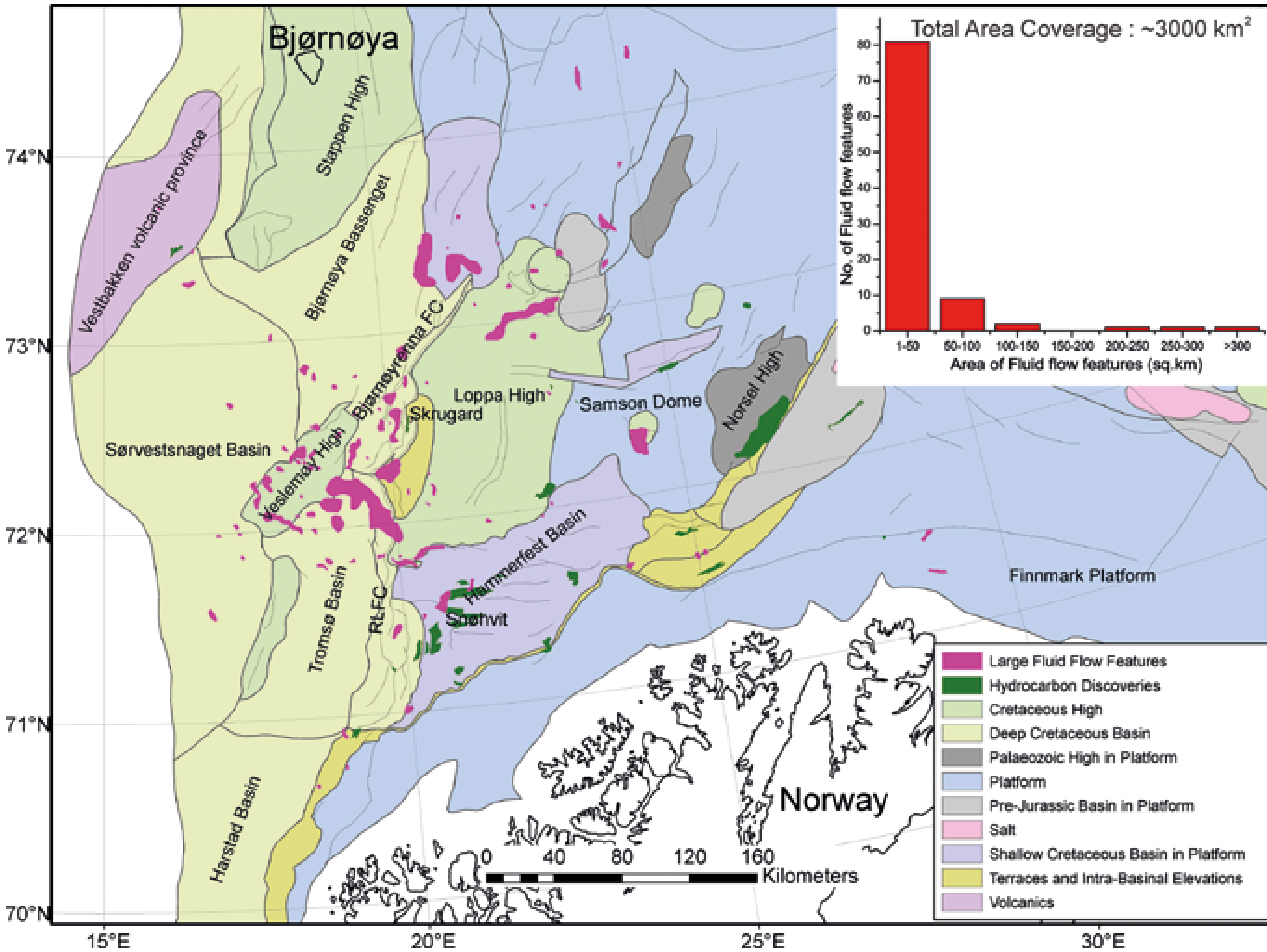
CAGE, headed by Professor Jürgen Mienert, focuses on issues related to energy resources in the Arctic and the role of Arctic gas hydrate reservoirs in the future marine environment and global climate system. The acronym CAGE obviously has a double meaning since gas hydrate contains methane trapped inside a rigid 'cage' of frozen water molecules, kept stable only by sub-seabed high pressure and low temperatures.

CAGE will be carrying out fundamental research on gas hydrates by bringing together geologists, geophysicists, geochemists, micropaleontologists, biologists, oceanographers and experts in statistical modelling, collaborating with researchers from a variety of countries, including Canada, Russia and the USA. Together with the Canadian and US researchers, the centre is taking the initiative in conducting experimental drilling for methane in the Arctic.

The scientists in Tromsø have focused on shallow overburden in the Norwegian Arctic areas, and performed detailed mapping of fluid-flow systems. A major part of these shallow hydrocarbons is probably gas hydrate. The research group has discovered that a significant portion of the

Seismic showing an anomalous reflector at 0.67s TWT interpreted as gas hydrates. (Løvø et al., 1990)





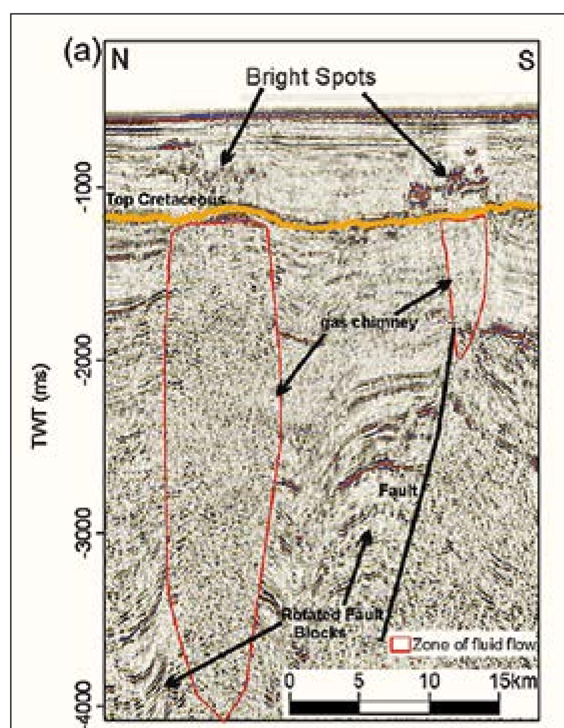
Distribution of large fluid flow features in the Barents Sea, some up to 600 km^2. A plot of the area covered by these large features shows 81% of them are between 1 km^2 and 50 km^2. From Vadakkepuliyambatta et al., 2013, Marine and Petroleum Geology, 43, 208-221.

hydrocarbons generated in deep source rocks has leaked or migrated into the shallow subsurface, and is now trapped in gas hydrate and shallow gas reservoirs. The widespread distribution of these shallow accumulations was not previously recognised. In addition, the complex nature of these deposits and their mechanism of formation were not known.

Mapping Shallow Fluid-Flow

The Barents Sea is named after Willem Barents (1555–97), a Dutch explorer and navigator who discovered Bjørnøya and Spitsbergen when searching for the Northeast Passage to Asia. It extends from 70°N (equivalent to the northern coast of Alaska) to 82°N, covering an area of 1.2 million km^2, more than twice the size of the entire Gulf of Mexico. It is bounded by the Scandinavian peninsula to the south, the Svalbard archipelago to the west, and Frans Josef Land and Navaya Zemlya to the east.

The average water depth of the Barents Sea is 230m, significantly deeper than most of the present day high Arctic shallow (10–100m) shelves outside North America and Russia. To the west and the



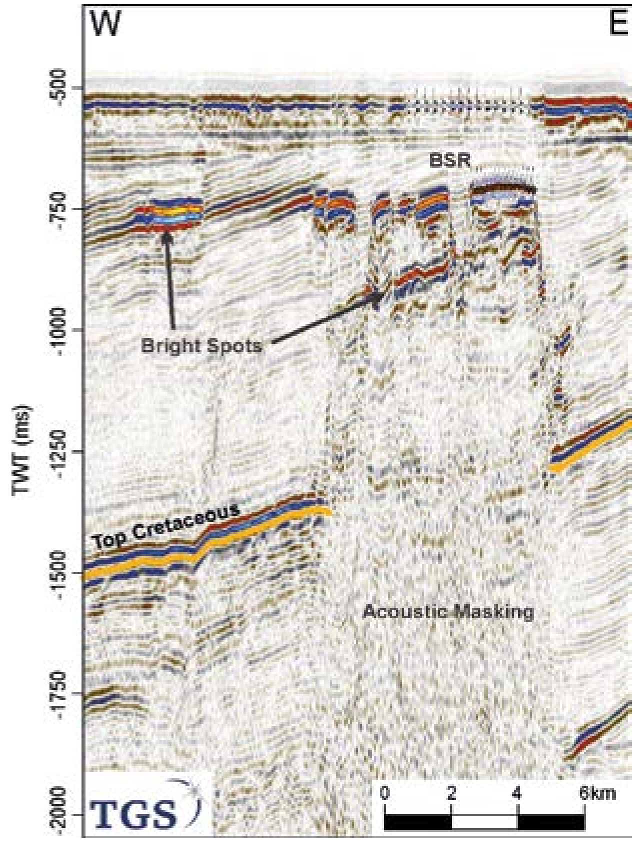
Typical fluid-flow system seen on seismic. Gas chimneys (chaotic areas with no coherent seismic signals within red polygons in the seismic) indicate the fluid flow path (migration), and the corresponding bright spots above indicate the top of the gas accumulation. The small chimney sits on top of or close to a major fault, suggesting a link between the fault and the leakage of fluids.
From Vadakkepuliyambatta et al., 2013, Marine and Petroleum Geology, 43, 208-221.

north, when entering the North Atlantic Ocean and the Arctic Ocean floored by oceanic crust, water depths increase rapidly to more than 1,000m. The Barents Sea is influenced by two different types of water masses: Atlantic water (T>0°C) and Arctic water (T<-1°C). In the northern Barents Sea, the flow of cold Arctic water maintains the seabed below 0°C in areas where the water depth is shallower than 200m. Below 200m, positive (+1 to +4°C) sea floor temperatures are widely distributed due to the influx of Atlantic water.

Gas hydrates of the southern Barents Sea were first inferred by a detailed geological study by Løvø and co-workers in 1990. They found that methane hydrate was stable in areas with water depths exceeding approximately 280m where the water bottom temperature was 1°C, finding that the zone of stability in such a case extends to a depth of approximately 400m. By interpreting seismic lines from different areas in the Barents Sea where anomalous reflectors had been observed, they mapped several anomalies probably caused by gas hydrates (Løvø et al., 1990; Laberg and Andreassen, 1996). The anomalous reflectors cut across other reflecting horizons and paralleled the seabed, fulfilling the requirements of a bottom simulating reflector (BSR).

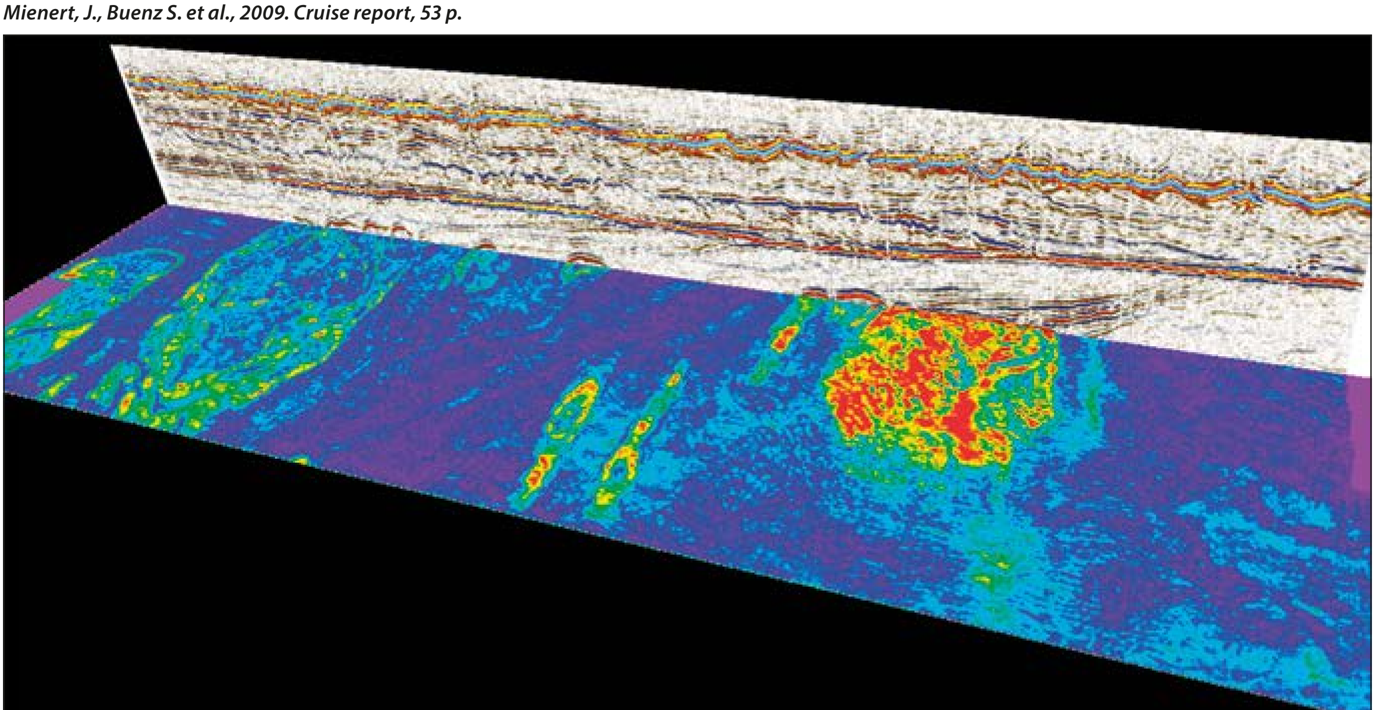
In the south-western part of the Barents Sea, a significant volume of hydrocarbons is believed to have migrated upward from deeper portions of the basin into the shallow subsurface, where it is now trapped in gas hydrate and free gas reservoirs. The figure on the right shows shallow fluid-flow systems in this area. The extents of such anomalies vary from 1 to 600 km^2 (Vadakkepuliyambatta et al., 2013), and might therefore represent a considerable quantity of hydrocarbons, although not of direct commercial interest.

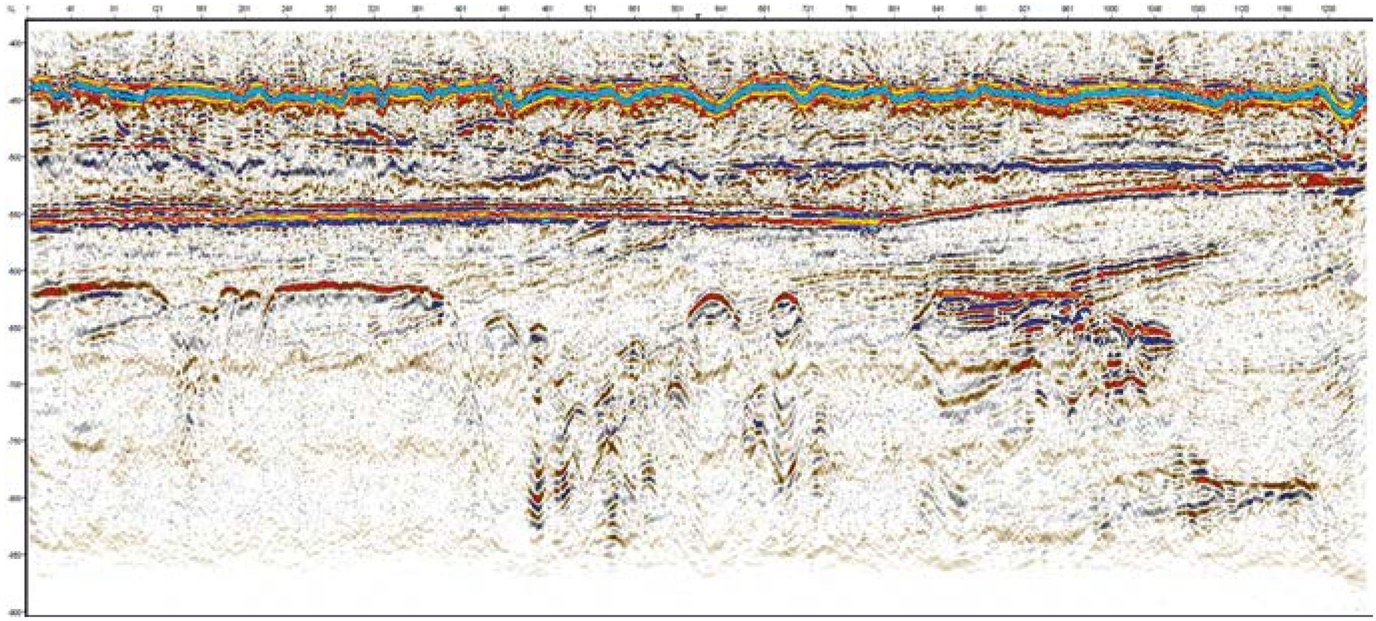
CAGE scientists find a strong correlation between these shallow fluid-flow systems and deep-seated faults, suggesting that extensional tectonics, uplift and glaciations are closely linked to fluid leakage.



Crosscutting high-amplitude reflectors associated with the gas chimney from the Bjørnøyrenna Fault Complex. A large area of masked acoustic reflections and polarity reversed high-amplitude anomalies show fluid flow and gas accumulation. The patchy, crosscutting high-amplitude reflector mimics the seafloor and is interpreted as the base of the gas hydrate stability zone. From Vadakkepuliyambatta et al., 2013, Marine and Petroleum Geology, 43, 208-221.

RMS amplitude time slice showing high amplitude anomalies, indicating the accumulation of free gas at the base of the gas hydrate stability zone (BHSZ). P-Cable 3D seismic cube from the SW Barents Sea (length ~ 9 km, width ~ 4 km, water depth ~340m, BSHSZ at ~300ms beneath seabed). Mienert, J., Buenz S. et al., 2009. Cruise report, 53 p.





3D seismic example of interrupted BSRs and acoustic anomalies at ~620 ms TWT.

Fault reactivation and glaciotectonics during Late Cenozoic time likely have led to the depletion of deep-seated hydrocarbon reservoirs and upward migration of hydrocarbon gases through gas chimneys (Henriksen et al., 2011; Vadakkepuliyambatta et al., 2013).

Interpretation of Gas Hydrates

Interpretation and especially quantification of gas hydrates is more challenging than detection of gas, since geophysicists have to rely on indirect methods such as the BSR to identify the hydrate zone or on detailed velocity information and rock physics modelling. An example from the Barents Sea is shown on page 66, where the BSR is not an easily interpreted continuous event, but a discontinuous feature that brightens and dims along the horizon. Despite this, the interpretation is that the gas hydrate is situated above this level, probably all the way to the seabed, an interpretation strengthened by the hydrate stability and temperature curves representing typical conditions for the Barents Sea. Below the BSR there is gas, and the presence of this gas is the major cause for the brightening observed on the seismic. The dim spots along the interpreted BSR event are often connected to pockmark-type depressions on the seabed; from 2D seismic data it is hard to tell whether these are pockmarks or, for instance, iceberg plough marks. However, a likely assumption is that some gas has migrated through the hydrate area and into the water layer, causing the discontinuous appearance of the BSR.

In order to map and understand the complex nature of shallow gas accumulations, high-resolution 3D seismic is required. The seismic time slice on page 66 shows the top of a large amplitude anomaly interpreted as the base of the hydrate stability zone (BHSZ). The RMS amplitude time slice highlights the distribution of shallow gas accumulations at the base of the BSR within the seismic cube. The BHSZ reflection is discontinuous, with isolated, elongated and oval-shaped patterns up to 1,400m wide. Significant amplitude variations exist within these features, which may imply a considerable variability of shallow gas and gas hydrate concentrations across the region.

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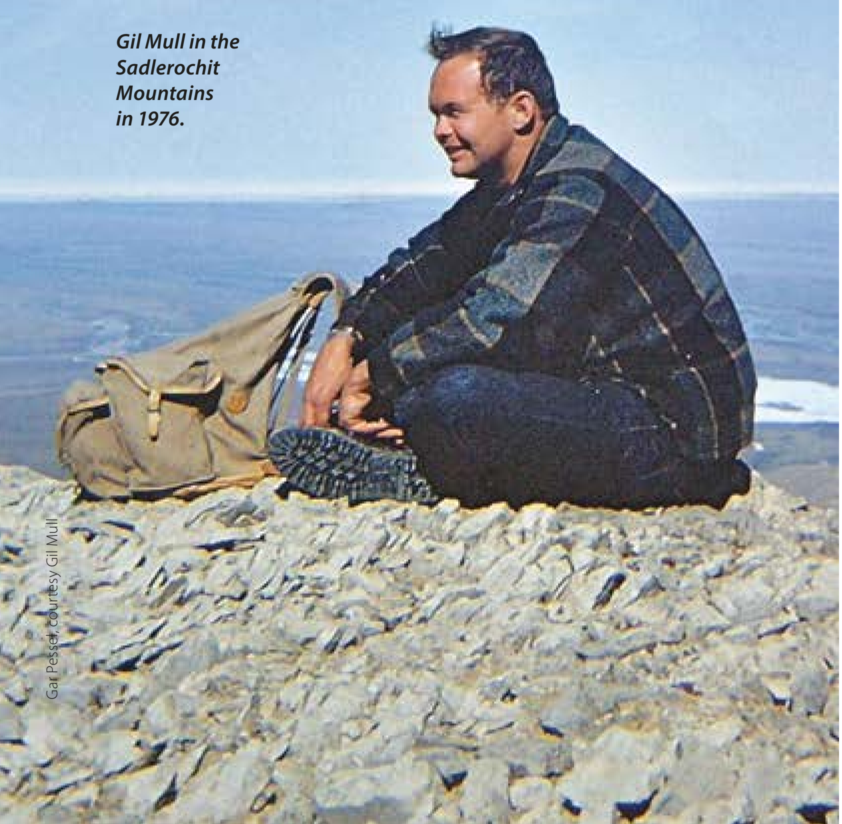
Jürgen Mienert is director of the Centre of Excellence CAGE – Centre for Arctic Gas Hydrate, Environment and Climate at UiT The Arctic University of Norway. He holds a professor position in Applied Geophysics and Arctic Marine Geology at UiT located in Tromsø, the gateway to the Arctic. During his career he has been at Lamont-Doherty Earth Observatory, Columbia University, New York, USA; GEOMAR research institution, Kiel, Germany; Woods Hole Oceanographic Institution, Woods Hole, USA; Scripps Institution of Oceanography, San Diego, USA; Institut français de recherche pour l'exploitation de la mer, IFREMER, Brest, France. Jürgen has published more than 400 papers including books and abstracts.

Prudhoe Bay and Beyond

A geologist's career on the North Slope helped lead to the discovery of North America's largest oil field and, later, his own geological find.

HEATHER SAUCIER



Gil Mull in the Sadlerochit Mountains in 1976.

Gar Pessel, courtesy Gil Mull

Through the windows of the chemistry lab at the University of Colorado in April of 1954, sophomore Gil Mull gazed out at the Flatirons, admiring their beauty and mystique. As the odours of the smelly lab wafted through the air, Mull realised that he really belonged outside, and to get there he needed to change his major to geology.

That change in track eventually took Mull to Alaska to map in the Brooks Range and, in a serendipitous chain of events, put him at the historical well that first tapped North America's most prolific petroleum reservoir at Prudhoe Bay.

His astute observations in the field and experience as a wellsite geologist paved an upwardly mobile path for Mull that pointed toward a comfortable office in a skyscraper, rather than months living in 2.5-by-3m canvas tents. But he did not take that path.

After the swells of excitement from the Prudhoe Bay discovery subsided, Mull retreated to the hills of the Brooks Range and the North Slope to continue mapping projects that took him from the Canadian border to the Chukchi Sea. He became one of the few geologists who gained personal familiarity with the entire Brooks Range, and is recognised today as one of the top authorities on North Slope geology.

The discovery of Prudhoe Bay was a team effort. Reminiscing on the experience decades later, Mull, now 80, marvels over being a part of it. But 13 billion barrels of produced oil aside, Mull made important geological contributions of his own, and smiles just as widely when talking about them.

A Pair of Punk Kids

The location was Peters Lake in the north-eastern Brooks Range, and Mull and his field mapping partner, Gar Pessel, found themselves in 1963 camped near a group of geologists from Shell who were older, had PhDs, and "worlds of experience", Mull recalled.

Mull and Pessel have often wondered why their supervisors at Richfield Oil, which made the first significant oil discovery in Alaska in 1957 near Cook Inlet, chose relatively inexperienced "punk kids" in their late 20s to represent Richfield on the North Slope.

"We were given a lot of leeway. They gave us a helicopter, a float plane and a budget of $150,000 and told us to go map," Mull said. "It was a hell of a deal."

Harry Jamison, who headed regional exploration in Alaska for Richfield, spotted a natural affinity for field mapping in the pair, but especially had his eyes on Mull, who worked at Richfield in the summers while earning his master's degree. "I wanted Richfield to become more aggressive in their exploration programme on the North Slope," Jamison recalled. "Gil popped right into my head."

Needle in a Haystack

Mull and Pessel went to work searching for hydrocarbons north of the Arctic Circle, specifically the areas between the Arctic National Wildlife Refuge (ANWR) and the National Petroleum Reserve – Alaska

(NPRA) – an area known to contain oil and gas. Relying heavily on the United States Geological Survey's (USGS) "invaluable" basic framework, they bridged the gaps by identifying potential reservoir rocks and organic-rich shales.

"We covered a lot of country but it was slow," Mull said. A Cessna 180 on floats or skis transported their camps from lake to lake. A Bell G2 helicopter, which took them into the field daily, could haul little more than its pilot, two geologists and 40 gallons of fuel. A full-time mechanic was needed to balance its balsawood rotor blades, which soaked up moisture when it rained. "You were elbow to elbow in parkas. It was like being in a straightjacket," Mull recalled.

Yet they pressed on, spurred by the excitement of exploring the geology of relatively unknown areas and, later, by rocks they observed in the Sadlerochit Formation that showed promise of reservoir potential in the subsurface.

"We really did put our finger on the secret to North Slope geology," Pessel said. "Toward the end of the summer, we realised that Richfield had to do seismic to look for exploratory targets."

Believing their recommendations were sound, Jamison convinced Richfield executives to send a seismic crew to shoot general reconnaissance lines on the North Slope in the winter of 1963–4. The following winter, regional lines revealed a structural high near Prudhoe Bay.

"I remember someone asked why we were spending so much time on the North Slope when all the action was in Cook Inlet," Mull recalled. He kept mum, never mentioning the findings.

Field work in the Arctic National Wildlife Refuge in 1963.

Right Place, Right Time

Richfield, which had merged with the Atlantic Refining Company to become ARCO, sent a rig by cat train to Prudhoe Bay in the spring of 1967 to drill the wildcat well Prudhoe Bay State No. 1, in partnership with Humble (now ExxonMobil).

Around this time, Mull joined Humble's team, not long before the company's wellsite geologist at Prudhoe Bay resigned to take another job. Mull was ushered in as his replacement. That December, drill cuttings and cores cut from the Sadlerochit Formation revealed porous sandstone and conglomerate.

At that point, daily drilling reports could no longer be sent by radio. Instead, Mull made daily, 1,126 km roundtrips in a Beechcraft King Air to Fairbanks or Barrow to phone them in.

"Well-sitting was something you sent your junior people out to do. It can be awfully boring," he said. "Well, most of the time."

The first drill stem test in the Sadlerochit Formation the day after Christmas brought a present that eventually would give Alaska billions of dollars in tax revenue and the United States an estimated 25% of its oil reserves at the time.

The thickness of the sandstone and conglomerate and the high pressure showed "promise beyond our wildest imagination," Mull said. "There was an immediate flow of gas to the surface. When ignited, it burned with a roar, a rumble like a jet plane overhead. This test flowed gas for about eight hours and the flare burned all night."

While the drilling crews conducted a fishing operation, Mull flew to Anchorage to hang out with friends at the Alyeska Ski Resort. There, he was approached by the late Bob Atwood, publisher of the *Anchorage Times*, who likely heard from airline passengers news of a 15m flare burning in the Arctic darkness. "I hear you have a discovery up there," Atwood prodded. Mull simply responded, "Oh? I don't know anything about it."

In May 1968, the Sag River State No. 1 well, drilled 11 km away and 120m stratigraphically lower, was cored. Roughnecks were screened off from the derrick floor when oil-saturated cores, which consisted of almost unconsolidated sand and gravel, were extracted from the core bit and sent for analysis.

Confirmed: Prudhoe Bay was a world-class, Persian Gulf-sized oil field with an estimated 9.6 Bb of recoverable oil. Dozens of development wells were drilled, topped with Christmas trees,

Gil Mull in Otuk Creek, 1965

and awaited the completion of the Trans-Alaska Pipeline in 1977.

"Many petroleum geologists can spend their entire careers never seeing a producing well," Mull said. "This was incredible."

Outdoor Office

As exploration on the North Slope increased exponentially in the late 1960s and early '70s, Mull essentially was given carte blanche by Humble to lead field parties, mapping the Brooks Range and North Slope from Point Hope to the Canadian border as he saw fit. "To me, the real excitement was going out and wandering around the hills to places no geologist had ever been before and putting together a geologic map. It's not only a physical challenge but an intellectual challenge," he said.

During this time, Mull made an important discovery of his own. In 1970, he took Dietrich Roeder, an Exxon research geologist, on a guided tour of the thrust-faulted northern flank of the central Brooks Range. Along the upper Noatak River 112 km south of the mountain front, they noted how the thrust faults had been folded and dipped northward. Roeder suspected that a tremendous amount of movement had occurred in the mountains that lay north of them as a result of an obscure concept at the time: plate tectonics.

A cautious Mull didn't fully embrace his peer's assessment until 1972, when he found himself on the flank of Mount Doonerak, 100 km south of the mountain front and many kilometres east of the upper Noatak River. There, he discovered a distinctive rock sequence with fossils that were identical to those in the north-eastern Brooks Range and in the subsurface at Prudhoe Bay. Realising they were very different from the rocks in the mountains north of him, Mull thought, "Wow, Dietrich was correct!"

"The mapping showed that distinctive rock sequences had been telescoped and shuffled like a deck of cards and then folded, representing hundreds of kilometres of crustal shortening. That was mind boggling," Mull said.

The USGS confirmed the age of the fossils, and agreed that a 650-by-160 km portion of the western and central Brooks Range north of Mount Doonerak had been thrusted hundreds of kilometres northward and then folded by uplift and further shortening in the core of the Brooks Range.

"In terms of geological discoveries, that's probably the thing I am most proud of," Mull said.

When Mull caught wind that Humble might send him to Houston for an office job, he quickly jumped ship and joined the USGS's Branch of Oil and Gas Resources in 1975 to continue his field mapping work, particularly to assess oil and gas potential in NPRA and ANWR, and to help update the USGS' maps. "We were having fun chasing the mapping. It was like a kid in a candy shop," said Mull, who also authored an extensive list of technical papers and maps on North Slope geology.

He continued that work when he moved to the Alaska Department of Natural Resources' Division of Geological and Geophysical Surveys in 1981 and then to the Department's Division of Oil and Gas in 2001. During this time, Mull led field parties that included graduate students from the University of Alaska Fairbanks that he described as "heroes", as they provided a lot of the geological documentation critical to many projects.

The Go-To Guy

Mull, who is married with two children and three grandchildren, retired in 2003 and has settled in Santa Fe, N.M. He continues to take calls from fellow geologists to discuss the rocks he knows so well on the North Slope.

"I think Gil was one of the best field geologists I have known in my long career, and in this business I've known some good ones," Jamison said. "His expertise on the North Slope is basically unrivalled. From that standpoint, he occupies a unique niche in the geological fraternity. Gil was one of the foremost historians in the discovery of Prudhoe Bay."

As important as the discovery was to his country, a modest Mull holds the years he spent in the Brooks Range as the most meaningful. They fuelled his mind and soul and gave him a career that had few boundaries, two being the rugged terrain beneath his feet and the canopy of sky above his head.

With that freedom, he pushed science a step forward.

Mull often borrows the words of Alaskan geophysicist John Eichelberger: "Although it's risky, exploration is still the heart of science." Then, he adds a few of his own: "And, science is the heart of exploration." ■

Gil Mull, outside his Santa Fe home last August.

Super-High Resolution Seismic Data in

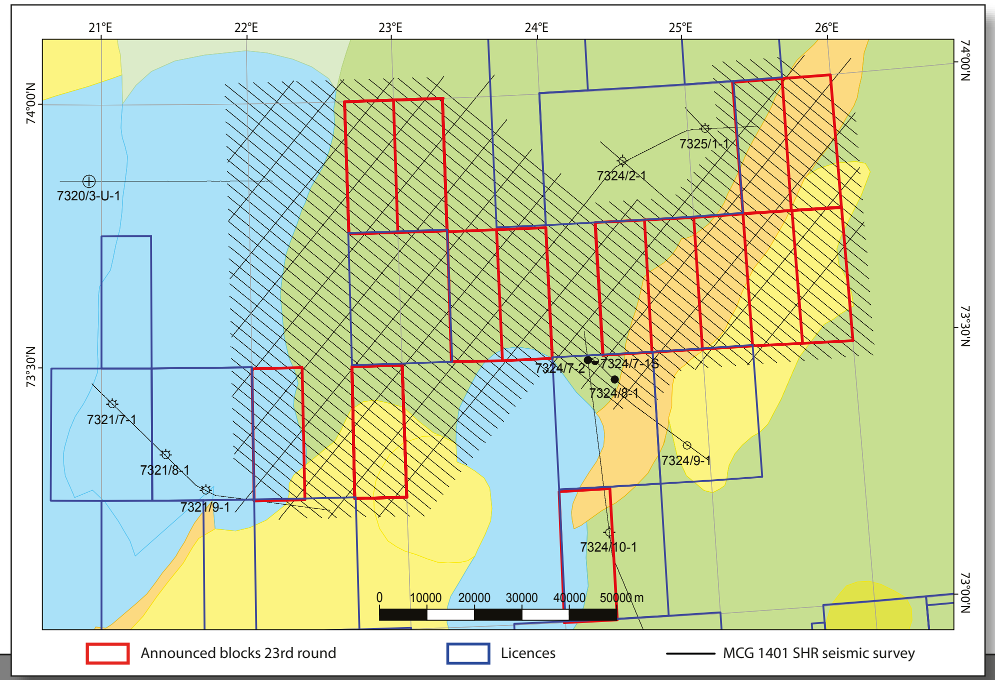
The Hoop Area Norwegian Barents Sea

In 2014, 5,600 km of very high resolution 2D seismic data was acquired by MCG and Exploro in the Hoop Area of the Norwegian Barents Sea. The data ties in all the recent wells and covers 13 of the announced blocks for the 23rd Concession Round for offshore Norway. The dataset is uniquely suited to mapping out the shallow Upper Triassic to Jurassic prospectivity in the area in great detail.

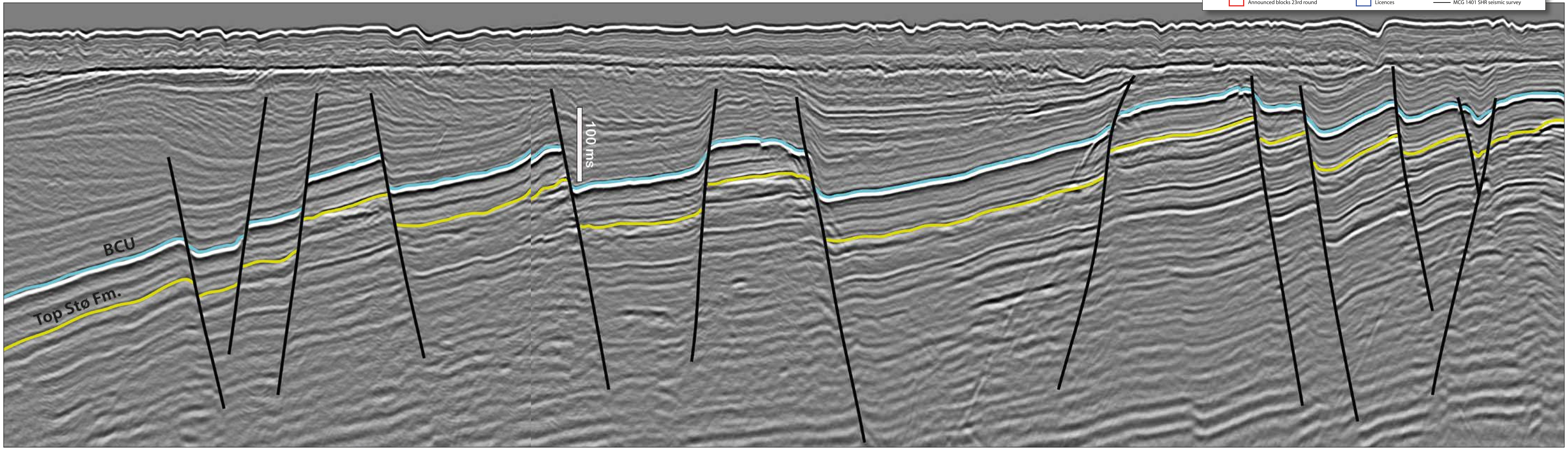
exploro geoservices

MCG

Location map of the Super High Resolution MCG 1401 seismic survey in relation to the announced blocks for the 23rd Concession Round in the Norwegian Barents Sea.



Semi-regional 2D super-high resolution seismic line in the Hoop Area.



Imaging Shallow Reservoirs

Using super-high resolution seismic data in the Hoop Fault System area of the Barents Sea allows for the clear imaging of very shallow reservoirs, with AVO effects visible even at shallow depths.

TOMAS KJENNERUD, JAN OVE KNUDSETH, GAETANO SALVAGGIO, FJALAR REYNISSON, Exploro AS; and **TOR ÅKERMOEN**, MCG ASA

The area surrounding the Hoop Fault System in the Norwegian Barents Sea is at present among the most prospective and enigmatic areas being offered in the 23rd Concession Round. Over the last year and a half, six wells have been drilled, two of which led to potentially commercial discoveries in the Jurassic, namely Wisting and Hanssen.

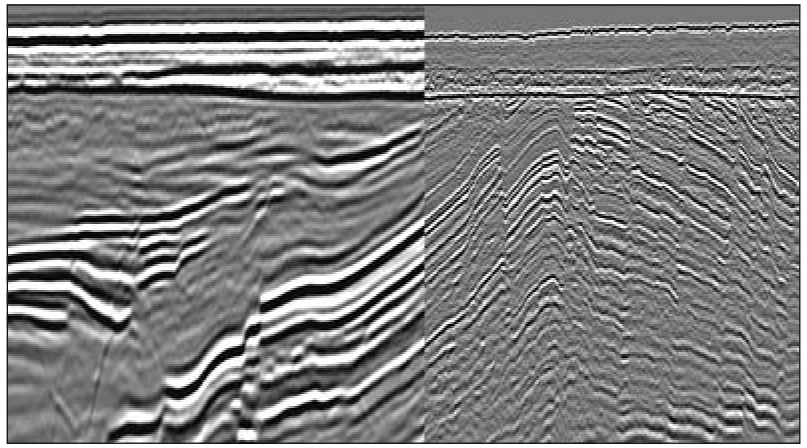


Figure 1: Comparison of conventional data (left) and MCG1401 high resolution data (right) in the Hoop area, showing significantly higher resolution on MCG1401.

Very Shallow Discoveries

An interesting characteristic of the area is that the prospective Jurassic reservoir rocks occur at very shallow depths; the reservoir of the Wisting discovery, for example, is only around 400m below the sea floor. In fact the prospective Jurassic reservoirs are mainly located above the first sea floor multiple in most of the area. The reason behind this is that we are looking at an exhumed petroleum system. The Hoop area experienced between 1,500 and 2,000m net erosion during the Cenozoic.

This setting has enabled Exploro and MCG to design a regional super-high resolution multiclient 2D seismic survey, which is particularly suited to map the prospectivity of the Hoop area in great detail, as well as investigate reservoir distribution and fluid contacts. A 2 by 8 km 2D seismic grid has been acquired using site survey parameters. Full modern broadband processing was carried out by Down Under GeoSolutions (DUG). Near zero offset data was acquired, which is optimal for the processing of the data. A 2,000m-long streamer was used in order to be able to undertake AVO work, which is normally not possible at the shallow depths we are dealing with in the Hoop area. The data was sampled and processed at 1 ms and with a group length is 6.25m. Figure 1 shows a comparison between conventional 2D seismic in the area and data from the new high resolution survey, known as MCG1401.

Elements of the Petroleum System

The Hoop Fault system is a long-lived series of faults that has been periodically reactivated at least since the Carboniferous. Structuration in the Jurassic and Cretaceous resulted in the formation of the structural traps that are being explored in the area at the moment.

Potential reservoirs occur in the mid-Triassic to mid-Jurassic Kapp Toscana Group, and consist mainly of continental to marginal marine sandstones. Reportedly, the reservoir quality was excellent in the Wisting and Hanssen discoveries. The regional top seals are made up of the Upper Jurassic Fuglen and Hekkingen Formations.

Figure 2 shows an example of the detailed seismo-stratigraphic interpretation that is achievable with the new data. The section has been flattened on the Base Cretaceous Unconformity in order to enhance the internal variation of the potential Upper Triassic to Jurassic reservoir units. Here the Realgrunnen Sub Group has been subdivided into four units. The Lower constitutes the heterolithic Akkar Member of the Fruholmen Formation.The unit thickens towards the left in the section. Above sits the thick sandy Reke Member of the Fruholmen Formation, which has been sub-divided into two units here. The uppermost part of the Fruholmen Formation seems to be characterised by channels, which are probably fluvial in nature. The sandy Stø Formation is located above as a wedge thickening towards the left. The variation in

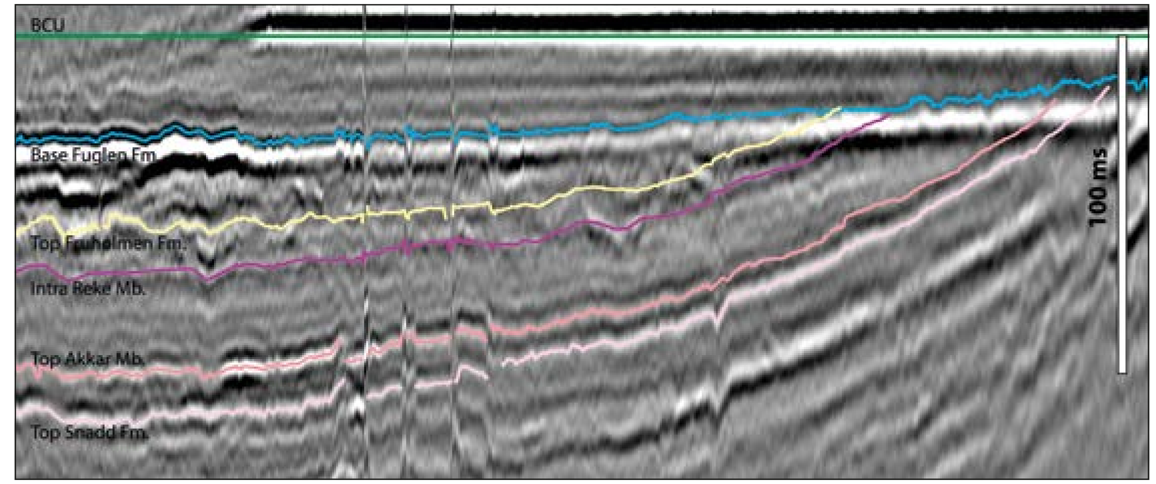


Figure 2. Detailed seismic section flattened on the Base Cretaceous Unconformity (BCU) demonstrating the amount of detail in the data.

thickness is partly due to local late Jurassic erosion. The high amplitude reflector cross-cutting the strata in the left part of the Stø Formation corresponds to a flatspot in the normal (un-flattened) section.

There is no shortage of source rocks in the Barents Sea, and the most likely contributors to the prospects in the Hoop area are marine oil-prone Lower Triassic and Upper Jurassic sources. Hydrocarbon systems modelling carried out by Exploro has demonstrated that expulsion from the Upper Jurassic Hekkingen Formation in the Maud Basin migrating updip through Jurassic sandstones is sufficient to charge the Wisting and Hanssen discoveries as well as several undrilled prospects in the area. The main critical aspect to the petroleum system in the Hoop area is the Cenozoic uplift and erosion.

Prospectivity and Data

Based on this new multiclient 2D data, several potential prospects with variable sizes (the largest covering several blocks) have been identified in the Hoop area. Many of these are associated with DHIs. Fluid contacts are mappable and consistent in depth over several lines for some of the potential prospects. The wells drilled in and close to the Hoop area have demonstrated large lateral thickness variations in the Kapp Toscana Group reservoirs. The new super-high resolution seismic data will enable us to map out the lateral extent of each potential reservoir.

The example in Figure 3 clearly demonstrates AVO effects at shallow depths in the data. The section crosses an undrilled structure in PL722, operated by GDF Suez. The angle stacks show an increase in negative amplitude with offset, which indicates a possible AVO Class III response.

The super-high resolution 2D seismic survey will enable seismic interpreters to establish a much more detailed stratigraphic framework than is possible with other data in the area, as well as mapping fluid contacts and ideally separating one-phase traps from two-phase traps. In these challenging times with reduced exploration budgets, the new data will enable oil companies to license less 3D seismic data in this highly prospective and promising area.

For further info:

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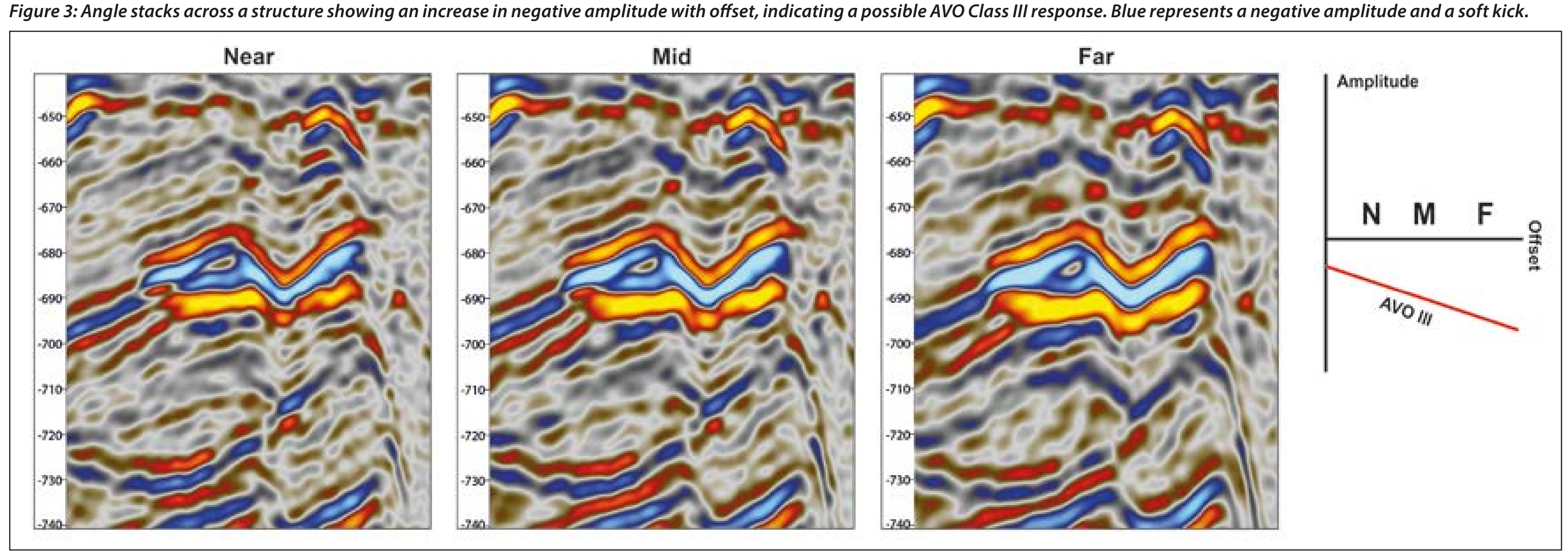
Email: tor.akermoen@mcg.no ■

Figure 3: Angle stacks across a structure showing an increase in negative amplitude with offset, indicating a possible AVO Class III response. Blue represents a negative amplitude and a soft kick.



South Falkland Basin: Darwinian Evolution

The South Falkland Basin has remained below the industry radar. Pioneering exploration efforts are slowly revealing the potential of this new frontier.

BRUCE FARRER, Borders & Southern Petroleum; **CHRIS RUDLING**, RPS

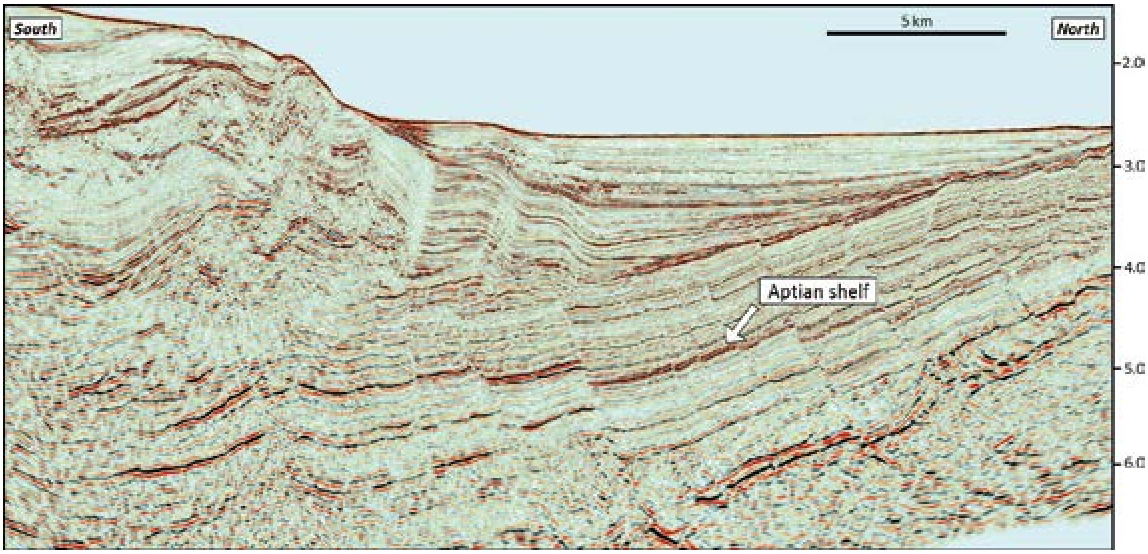
In 2012 the Darwin East-1 well successfully tested a well-defined tilted fault block structure that exhibited an excellent DHI anomaly with amplitude conformance to structure. The pre-drill target was identified by mapping of seismic interface amplitudes, the principal tool in the interpreter's toolbox. Following this discovery, could inversion data provide additional insight into the geological model?

Evolution of the South Falkland Basin

The South Falkland Basin is located along the southern margin of the South American plate. The present-day tectonic setting reflects the plate convergence that took place in the mid-Tertiary, creating an inverted foreland basin. From an exploration viewpoint the observer is initially drawn into the large thrust-cored anticlines, but on closer inspection the more subtle early basin architecture is revealed.

The basin initially evolved during the Late Jurassic/Early Cretaceous as a result of separation between Antarctica and South America. After initial rifting the South Falkland Basin developed as a passive margin bordering the expanding Weddell Sea. Local stratigraphy is broadly similar to the adjoining Malvinas and Magellanes Basins. The passive margin setting continued

Volunteer Point is home to a large king penguin colony, as well as many other birds.



Seismic time section traversing south to north over the South Falkland Basin.

throughout the Cretaceous period into the early Tertiary. During the early-mid Tertiary differential movements between the South American plate and Antarctica led to the development of a foreland basin. This was subsequently inverted through continued expansion of the Scotia Sea. Major tectonic activity ceased by the late Miocene.

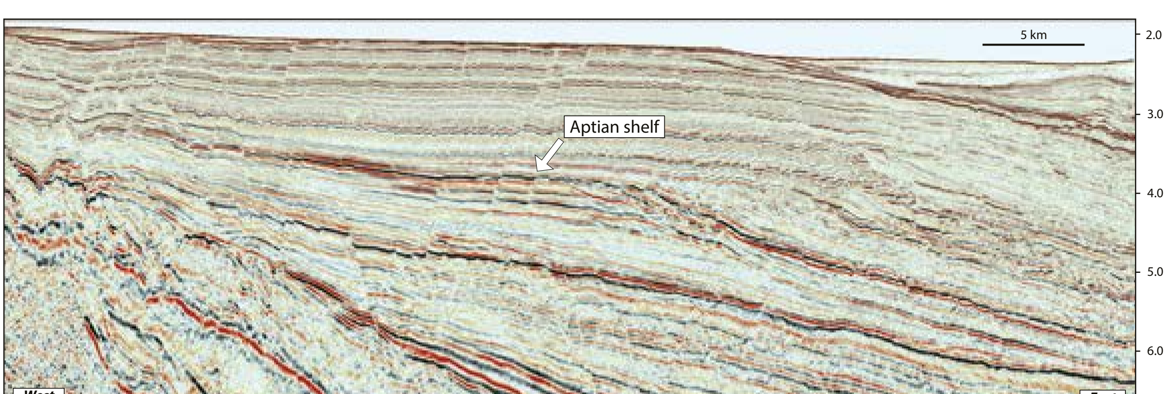
Play Elements

Anoxic marine shales of Late Jurassic to Early Cretaceous age form the principal regional source rocks. The conditions that allowed these rich source intervals to develop ceased in the late Aptian. Early Cretaceous laterally continuous shallow marine sands, deposited along the passive margin, form the main reservoir targets. Deepwater channels and fans of similar age provide additional prospectivity. Secondary targets are formed by Tertiary sediments that were flushed into the developing foreland trough. Trapping mechanisms are both structural and stratigraphic. Structures include tilted fault blocks and thrust cored anticlines.

Exploration Highlights

The initial exploration assessment was based on regional geology and sparse 2D seismic. In 2008 a 1,500 km^2 3D seismic survey was acquired over the western portion of the Borders & Southern (B&S) block covering the highest ranked leads. Processing of the 2008 data consisted of a standard time processing sequence including 2D SRME. The Darwin prospect was identified as two tilted fault blocks with excellent amplitude conformance to structure, denoted East and West respectively. Amplitude maps extracted along the top Aptian horizon clearly outlined the reservoir fairway on the Early Cretaceous shelf. Subsequent pre-stack work demonstrated amplitude behaviour consistent with the presence of a class 3 AVO anomaly on the Darwin prospect, providing increased confidence in the geological interpretation.

Prior to drilling the Darwin discovery, only one other well had been drilled in the South Falkland Basin. Toroa-1, drilled by BHP Billiton in 2010, tested an Early Cretaceous/Late Jurassic transgressive sand unit in a stratigraphic pinch-out play. The well was located on the basin margin. Although the well was dry it did encounter rich source intervals and thick high quality reservoir units within the Early Cretaceous. In 2012 B&S drilled 61/17-1 on the Darwin East tilted fault block. The key pre-drill risk was considered to be hydrocarbon phase. The target horizon was 2,600m below mud line, located in 2,000m of water. A gross hydrocarbon 'down-to' interval of 84.5m was encountered (net 67.8m). The wellbore penetrated a thick shale unit below the main reservoir, which continued below the depth of the hydrocarbon contact identified on seismic, consequently the nature of the fluid below the contact remains untested. The reservoir consists of quartz-dominated shelf sand with an average porosity of 22% and average permeability of 337 mD. Reservoir quality was similar to the equivalent stratigraphic interval penetrated by the Toroa-1 well located



West to east seismic time section. Note the broad Aptian aged shelf, slope and basin floor architecture.

70km to the north-east. Fluid samples recovered from the well confirmed the presence of a high yield gas condensate (148 to 152 bo/MMcfg). Detailed analysis indicates that the yield increases with depth. Current management assessment indicates a prospective liquid recoverable resource in excess of 263 MMbo.

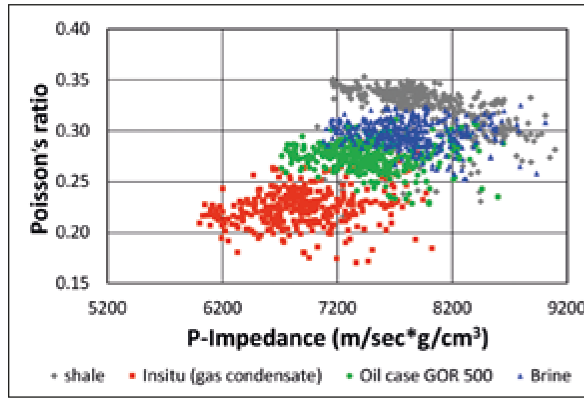
The third well in the basin probed a large anticline within the Tertiary fold and thrust belt. Although the well confirmed the presence of hydrocarbons, no viable Tertiary reservoir was penetrated and abnormal pore pressures prevented the well from reaching all the pre-drill target intervals.

A full suite of logs was acquired in the Darwin East well, facilitating quantitative seismic analysis. As anticipated, initial fluid substitution work demonstrated the strong seismic response of the gas condensate when compared to brine-filled cases. This separation is clearly observed on P-impedance/Poissons ratio cross plots. The separation between liquid oil and brine was less obvious and wholly dependent upon gas saturation.

Enhancing the Image

In 2014, a second 3D survey was acquired with Geostreamer™ in order to track the Darwin discovery play fairway beyond the limits of the 2008 survey. To ensure a seamless merge between the two 3D volumes, the conventional 2008 data was reprocessed. A depth-processing sequence was chosen and 3D SRME was included to minimise diffracted multiple leakage into the target levels. The datasets were merged pre-3D SRME to ensure no loss in multiple prediction. An early focus on low frequency preservation and wavelet control meant that no further residual matching was necessary. The later iterations were carried out using a 'finite offset' tomography scheme enabling smaller scale length velocity variations to be resolved in comparison to earlier phases of tomography.

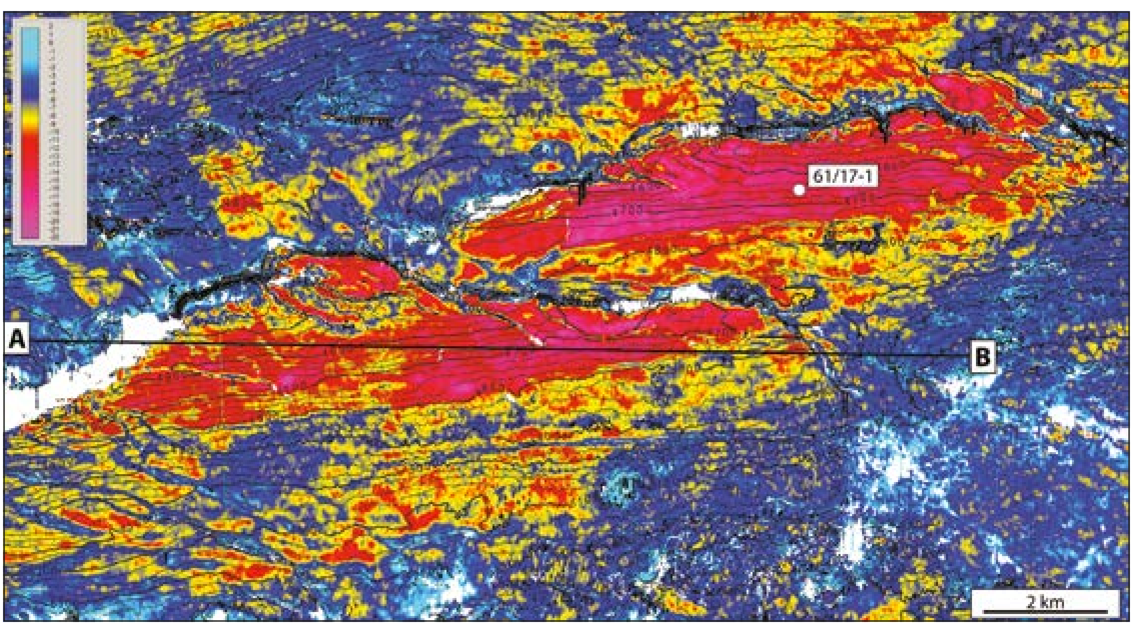
Reprocessing of the conventional 2008 data also reduced the residual multiples seen in the original data, resulting in a sharper image. The decision to go to depth has reduced the overburden affects resulting in an improved dataset for the interpreter.

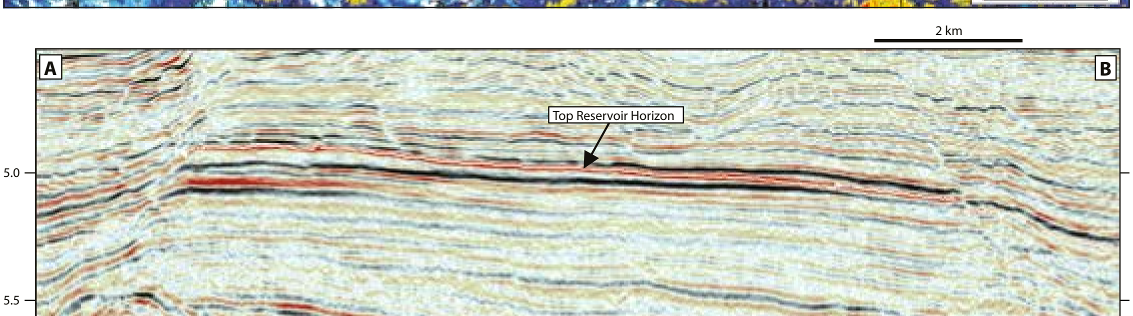


Cross plot of AI vs. PR for in-situ and modelled-fluid cases through the reservoir interval.

An Inverse Perspective

Following completion of processing and merging, a post stack inversion was run assisted by the use of the vertical seismic interval velocities. This cost-effective inversion product can





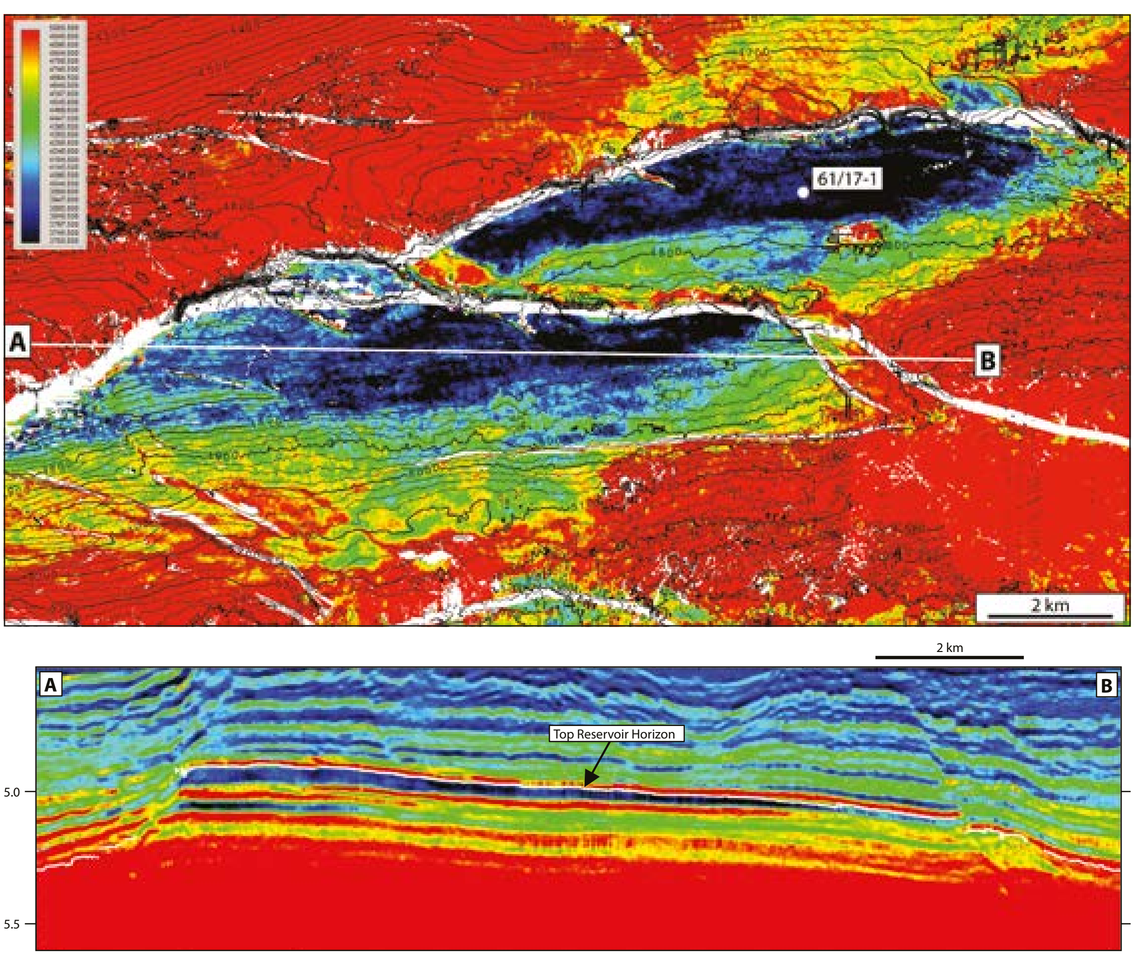
Full fold amplitude data: horizon amplitude map and accompanying seismic section. Note amplitude conformation to depth contours.

be generated shortly after processing, enabling the data to feed promptly into interpretation work. The inversion demonstrated an excellent match to the existing interpretation and a qualitatively good match to the well data. Whilst there are many factors that influence the success of a post stack inversion to recover a representative p-impedance sequence, the focus on low frequencies, wavelet control, careful monitoring of the interval velocities and targeted post migration conditioning were significant controlling factors. The standard approach to horizon mapping is through the picking of seismic amplitude peaks and troughs. These maxima and minima amplitudes are a property of the interface between two layers. Recovery of an acoustic impedance sequence, a layer property, which matches both seismic and well data, can be used to enhance the interpretation of seismic data by illuminating layer-based configurations.

A continuous horizon picked on an amplitude response may represent a particular stratal surface at a moment in time. But this surface may not reveal the subtle facies changes of the lithological units that reside below this interface. Inversion data can expose these variations in acoustic impedance and provide an additional interpretation tool. The differences in acoustic impedance may also help to differentiate between brine- and oil-filled sands. One uncertainty being tested on the Darwin discovery is the potential presence of a down-dip oil accumulation. The top reservoir amplitude map clearly defines the gas condensate accumulation but the rock property differentiation between certain oil cases and brine filled sands is more subtle and is not resolved with amplitude mapping. As expected, the inversion volume also highlights the lower impedance gas condensate. However, a variation in acoustic impedance between the reservoir interval below the gas condensate and the depth equivalent reservoir on the downthrown side of the bounding fault identifies a potential anomaly. The anomaly also expresses an apparent conformance to structure. It is possible that this variation could represent an oil rim below the gas condensate.

Evolution Beyond Darwin

Initial post stack inversion data has provided additional facies insights that were less obvious when reviewing amplitude data. The observed conformance to structure of the interval below the gas condensate in the Darwin Field could be coincidental but there is a physical expression that requires further investigation. To this end a standard simultaneous inversion workflow is currently being run to study the elastic response in more detail. Petrophysical log data from the Darwin East well will be fully incorporated within the low frequency model. Inversion data has led to an enhanced understanding of the facies relationships within the target play fairway. This knowledge can now be used to help de-risk the extensive prospect portfolio and identify new plays. It is anticipated that a refined inversion product will assist in generating further discoveries in this emerging play fairway. ■

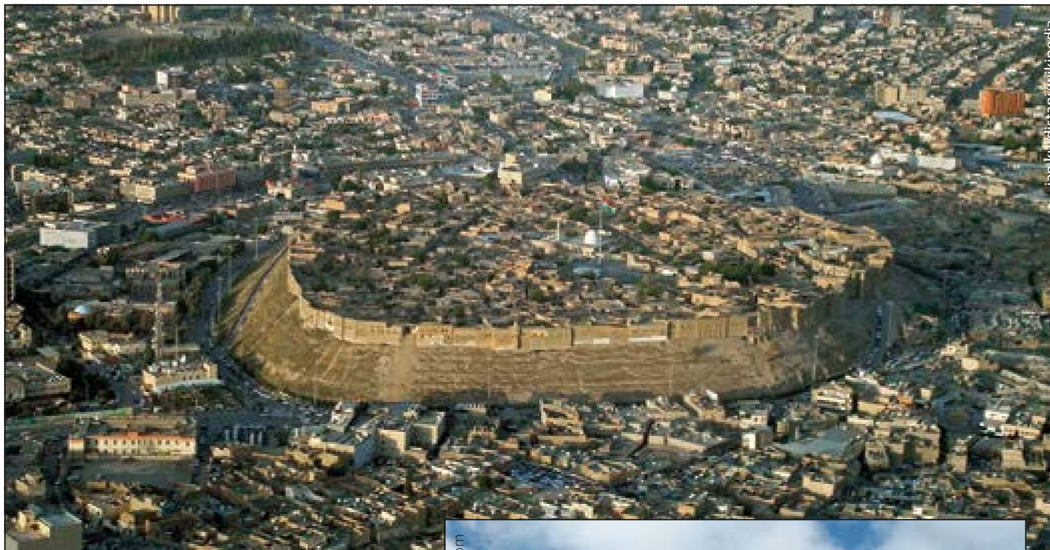


Sparse spike inversion data: map and accompanying seismic section showing the inversion response of the main Darwin East reservoir unit.

Erbil
Ancient City – and 'Second Dubai'

Contrary to many people's expectations, Erbil, the capital of Iraqi Kurdistan, is a peaceful, busy and surprisingly modern city, with a history that stretches back over 7,000 years.

MUNIM AL-RAWI, PhD, Carta Design Ltd.



Jan kurdistani/wikipedia

Less than half a kilometre across, the ancient mound of the Citadel dominates the city of Erbil.

SadikG/123RF.com

The walls of the houses which form the walls of the Citadel are highly decorated.

Erbil, known as **Hewlêr** (Kurdish: **Hewlêr**; Arabic: **Arbīl**), is the capital and largest city of the Iraqi Kurdistan Region, and is the third largest city in Iraq. It is located 88 km east of Mosul and has a permanent population of approximately 1.5 million (as of 2013).

Spared much of the violence which beset Iraq through the first decade of the 21st century, Erbil is a lively and modern city which prides itself on its new shopping malls, five-star hotels and skyscrapers under construction, revelling in the, possibly slightly optimistic, label of the 'Second Dubai'. Like that Middle Eastern city, Erbil's new prosperity is thanks largely to hydrocarbons – but at its heart, and dominating its surroundings, is its ancient Citadel, which in July 2014 was designated a UNESCO World Heritage Site.

Ancient City

Urban life at Erbil can be dated back to at least 6,000 BC, making it is one of the oldest continuously inhabited cities in the world. However, a recent archaeological excavation went further back and uncovered Stone Age flint tools dating back some 150,000 years to the Middle Palaeolithic, the oldest find of its kind in the region. This longevity is probably due in part to the existence of abundant ground water, which in turn helped keep the surrounding wheat fields productive.

Lying in the area of Mesopotamia, often referred to as 'the cradle of civilisation', Erbil is mentioned in Sumerian tablets written about 2,500 BC, but came to prominence as an urban centre in about the 8th century BC, when it was part of the Assyrian Empire, the most powerful state on Earth.

Before the rise of Islam and then during Islamic rule in the 7th century, Erbil was an important centre for Christianity. It was captured by the Mongols in 1258 after a six-month long siege and fell into decline as an important regional centre.

Manmade or Natural Feature?

Geologically, Erbil is located on a vast plain between two longitudinal folds

Oil Capital

Exploration for hydrocarbons in the Kurdistan region of Iraq has been underway since the mid 1920s (see *GEO ExPro,* Vol. 11, No. 2), but operations in the area were frequently difficult and dangerous, in part because of periodic uprisings of Kurds seeking independence from Baghdad. The Iraq Petroleum Company controlled all exploration in the country, including Kurdistan, until 1972, when it was nationalised by the Iraqi government.

In 2003, the fall of Saddam Hussein opened up semi-autonomous Kurdistan to foreign investment, and serious and independent oil exploration started soon after, initiated by the Kurdistan Regional Government (KRG), which is represented by the Ministry of Natural Resources and is based in Erbil. As of December 2014, the KRG was exporting almost 400,000 bopd, and by end of the first quarter of 2015 that figure is expected to rise to 500,000 bopd.

within the Tertiary Folded Belt. The plain is covered by basal Pleistocene detritus, primarily polygenetic synclinal fill deposits, consisting of a heterogeneous collection of sediments including debris flow and braided river deposits, reaching a thickness of over 120m. In the centre of that plain lies an almost circular hill, on the top of which is Erbil Citadel, the historic city centre of Erbil.

The hill is about 30m high, with slopes at an angle of about 45°, and is usually described as a tell or occupied mound of manmade origin, but it is actually composed of stacked polygenetic synclinal fill deposits. It is the result of vertical uplift and erosion, followed by human activity over many millennia, which eventually carved away the soft sediment surrounding the more consolidated material of the core.

Successive building throughout human history means that the Citadel is now a magnificent feature that dominates the city of Erbil, the continuous wall of tall 19th-century façades still conveying the visual impression of an impregnable fortress. These are not, however, fortified walls, but a ring of houses built on the edge of the mound and held in place by a series of buttresses. Although Erbil boasts such a long history of human habitation, the oldest house in the Citadel can only be dated back to 1893.

Renovation and Rejuvenation

The Citadel is roughly oval in shape, covering an area roughly 430m by 340m (102,000m^2), with three ramps leading up to gates in the outer ring of houses.

An inventory made in 1920 identified 506 housing plots in the Citadel, divided east to west into three districts: one for high class families, one for craftsmen and farmers, and one for 'dervishes' – Sufi Muslim aesthetes or monks. There were also mosques, schools, a hammam or bath house and, up to the 1950s, a synagogue. Until the opening-up of a main north–south thoroughfare in 1960, the streets on the Citadel mound radiated outward from the southern gate in a fan-like pattern believed to date back to Erbil's late Ottoman phase.

A lower town had gradually been developing at the foot of the mound, becoming by the middle of the 20th century a more attractive location to live in than the Citadel, so the number of inhabitants living on the mound gradually declined. By 1995 there were only 1,631 inhabitants living in 247 houses left. Finally, in 2007, all bar one of the remaining families in the Citadel were evicted (with compensation) as part of a large project to restore and preserve its historic character; just one family remained, so there would be no break in the millennia-long history of continuous human habitation.

Since 2007 the KRG have been working with UNESCO to preserve and restore the Citadel buildings, most of which are in a poor state, having been predominantly built from mud. Eventually, the hope is to have families living back in the Citadel, making it a thriving metropolitan centre again. ■

Erbil – a mixture of modern and traditional.

KEN WHITE

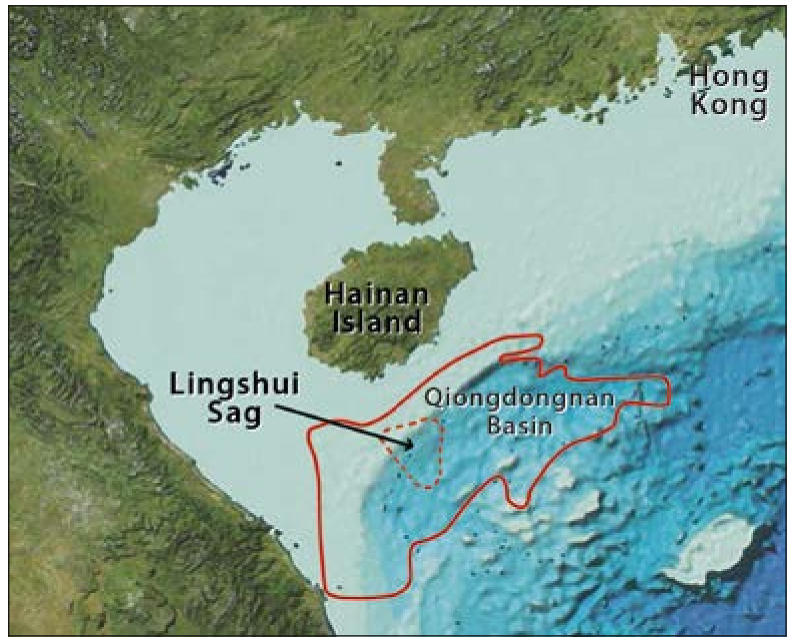
China: CNOOC Scores Second Deepwater Gas Find

Following a gas discovery in the area last year, CNOOC has now confirmed a second medium-sized find in the Qiongdongnan Basin in the deep waters of the South China Sea. According to the company, "the two discoveries have not only established the exploration potential of the structural and lithologic trap in the central Canyon channel of Lingshui Sag but also validate the superior exploration prospects in the deepwater area of the Qiongdongnan Basin." Located in 975m of water, the Lingshui 25-1-1 exploration well reached a total depth of 3,930m encountering 73m of gross pay in which a test flowed 35.6 MMcfgpd and 395 bopd.

The first find, Lingshui 17-2, was made in September 2014, in even deeper waters of over 1,500m, and is located 150 km south of Hainan Island, in the east Lingshui Sag. It is believed to be large, with reserves of about 3.5 Tcfg being reported.

The Qiongdongnan Basin experienced three tectonic evolutionary stages, with rifting from Eocene to Early Miocene forming discrete rifts. In the post-rifting stage from Early to Middle Miocene, the basin was filled with deltaic and shallow marine clastic and carbonate deposits, which contain important reservoirs. Late Miocene neritic, bathyal, and abyssal deposits formed basin-wide caprocks.

CNOOC, China's dominant producer of offshore crude oil and natural gas, should get a boost over the next three to five years from numerous development projects offshore China. The Chinese government anticipates boosting the share of natural gas as part of total energy consumption to around 8% by the end of 2015 and 10% by 2020 to alleviate high pollution resulting from the country's heavy coal use. ■

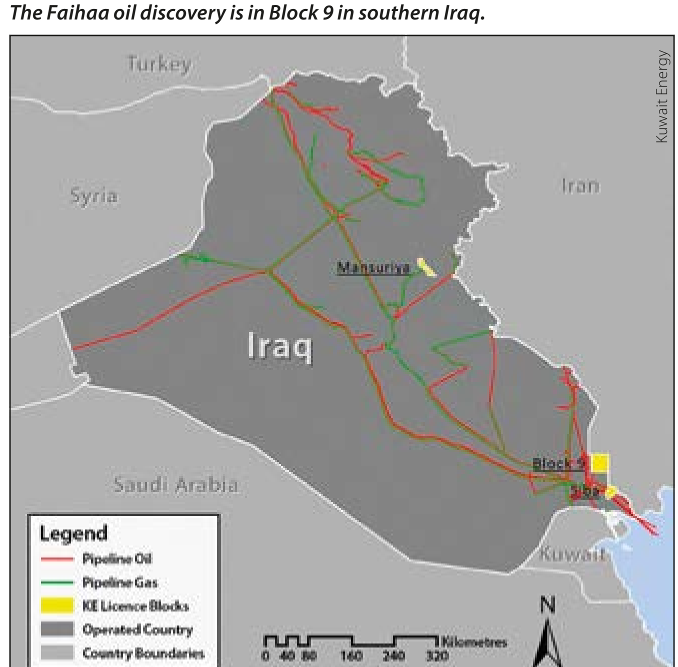


Iraq – Kuwait Energy to Fast Track Faihaa Oil Discovery

Having already flowed 2,000 bpd of 20° API oil through a 32/64" choke from the Cretaceous Mishrif Formation, Kuwait Energy has now produced oil at commercial rates from a secondary target in the Faihaa 1 wildcat in Block 9. Drilled to approximately 4,000m, oil flowed at approximately 5,000 and 8,000 b/d on 32/64" and 64/64" chokes respectively at 35° API from the Lower Cretaceous Yamama Formation. It is understood that additional testing will be undertaken and that 3D seismic will also be conducted in the block in the first half of 2015 once de-mining works are completed. Kuwait Energy is also planning to drill two appraisal wells at the discovery in 2015 to fast track the development. According to local media, the partnership, which also includes Dragon Oil (30%), is planning to spend US$ 80 million on initial exploration operations. This represents the first significant success in Dragon Oil's exploration portfolio.

The Iraqi federal government reached a new oil and revenue deal with the Kurdistan Regional Government (KRG) on 2 December 2014. According to the pact, Erbil will transfer 250,000 bpd of locally produced crude to the State Oil Marketing Organisation for export. The KRG will also facilitate the Iraqi government's export of up to 300,000 bpd of oil from Kirkuk and surrounding fields via the Kurdish pipeline to Turkey. In return, Baghdad is committed to restoring budgetary transfers to Erbil and to provide a US$1 billion defence grant. The deal should have come into force on 1 January 2015. ■

The Faihaa oil discovery is in Block 9 in southern Iraq.



Kuwait Energy

Colombia: First Deepwater Gas Discovery for Petrobras

With a significant part of its energy future reliant on new offshore and unconventional exploration, Colombia received a boost when a Petrobras-led consortium confirmed its Orca 1 wildcat in the Tayrona permit as the country's first deepwater gas discovery. Targeting the Siamana Formation, the well was drilled to a total depth of 4,240m in 674m of water in the Upper Guajira Basin, close to the border with Venezuela. So far neither Petrobras nor its partners have made any statement as to reserves, only commenting that the economic potential of the find is being evaluated. However, in an earlier presentation to analysts, partner Repsol indicated that the Orca prospect was around 4 Tcf.

This positive result confirms the hydrocarbon potential of this frontier offshore acreage and is seen as an indicator of the exploration opportunities which could lie in the deeper parts of the offshore basin. A drilling campaign by Ecopetrol and its partners is already planned for this basin, which will include two wells in 2015 and two to three additional wells in 2016. Beyond this, given the current low oil price environment, it seems unlikely that we will witness a significant rise in deepwater drilling off Colombia as companies are moving away from expensive frontier operations to focus on core producing assets. ■

The thriving city of Cartagena seen from the 400-year-old castle. Colombia is South America's best performing economy and expects to see continued growth despite the oil price fall.

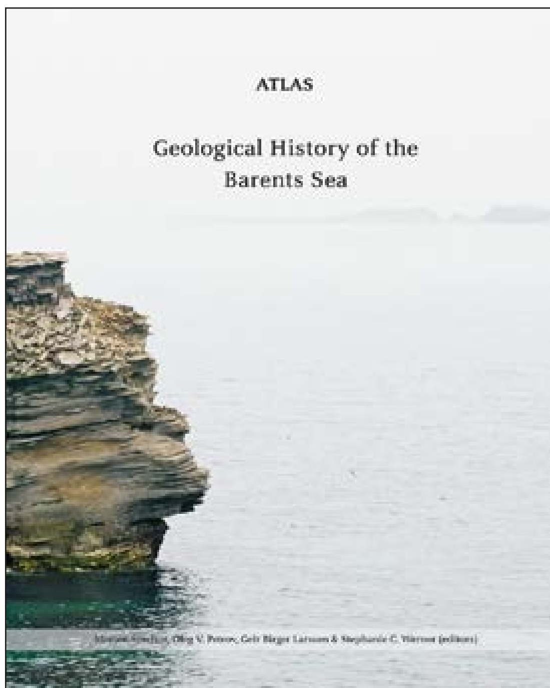
Barents Sea Atlas Goes Digital

Atlas of the Geological History of the Barents Sea
Editors : Morten Smelror, Oleg V. Petrov, Geir Birger Larssen and Stephanie C. Werner. Geological Survey of Norway, 2009.
Available online:
http://issuu.com/ngu_/docs/atlas_-_geological_history_of_the_b?e=3609664/9026048
http://www.ngu.no/no/hm/Publikasjoner/Boker/ATLAS-Geological-history-of-the-Barents-Sea/

BERNARD COOPER

The beautifully illustrated Geological Atlas of the Greater Barents Sea, originally published in hardback in 2009, is the result of a joint project between the Geological Survey of Norway and the A.P. Karpinsky Russian Geological Research Institute (VSEGEI). Their objective was to synthesise all available Norwegian and Russian geological and geophysical data from the Greater Barents Sea, Kara Sea and Northern Pechora regions in order to better understand the geological history and prospectivity of this huge Arctic area through a series of regional palaeogeographical maps. StatoilHydro and the NPD were also partners in this project.

This unique book has now been made freely available through online access and downloadable pdf. With the settlement of the Barents Sea border dispute between Russia and Norway, it will be a highly useful resource to students, researchers and industry.



Comprehensive Study

It starts with a summary of the history of the early Arctic expeditions and the more recent history of seabed mapping and hydrocarbon exploration of the area, before moving to the principles of gravity and magnetic surveying, the extent of available regional data and the interpretation of gravity and magnetic anomalies. A series of regional maps relate gravity and magnetic anomalies with the major sub-basins and highs of the Greater Barents Sea, and heatflow data from the western and eastern Barents Sea is discussed.

Chapter 3 discusses the compilation of a regional Top Basement depth map and compares a Top Moho depth map based on isostatic residuals with one based on seismic data. The following chapter describes the plate tectonic and structural history of the Greater Barents Sea, illustrated by a number of cross-sections (usefully illustrated with combined field data), composite maps and global reconstructions. An excellent three-page pullout summarises the lithostratigraphy and tectonic history of all the geographical areas covered by this study: an essential regional simplification, as each has its own detailed lithostratigraphy, which can be very confusing on a regional scale. A small issue in the earlier chapters is that it is not always easy to relate the text to the diagrams, which may be a page or two further on.

Chapters 5–22 are each an excellent summary of the palaeogeography and geological history of an individual stage, commencing with the Lochkovian and ending with the Late Neogene. The individual palaeogeography maps are clear and high quality, each supported by a page of text describing each stage's structural history, sedimentary environments and lithologies. Potential source and reservoir rocks are summarised. Each section is accompanied by superb photographs, illustrating lithologies both regionally and in detail. Helpfully, the essential geological history and most commercially prospective lithologies of each stage are summarised in a few words at the beginning of each chapter.

Unique Regional Compilation

This Atlas is a unique regional compilation of all Norwegian and Russian geological and geophysical information on the Greater Barents Sea available in 2009. It is an excellent regional introduction to the area, especially for students, and the fact that there is now digital open access to it is a very exciting development.

More recent publications have dealt in detail with the major Cenozoic uplift and erosion of the north-western part of the Greater Barents Sea (over 3,000m in western Spitsbergen), compared with the minor regional uplift of the South Barents Basin. Major uplift leads to gas expansion in existing fields, resulting in oil and gas leakage and re-migration, so very large gas fields, such as Shtokmanovskoye and Ludlovskoye, are likely to be confined to the Russian sector, in contrast with the recent re-migrated oil discoveries in the Norwegian sector. This degree of uplift in Spitsbergen is mentioned in Chapter 22, while its contrast with the uplift of the South Barents Basin can be inferred from the Basement depth map in Chapter 3, but more details on regional uplift would be potentially useful. It could also say more on hydrocarbon distribution and potential. Possibly a chapter covering recent researches will be considered in due course to update this very informative and beautifully illustrated book. ■

Let's Talk About Shale

Ken Cronin is CEO of UKOOG, which represents the onshore oil and gas industry in the UK, and is therefore heavily involved in ongoing discussions about unconventional exploration in the country.

Do you think shale gas will be important for the UK economy?
We have to look at why gas is so important to the UK. Today, 84% of our homes depend on gas for heating, and over 500,000 jobs rely upon gas as a feedstock to produce things like cosmetics, toiletries and clothing. Within 15 years over 75% of that gas will come from outside the UK, from supplies that will not pay corporation tax or create jobs in the same way as the North Sea does now. The current low price environment will not remain for ever but by then it will be too late and we will have handed our energy security over to others.

Why is there such vehement opposition to fracking in the UK?
We shouldn't translate the very vocal views of a small minority as vehement opposition. Most studies show that the industry has a positive rating of over 50%, with many of the rest undecided. That does not mean we should be complacent; we need to work hard so that local communities are given the facts and have an opportunity to ask questions and understand what the issues are and how our industry addresses them.

Are UK onshore regulations strong enough to satisfy the objections?
I believe that UK regulations are some of the most stringent in the world, particularly when it comes to chemical usage and well integrity. Many of the protestors point to a "toxic cocktail of chemicals" used in the US, when in reality the environmental regulators in the UK would simply not sanction anything other than non-hazardous chemicals. Many of the small number of issues reported in the US with respect to methane contamination of water are down to poor well design and build; in the UK our well designs are regulated by the Health and Safety Executive and signed off by an independent well examiner.

Do most protesters have a good understanding of the facts?
I think the major debate is around climate change. Our view is that we need to remove the dirtiest form of carbon, coal, from the mix as quickly as possible. While we continue to debate shale gas, European consumption of coal rose by 8% between 2009 and 2013, with net imports up by 30% over the same period. If Europe wants to reach its ambitious climate change objectives and provide energy security, indigenous shale gas offers a real alternative.

What is your 'Let's Talk About Shale' initiative?
We asked members of the public in two pilot areas in the North West and East Midlands to submit their questions to a dedicated website or to the 'Let's talk about shale' team and then used academics, experts and public bodies to answer the questions. We did this because we were aware that there is a lot of information on the subject of shale gas, much of it contradictory, confusing and pushed onto people by others. We wanted to take a step back and ask the public for their questions rather than just publish more information.

We decided that the best way of doing this would be to reach out to people in their own communities and create a conversation. The most successful thing we did was to take a branded vehicle hooked up to the internet to town centres, shopping malls and market places. Members of the public could come up to the vehicle and submit their questions. We also used other methods of engagement like leaflet drops with Freepost postcards and, of course, the website: www.talkaboutshale.com.

Has it made a difference?
In total, these methods resulted in over 1,550 responses. We knew this was a subject people wanted to know more about but were genuinely surprised by the sheer volume of questions we received, not least as we were committed to writing personally to everyone who responded! It was really important for us to do this and I hope it shows that the industry genuinely wants to listen and respond to peoples' concerns. In terms of volume, the most frequently asked question was: 'What is fracking?' Other topics included energy security, environmental impacts and the economic benefits that shale gas extraction could bring.

Most importantly, it tells us that we should do more of this. Even those who are not in favour of shale gas extraction should be given access to the facts, rather than propaganda put on the internet by anti-groups. We want people to be able to make up their minds from a position of knowledge. ■

Ken Cronin, CEO of UKOOG

Karim Merie/PESGB

Western Arctic Russia
The Kara Sea

The northernmost oil discovery in the world could be the opening salvo needed to jump start this very prospective frontier area.

THOMAS SMITH

In 2012, ExxonMobil and the Russian state oil company, Rosneft, signed a partnership deal that would give ExxonMobil a stake in developing Russia's vast energy reserves in the Arctic and Black Sea. Universiteskaya-1 was the first of what may be many wells to be drilled in the Arctic under this agreement. In the final quarter of 2014, the Norwegian-owned West Alpha rig drilled the well 250 km offshore in 81m sea depth to 2,113m total depth in a record time of one and a half months. Rosneft's president, Igor Sechin, said, "I can inform you about the discovery of the first oil/condensate field in the new Kara Sea oil province… The resource base estimate of just this oil trap is 338 Bcm of gas and more than 100 million tonnes of oil…"

Kara Sea Potential

Extending north from the West Siberian Basin, the world's largest petroleum province, the Kara Sea has long been recognised as being an area very favourable for hydrocarbon accumulations. A classified CIA research paper authored in 1988 and released in 1999 entitled *The Kara Sea: A Soviet Oil Resource for the Turn of the Century* touts the area's potential. The speculative paper says, "The Kara Sea could become one of the major petroleum regions in the USSR early in the next century. We estimate that recoverable oil resources in the Kara Sea amount to 20 Bbo…" The report goes on, "The circumstances that make the Kara Sea a foreboding exploration area to the Soviets also make it an excellent candidate for joint ventures with Western firms." This is exactly what has happened between ExxonMobil and Rosneft.

The resource estimates vary widely, from just over 20,000 MMtboe (US Geological Survey) to over 60,000 MMtboe by the All-Russian Research Geological Oil Institute (VNIGNI), which estimates that more than half of Russian Arctic Sea resources are concentrated under the Kara Sea bed. Already, state oil companies Rosneft and Gazprom have obtained licences for a significant portion of the offshore Arctic areas, including the Kara Sea, and have plans for more drilling.

The Road Ahead

Before Universiteskaya, there were 12 commercial discoveries in the Kara Sea bays, mostly offshore extensions of onshore structures that include gas, gas-condensate, and oil-gas condensate fields. Drilling operations between 1988 and 1990 discovered two unique and very large gas-condensate fields, Rusanovski and Leningradshoye.

While the new discovery is very encouraging, gas fields could dominate, with VNIGNI allocating oil to be 11% of the initial petroleum resources and gas to represent 83%. It will take some huge oil discoveries to overcome the obstacles facing the companies exploring this region. The development will be a difficult and costly process. Developing accumulations far from shore, such as the Universiteskaya discovery, will require new technologies in this harsh environment. It is in this context that Rosneft entered into its partnership with ExxonMobil. Their management recognised the need to use the expertise provided in this partnership and from companies such as Nord Atlantic Drilling, Schlumberger, Halliburton, Weatherford, Baker, Trendsetter, and FMC.

Now, international politics could get in the way as the well was completed just before the October 10 deadline that ExxonMobil was granted by the US government under sanctions barring American companies from working in Russia's Arctic offshore. The US government instituted these sanctions, recognising that Russia needs offshore Arctic drilling to offset declining Siberian fields.

For now, according for Rosneft, there is still a lot of work ahead interpreting results and further assessing more prospects. For ExxonMobil, future plans are on hold in evaluating its access to 46,000 km^2 in Russia, second only to their 61,000 km^2 US acreage. Both companies would like to get back to exploring their very promising holdings and are hoping for a quick resolution to the sanctions in this high stakes game of poker. ■

Environmental issues are always at the forefront when drilling in Arctic waters.

Only Two Sizable Discoveries

While there were 22 discoveries on the Norwegian Continental Shelf last year, only two of them had significant volumes.

A total of 41 wildcats were drilled last year on the Norwegian Continental Shelf. Most of these wells were in the North Sea, but the only substantial discoveries were made in the Norwegian Sea and the Barents Sea. In fact, only two significant discoveries were made: Pil in the Norwegian Sea, and Alta in the Barents Sea, operated by VNG Norge and Lundin Norway, respectively.

Alta, with oil in Upper Palaeozoic carbonates, is certainly the biggest with potentially 300 MMbo recoverable, while Pil, which has Upper Jurassic sandstones as reservoir, has potential for some 130 MMbo recoverable.

Both discoveries are among the largest discoveries in the world last year (Alta is no. 9 on the list, Pil no. 24, according to Rystad Energy), and it is perceived by many that additional resources can be proved in nearby prospects. Both Lundin and VNG are planning further drilling in 2016, and the Gohta-Alta trend is part of the 23rd Round (closing 2 December 2015) exploration acreage. (Gohta is a sizable discovery made in 2013 by Lundin, also in Paleozoic carbonates).

The 20 other discoveries were all small or too small to be commercial because of their distant location. The Pingvin discovery, for example, may hold some 125 MMboe, but because it is located in a remote part of the Barents Sea, it is most likely non-commercial. What would have been a significant discovery in the North Sea, close to infrastructure, is therefore merely a technical discovery in the Barents Sea.

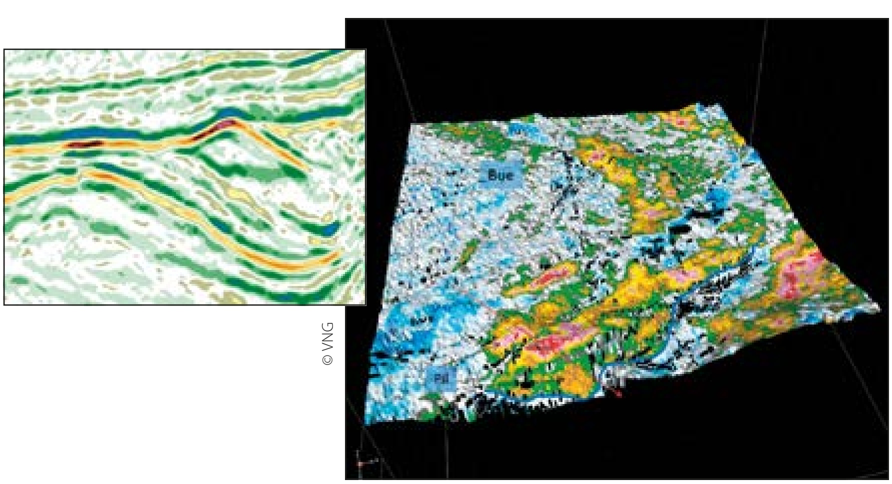
An appraisal well close to the Grane field shows the importance of near-field exploration. Statoil made the discovery in 1994, but proved only 6 MMbo. The 2014 well on the same structure proved an oil column of 25m, and the estimated volume of the discovery is in the range of 30–80 MMbo (recoverable).

According to the Norwegian Petroleum Directorate, the resources in the 2014 discoveries amount to between 250 and 700 MMb of recoverable oil and condensate and 883–2,650 Bcf of recoverable gas. The high estimate exceeds Norway's annual production (550 MMbo).

At the annual Gullkronen event, hosted by Rystad Energy in early February, VNG Norge was named 'Explorer of the Year' for the Pil discovery. The jury reasoned that the company was a rightful winner as it stood behind "the most positive surprise on the NCS last year". It was also pointed out that the discovery was in an area that had been relinquished twice, and that the company has made extensive use of existing well data and new geophysical data, including novel technology.

Halfdan Carstens

The Pil discovery, with a seismic section showing a flat spot across the structure. The structure to the north is a smaller oil discovery, also made last year.



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Conversion Factors

Crude oil
1 m³ = 6.29 barrels
1 barrel = 0.159 m³
1 tonne = 7.49 barrels

Natural gas
1 m³ = 35.3 ft³
1 ft³ = 0.028 m³

Energy
1000 m³ gas = 1 m³ o.e
1 tonne NGL = 1.9 m³ o.e.

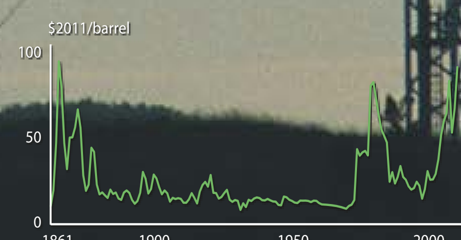
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

Supergiant field
Recoverable reserves > 5 billion barrels (800 million Sm³) of oil equivalents

Giant field
Recoverable reserves > 500 million barrels (80 million Sm³) of oil equivalents

Major field
Recoverable reserves > 100 million barrels (16 million Sm³) of oil equivalents

Historic oil price

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