VOL. 11, NO. 1 – 2014

GEO ExPro

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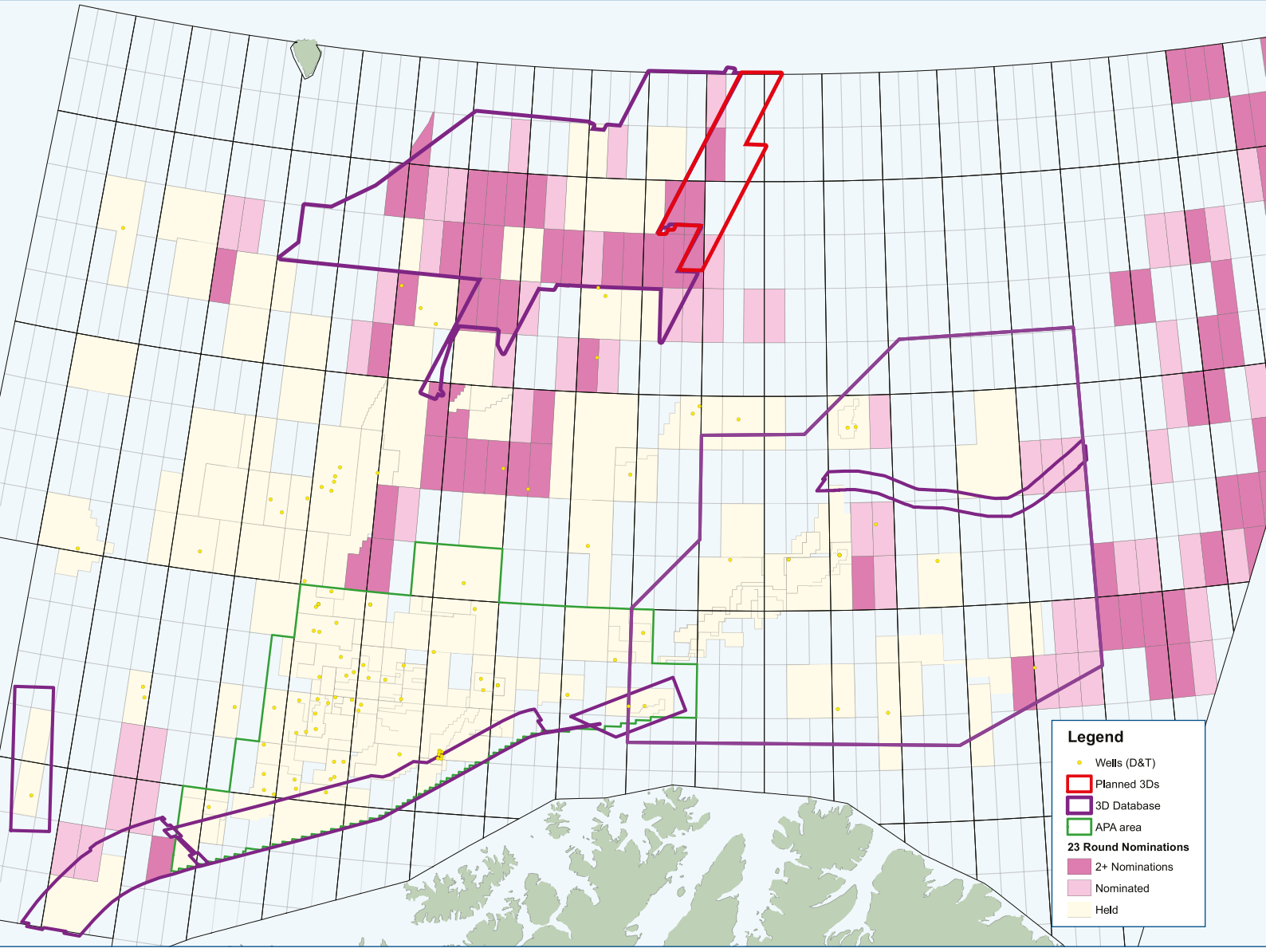

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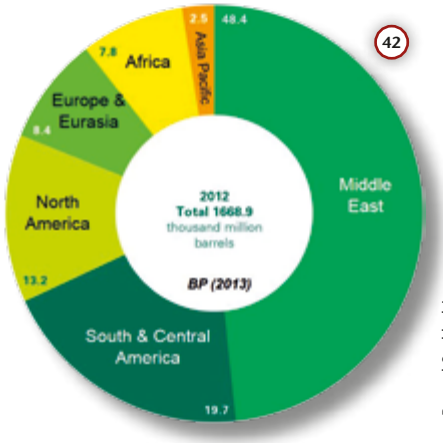
This edition of GEO ExPro Magazine focuses on the Middle East and Petrophysics



Just how much oil is there in the Middle East?

Rasoul Sorkhabi

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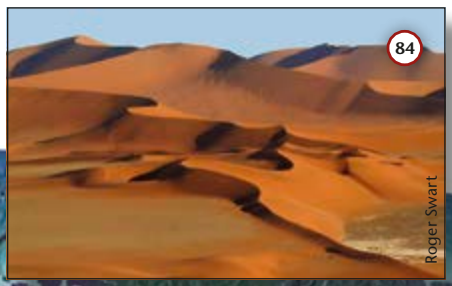
The Namib, one of the driest and oldest deserts on Earth



Roger Swart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Looking to the Future


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The Middle East: a vague geographical concept which conjures up images of vast swathes of rock, desert and dunes, empty expanses of sand, and the occasional camel. Or of futuristic cities reaching for the sky, never sleeping, harnessing the most innovative and novel technologies in the pursuit of both wealth and pleasure. And, of course, oil: the lifeblood of this complex region, which originates in the rocks of the desert and has built the cities and lifestyle.

At the moment, unfortunately, this fascinating and beautiful region also invokes less pleasurable images, with a number of countries struggling with increasing internal strife and unrest – terrible for those living in the midst of such trouble, and of deep and growing concern for the rest of us looking on. Most recent estimates suggest that the Middle East holds 43% of the proven gas and nearly 50% of the oil reserves in the world – and its wealth in shale gas and other unconventional resources is only just beginning to be assessed. It is effectively the power house of the world; when the Middle East sneezes, the rest of the world catches a cold, so we must hope that peace will ultimately prevail over the whole area.

In this issue of *GEO ExPro* we review these reserves figures for the Middle East, as well as appraise the hydrocarbon potential of one of the less well-known countries in the region, Jordan: a beautiful land with a long history of civilisation. And if that whets your appetite for desert landscapes, take a look at the stunning scenery in the Great Sand Sea in Namibia, our latest geotourism destination.

We also focus on one of the most important disciplines in the hydrocarbon industry, petrophysics. What exactly is this science, and how and where does it fit into the search for oil and gas? We talk to some petrophysicists and find out what they do and where the science is going.

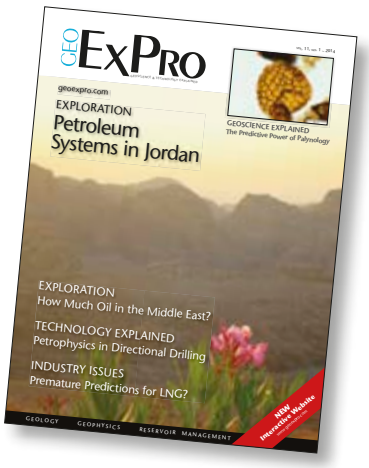
Want to learn more? Just visit our new interactive, multimedia-rich website – a cross-platform interface which means you will be able to enjoy reading your favourite articles wherever you are, on whichever device you have to hand. The future has arrived!

JANE WHALEY
Editor in Chief

THE PETROLEUM POTENTIAL OF JORDAN

Behind these mountains hides the ancient city of Petra in Jordan. Despite a long exploration history only two producing fields have been found in the country, but there are proven petroleum systems and encouraging signs of extensive shale oil and shale gas deposits.

Inset: Palynologists – experts in the identification of the microfossils which indicate the presence of hydrocarbons in rocks – are back in demand.



GEO ExPro

www.geoexpro.com

GeoPublishing Ltd
15 Palace Place Mansion
Kensington Court
London W8 5BB, UK
+44 20 7937 2224

Managing Director
Tore Karlsson

Editor in Chief
Jane Whaley
jane.whaley@geoexpro.com

Contributing Editors
Thomas Smith
Thomas.smith@geoexpro.com

Ken White
ken.white@geoexpro.com

Halfdan Carstens
halfdan@geo365.no

Rasoul Sorkhabi
rsorkhabi@egi.utah.edu

Paul Wood
sciwrite@btinternet.com

Editorial enquiries
GeoPublishing
Jane Whaley
+44 7812 137161
jane.whaley@geoexpro.com
www.geoexpro.com

Marketing Director
Kirsti Karlsson
+44 79 0991 5513
kirsti.karlsson@geoexpro.com

Subscription
GeoPublishing Ltd
+44 20 7937 2224
15 Palace Place Mansion
Kensington Court
London W8 5BB, UK
kirsti.karlsson@geoexpro.com

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How Equal is Equal?

More women are taking advantage of opportunities in the oil and gas industry

The results of a recent online 'Global Diversity and Inclusion' survey of over 3,000 oil and gas professionals worldwide suggests that career prospects for women in the hydrocarbon industry have improved in recent years and an increasing number of women are taking advantage of those opportunities. However, there remain social and discriminatory barriers to overcome in an industry which is still dominated by men.

The survey, conducted by BP in conjunction with Rigzone, invited respondents to comment on a variety of issues, in order to examine female representation in the energy workplace. Topics covered included asking if career prospects in the industry have improved for women in recent years; how important it is that the sector is attractive to women; and whether there is pay parity or gender-based discrimination in the industry. For example, 20% of respondents 'strongly agreed' that gender-based discrimination occurs in the energy workplace, citing societal conditioning, a lack of qualified candidates and family care responsibilities as the most significant barriers to increasing the proportion of women in the industry – although 12% 'strongly disagreed' that gender discrimination existed. Similarly, over half of those surveyed think that it is important that the oil and gas industry ensures it is an attractive employment sector for women, while 23% think that this is not important.

About three-quarters of the respondents believe that career prospects for women within the industry have improved in recent years, although there was an interesting regional disparity, with 78% of Canadian respondents agreeing, but only 63% from Europe. And although nearly half of those questioned believe gender plays a role in setting pay, only 36% actually said that male oil and gas professionals are more highly paid than their female counterparts.

Mentoring and Flexible Working

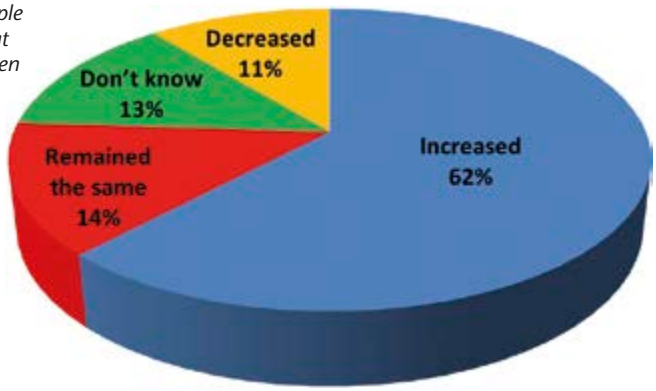
While all respondents agreed that transparency in remuneration structure, availability of mentoring and sponsorship programmes, and flexible working arrangements are important, female respondents placed more importance on mentoring and pay transparency, while male respondents considered childcare-specific benefits more important – and both men and women placed value on flexible work arrangements when selecting an employer. About two-thirds of the women questioned think it important to see female representation at senior level, while 27% of men think this actually unimportant.

These statistics point to progress in gender equality. However, the most compelling statistic was hidden not in the results but in the details of the survey demographics.

Of the over 3,000 people who responded to the survey, nearly 90% were male. ■

JANE WHALEY

The majority of people surveyed believe that the number of women working in the oil and gas industry has increased in recent years.



2013 Global Diversity and Inclusion Report BP/Rigzone

ABBREVIATIONS

Numbers
(US and scientific community)

M: thousand	= 1 x 10^3
MM: million	= 1 x 10^6
B: billion	= 1 x 10^9
T: trillion	= 1 x 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

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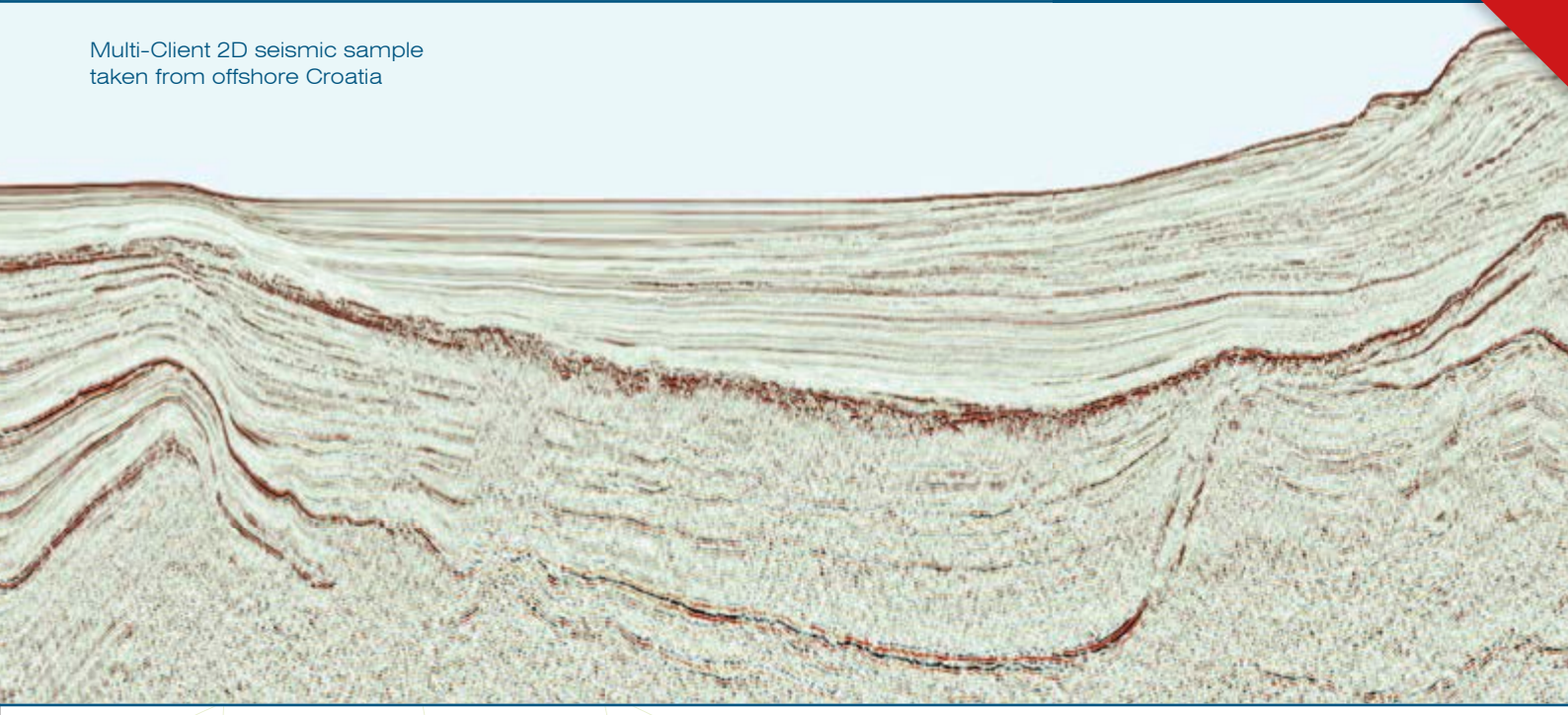
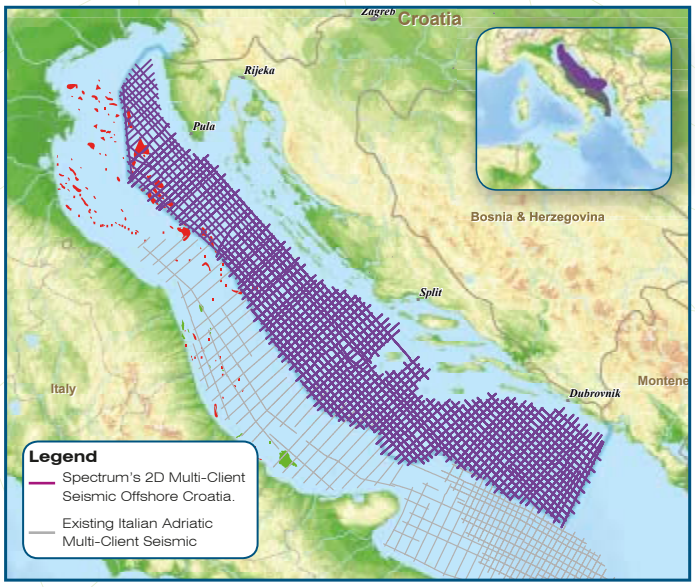
Multi-Client 2D seismic sample
taken from offshore Croatia





Spectrum has acquired a truly unique Multi-Client seismic survey offshore Croatia. This is the only seismic data available to license in this hugely underexplored region which expects to see its first offshore licensing round this year.

The survey, acquired under contract to the Ministry of the Economy in Croatia, covers approximately 15,000 kilometres of long offset seismic data with a 5 km x 5 km grid. It extends across most of the Croatian Adriatic Sea and connects with Spectrum's reprocessed seismic data covering the Italian Adriatic Sea.

Final PSTM data will be delivered at the beginning of February with all processed data available in early April. The Government of Croatia plans to hold a licensing round over the country's offshore continental shelf in Q2 2014.

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Transferring Skills Mitigates Risk

Unlocking the potential of skills transfer to local communities is vital for mitigating risk in Africa.

The discovery of huge hydrocarbon reserves will potentially transform East Africa. International energy companies are set to invest more than US$100 billion in developing the resources discovered in the last decade in Kenya, Mozambique, Tanzania and Uganda. However, to fulfill its potential, Africa requires urgent attention to address its current challenges around the deterioration not only in its physical infrastructure such as road, rail and seaports, but also of the infrastructure around further education.

A lack of sustained investment in education has led to chronic skills shortages and perpetuates a cycle of disadvantage in Africa's global competitiveness. This represents an obstacle to business that requires renewed dialogue between industry, development donors and African governments. The UN Economic Commission for Africa, Africa Development Bank and Africa Union and Regional Economic Communities have all identified this as a problem. They have signalled the absence of science, technology and innovation strategies in many individual African countries as a barrier to sustainable growth, which needs to be addressed.

Many major frontier oil- and gas-producing regions, including Africa, have introduced local content requirements into their regulatory framework to create jobs for nationals, develop skills, and promote technology transfer. Companies also recognise the importance of reducing the high cost of maintaining an international workforce by recruiting local talent. Gone are the days where the oil and gas companies paid for a school to be built, only to realise that there are not any teachers available to teach there. There is no place for tokenism in the corporate social responsibility (CSR) initiatives of today, which demands a far more sustainable, long-term approach.

Community Engagement in Security

From a security perspective, for example, local engagement is absolutely central to overall risk management. Security strategies in Africa require an approach that marries hi-tech responses to the physical security of assets, combined with a more nuanced approach to creating local community support and 'buy in' to commercial activity. Common sense and appropriate risk management dictates that, for an oil and gas company, community engagement through the employment of local security officers automatically applies the first layer of defence to an installation and reduces the overall number of security incidents.

However, risk management is one of many skill sets that are not yet readily available in local African markets. This is why risk management partners such as PGI that are serious about long-term operations in this region are training local people so that they are properly qualified to work in security management positions.

There are obvious challenges related to baseline skill sets. Former Royal Marines all have a certain level of training, but this does not apply to Africa, where there is a considerable variation in military skill levels across the continent. While the Kenyan military and navy have honed their skills through deployment in Somalia, countries such as Tanzania and Mozambique have not had that exposure. And not only combat skills are missing. Many naval personnel in East Africa have not been to sea and lack basic sea survival skills – a fundamental prerequisite for any security professional working in the offshore environment.

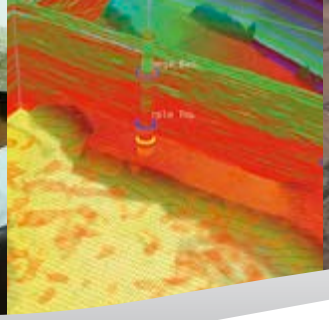
We cannot pretend that a month's training followed by regular refresher courses can replace the rigour of the training considered standard for expatriates from developed nations. But by empowering local people to undertake training that achieves a minimum standard, followed by continuous mentoring by colleagues whilst 'on the job', an evolutionary cycle of development can ensue.

This approach is not an exercise in exemplary CSR credentials, but is central to future proofing the flow of business in the region. Take Brazil, which currently has some of the most demanding local content laws in the world, where awarded contracts require that exploration phase activities use between 37 and 85% local goods and services, while those in the development phase must use 55–80%. The stringency of these laws has the potential to stifle supply, and create bottlenecks and inefficiencies. Should production in East Africa move forward apace, the very same challenge could present itself, exacerbating the inherent skills shortage.

The backdrop of indigenisation, skills transfer and local content, and procurement requirements increasingly adopted across the continent, can prove challenging for energy companies operating within this complex environment. However, the early adopters and developers of creative partnerships that enable them to 'walk the talk' will mitigate reputational risk and gain competitive advantage.

JAMIE MAIN,
Protection Group International (PGI)

Risk management is one of many skill sets that are not yet readily available in local African markets.

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Bad Science for Good Reasons?

There is a clear desire within the industry to grow a European shale gas market.

In his book *Bad Science*, Ben Goldacre expertly attempts to explain 'why clever people believe stupid things'. When offered up so succinctly, the pitfalls to bad decision-making are obvious, if not unavoidable. Who amongst us can claim to never rely on bias or intuition from time to time at least?

When presented with complex problems, we all have a tendency to want to simplify them, to reduce the issue to its essence and concentrate on the things that matter. We know that the subsurface is complex and difficult to describe but we still build models and reduce the problem to a series of simpler issues. With more data and time we then attempt to quantify uncertainties, to reduce the risks to a manageable level. But mostly, all we really want is a simple tool with which to communicate a message to those with less knowledge.

The same is true the world over, not least for the well-intentioned environmentalists and green campaigners, where global energy issues seem to have been reduced to one simple message – 'all fossil fuels are bad fuels, period'. This simplistic view gives those who do not have much time an easily conveyable message, a mantra and a rallying cry, a slogan to energise the masses. But we do not live in a simple world where issues can be boiled down to irreducible 'facts'. Sometimes we need to take a more sophisticated approach, to consider the wider picture and attempt to integrate and reconcile all the data, to stop our 'prejudices running unchecked and unexamined', to borrow Ben Goldacre's phrase.

A New Mantra

In Warsaw at the Shale Gas World 2013 conference, delegates attempted to do just that. Bringing together practitioners from fields as diverse as water management and directional drilling, the intent was to facilitate discussions between policy makers, industry key players and technology firms. One thing is sure; while the public voice their concerns for the impact of shale gas on the environment, the industry is not simply sitting idle, ignoring the issues. Conferences like this show that it is capable of calling on experienced practitioners and well tested technologies and is prepared to go the extra few yards to ensure that risk is reduced to the lowest acceptable levels.

The desire within the industry, and within some sections of the political classes, to grow a European shale gas market is clear. Environmental issues aside, some caution is needed. At a recent UK House of Lords Economic Affairs Committee meeting Professor Dieter Helm said, "…normally…when the price of fossil fuels rises, that contains the seeds of its own destruction (as in the 1970s) and actually a lot more resource comes online. You can understand shale gas and shale oil as being a response to relatively high prices in the 2000s."

That may be true but what if shale gas and oil are about more than providing us with a cheaper energy source? What if there are other benefits? Professor Helm went on to say, "I do find it extraordinary that people want to ban fracking in a context where they are not prepared to ban coal mining and indeed, areas of Europe promote coal mining. Because when one thinks about the relative environmental impacts of the alternatives, coal mining is truly evil in comparison."

Shale gas has been shown to work in the US. While it is true that not all shales are the same, that can also be said of 'conventional' reservoirs – never a problem for the scientists and engineers working on those fields. Shale gas deposits should be capable of relatively fast development times, providing a quick fix for governments attempting to meet increasingly strict carbon emissions hurdles by replacing coal in the energy mix.

There is a message here. It is not a simple one and it requires careful consideration but the new mantra should be clear – 'fossil fuels are not all equal'. Recognising that is the first step – let's rally behind good-science-for-the-right-reasons and not bad-science-for-good-reasons. ■

WILL THORNTON

Will Thornton is Digital Editor for the new GEO ExPro interactive website

San Leon Energy flow testing in the Ordovician shales in the Lewino-1G2 well on Gdansk W Concession in Poland's northern Baltic Basin.

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UKCS 28th Round

The past is the key to the future

The UK 28th Licensing Round is anticipated to open in February 2014, the seventh since the Fallow and Promote initiatives were introduced in 2003 to encourage exploration growth (*GEO ExPro,* Vol. 3, No. 6). Although some areas were excluded from the earliest of these rounds due to the necessity to conduct progressive SEAs, by the 26th Round in 2010 these had been completed and all open acreage, with a few exceptions resulting from logistical, environmental or military restrictions, is now routinely offered for licensing. Tightening of environmental legislation has meant the last three rounds were awarded in two phases as more environmentally sensitive areas required further assessment – in particular delaying awards in the Southern North Sea and, to a lesser extent, the East Irish Sea and Inner Moray Firth.

Although the UKCS has been mapped and re-mapped for nigh on 50 years, it is only in the last ten or so years that the fruits of these exercises have become more widely disseminated, both by oil companies and government. This historic data has considerable value in determining the potential of acreage that will be available in the 28th Round. It is noticeable that new plays and ideas gestated by Promote companies over the last ten years are being adopted by more established players with the financial clout to drill. Most high profile is the Catcher area, in Quad 28, previously neglected except for rare wells on conventional plays, which had little success. The emergence of a Promote company with the freedom to work up its own plays led to the Catcher discovery and the opening of a new play fairway, significantly increasing activity along trend. Similarly, a succession of Promote companies working the northern flank of the Mid North Sea High developed a play that relies on a new source rock for the region and interesting new geological concepts, now being adopted by more established companies and hopefully soon to see the drill-bit.

These examples highlight that through knowledge of previous interpretation, explorers can avoid the pitfall of re-inventing previous mapping, and thus advance new play concepts. By understanding the past, smart work programmes can be designed that address the key issues relating to a prospect or discovery, whether geological, geophysical, engineering derived or commercial. The application of new geological ideas, the acquisition of better seismic data and advanced processing techniques can all result in step changes in understanding. The evolution of exploration ideas through multiple generations of interpretation is a powerful tool when determining what further work could best enhance prospectivity.

Potential in Unlicensed Acreage

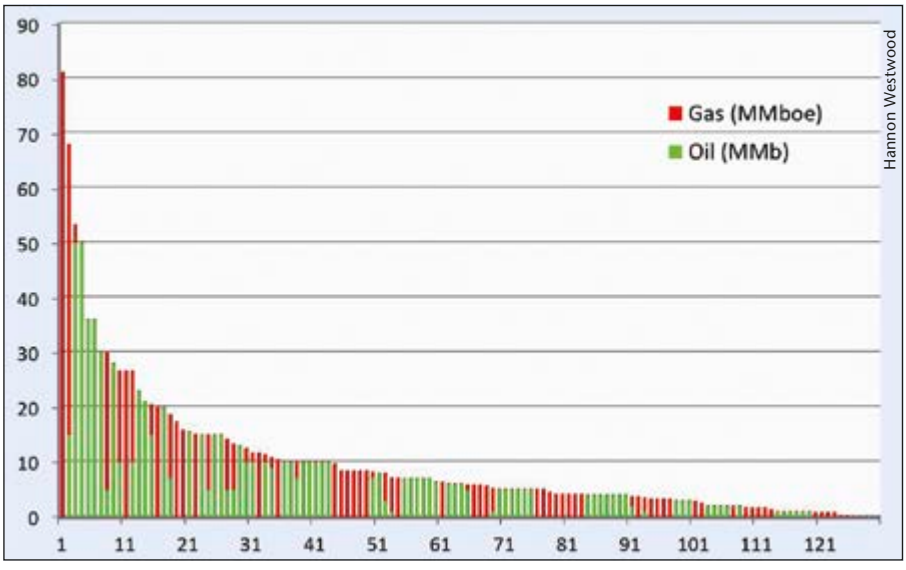
There are over 2,000 undrilled prospects/leads and nearly 500 undeveloped discoveries in the Hannon Westwood database, with 834 prospects/leads and 130 discoveries lying in unlicensed acreage. Significant acreage was relinquished at the end of 2013, which will increase with additional relinquishments expected in the run-up to the 28th Round. The database information has been derived from a variety of sources and is sometimes sketchy but each case was interpreted as a prospect or lead – and at one time believed in by a geoscientist.

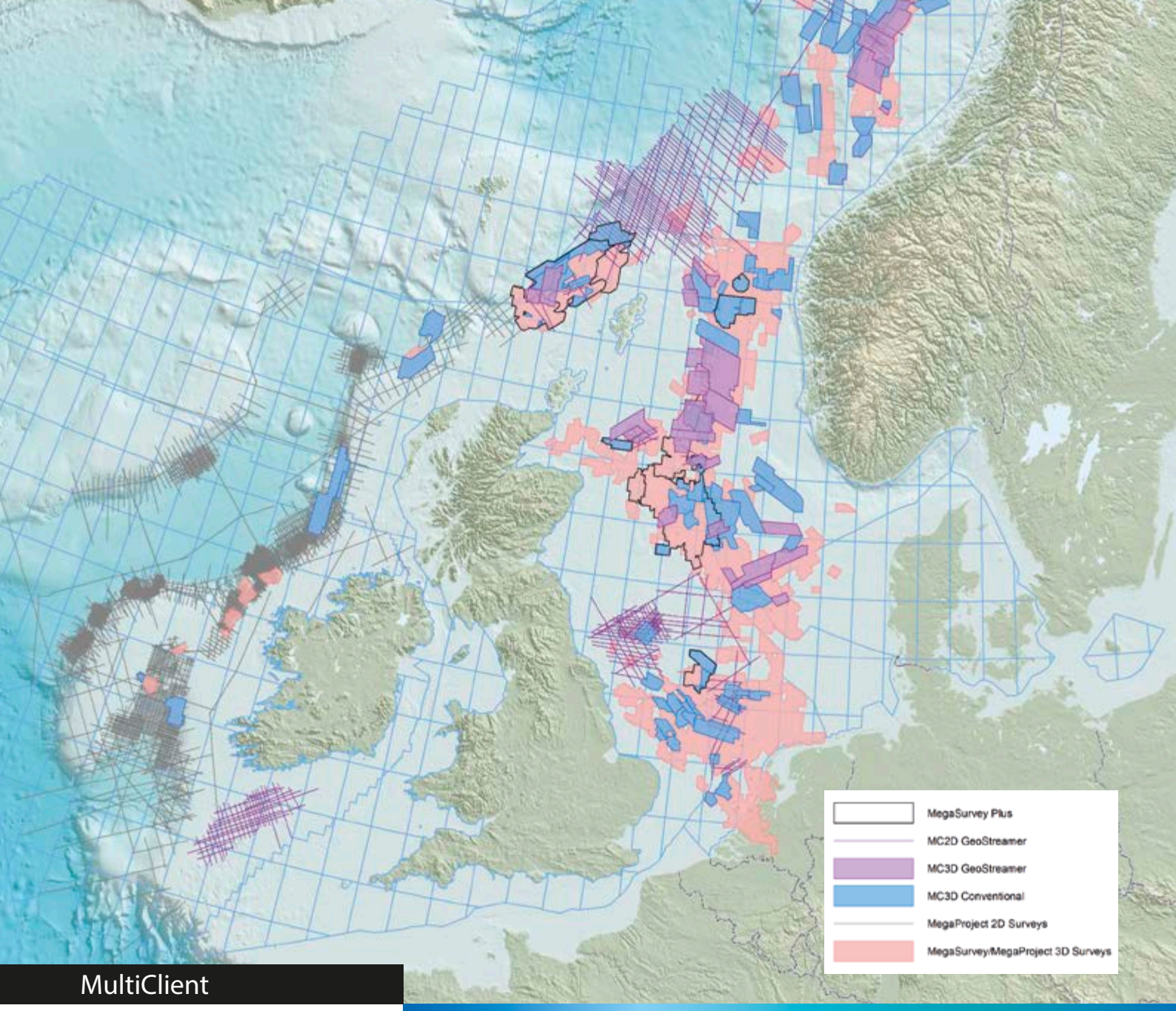
The gross unrisked recoverable resources for the unlicensed prospects are 35.75 Bboe and about 1,275 MMboe for the unlicensed undeveloped discoveries. By size, prospects are shown to have a good normal distribution, although the nine largest, and possibly most nebulous, prospects have been omitted. Over 150 have estimated potential in excess of 50 MMboe recoverable resource, and with a similar distribution, over 30 of the undeveloped discoveries have potential in excess of 10 MMboe recoverable.

Although there is little acreage on the UKCS that has not been available at some point in the last ten years, there is room for new ideas and plays. There is a surprising amount of previously mapped potential which is publicly available, while re-working of data by successive licence groups has increased the understanding of prospect risks. Better geological understanding, seismic acquisition and processing techniques, combined with tools such as EM, have improved resolution and reduced uncertainty. Robust and stable oil prices have enhanced project economics despite rising costs, although to the detriment of some gas-dominant projects. Clearly, by understanding previous technical work and mapped potential, new evaluation of old acreage can be advanced in the most efficient and effective fashion. ■

CHRIS BULLEY
Hannon Westwood

The distribution for the undeveloped discoveries in unlicensed UKCS acreage is near to normal.





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Asia and Africa Investment Dominate Early 2014

Egypt

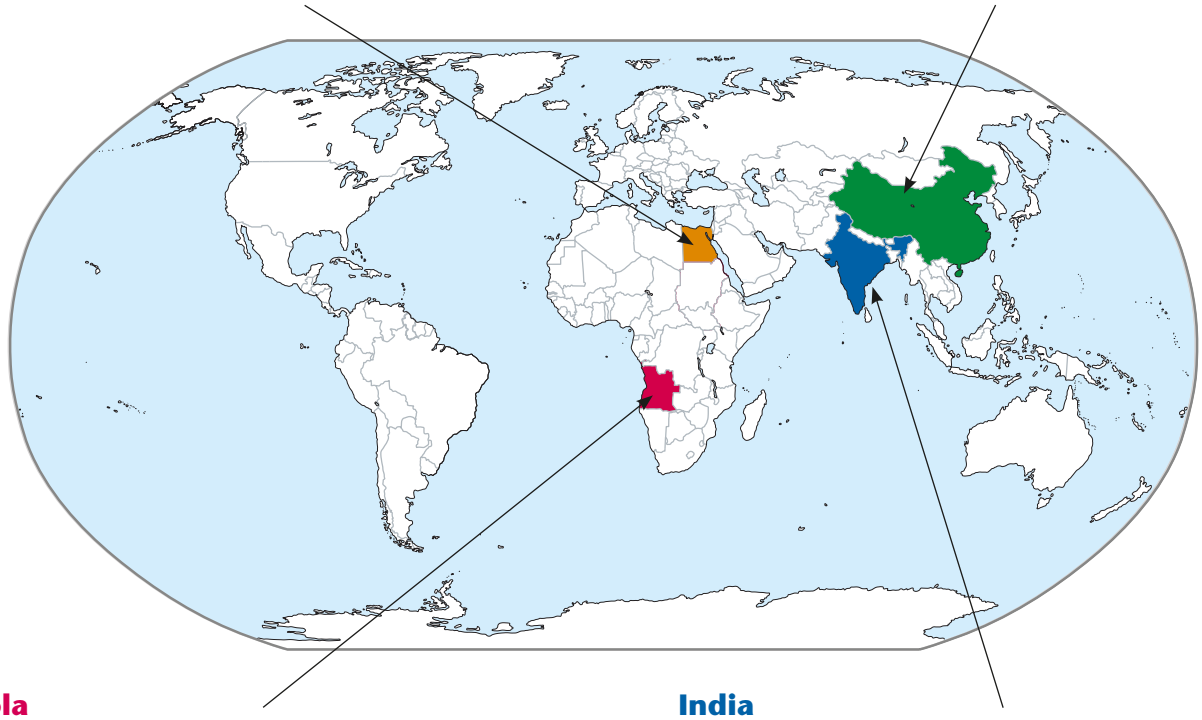
Both the Egyptian General Petroleum Corporation (EGPC) and the Egyptian Natural Gas Holding Company (EGAS) launched international bid rounds early in January 2014. EGPC is offering 15 exploration blocks comprising five offshore Gulf of Suez blocks and 10 onshore in the Western Desert. EGAS is offering seven blocks in the Mediterranean Sea and Nile Delta Basin. In both cases the bid round closing date is set for 19 May 2014.

After the mid-January election, Egypt is facing an economic and investor crisis as it continues a period of turbulent political transition, with basic issues over its political system and electoral future still unresolved. With decline rates at mature oil fields and problems with natural gas availability both supporting the argument for an increased role for foreign investors, the lack of regulatory stability is seen as a major stumbling block. The award process has been shortened in an attempt to retain investor interest but other issues still linger, gas prices in particular. Nonetheless, BP, Eni, BG, and Apache remain major players and neither Egypt's level of production nor the Suez Canal was significantly affected by the 2011 revolution. Oil consumption has increased at an average of 3% per year over the last decade and has exceeded the production rate since 2010, while gas consumption climbed an average of 11% per year since 2001.

China

China National Offshore Oil Corporation (CNOOC) is offering foreign operators a chance to partner it in 25 blocks offshore China, covering over 100,000 km^2. Of the blocks on offer, two are located in Bohai Bay; three lie within both the East China Sea and South Yellow Sea; 10 are in the eastern South China Sea while the remaining seven are located in the western South China Sea. Notably, this is the first time that CNOOC is making blocks in the South Yellow Sea available for foreign company participation. This region is underexplored, and while an understanding of petroleum systems needs to be improved, there is a good deal of optimism regarding its potential. The bidding closes on 30 April 2014.

This round offers a significant amount of offshore acreage, testifying to efforts to boost domestic exploration and production as well as a strategy to bring in foreign investors to buttress territorial claims to acreage in the South China Sea. As yet, no opposition to the round has been mooted by neighbouring countries.



Angola

Following the approval of the strategic framework for the licensing of 15 onshore blocks in the Kwanza and Lower Congo Basins, Sonangol is proceeding to hold its first major onshore concession tender. The decree includes the granting of five onshore blocks exclusively to Sonangol for initial assessment; if they are successful, interested parties will bid on the acreage at the development stage, with Sonangol retaining a participating interest. It is understood that four of the blocks are in the Kwanza Basin and one in the Lower Congo Basin. For the remaining 10 new concessions, national and international interested parties are invited to compete for three blocks in the Lower Congo Basin and seven in the Kwanza Basin. It is believed the decree specifies that Sonangol will retain a 50% share in four of the Kwanza Basin blocks. It is also reported that the state will provide financial support to encourage private domestic companies to bid on the onshore blocks to increase local content in the industry, which only employs about 1% of Angolans, while investing about US$20 billion a year. The authorities intend increasing domestic production from 1.75 MMb/d to 2 MMb/d by 2015, a target that seems unlikely given the delays in launching the round.

India

At the Petrotech 2014 conference in January the Indian government announced that 46 blocks have so far been finalised for inclusion in the 10th round of the New Exploration Licensing Policy (NELP X) which will be launched in February. According to Petroleum Minister, Dr Verappa Moily, the total numbers of blocks to be offered may reach 60 if the government can secure additional environmental, defence and other permit clearances. The 46 identified blocks, with a total area of 166,053 km^2, have received all statuary clearances from relevant ministries and include 17 onshore, 15 shallow water and 14 deepwater blocks. It is understood that they will be offered under 'completely revamped terms' based on revenue-sharing rules and new gas pricing. Revenue sharing will be determined in a competitive bid process with the bidder offering different percentage revenues for different levels of production and price levels. The proposed new regime is yet to be approved but analysts are sceptical, believing that revenue-sharing models only really work in areas of significant oil reserves, which India does not have.

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Tales of the Unexpected

A look ahead at the next two years

THINA MARGRETHE SALTVEDT, PH.D

The Brent oil price is expected to be marginally lower, at US$106/barrel in 2015, down from US$108/barrel in 2013. Non-OPEC oil production will increase more than growth in demand until the global economy and consequent demand for oil accelerate. The OPEC buffer capacity is expected to increase, resulting in a more balanced market and less upward price pressure. With significant risk of supply-side disruptions in oil-producing countries, oil prices could end up higher than estimated. Oil price volatility will remain low.

Global oil consumption growth in 2013 was about 1.2 MMbpd, as the US economy shifted into a higher gear and Europe crawled out of recession. Overall, OECD demand was stronger than expected last year, while non-OECD demand was weaker. The forecast for global oil demand growth rises to 1.3 MMbpd for 2015. Higher economic growth forecasts for large oil-consuming countries such as the US, China and Japan contribute most to this increased demand forecast, while macroeconomic growth remains the main downside risk.

OPEC and Non-OPEC Outlook

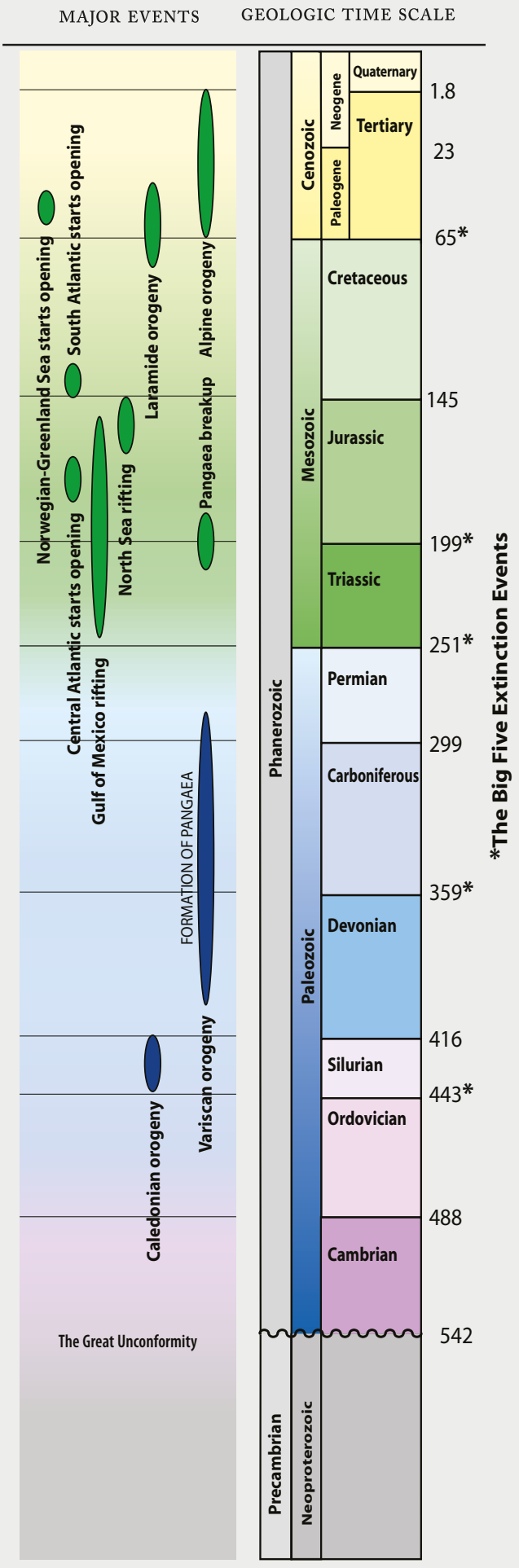
The impressive growth in the supply of oil outside OPEC is expected to continue, the lion's share generated by unconventionals in the US and Canada. Russia has proved a positive surprise recently, and Brazil, China and Kazakhstan will also contribute to non-OPEC production growth next year. Elsewhere, Mexico plans to reform the country's oil industry although this may prove difficult. South Sudan's production has risen sharply, but political unrest suggests additional disruptions. Meanwhile, total North Sea oil production is set to fall in 2014–2015, while on the Norwegian Continental Shelf it is expected to have bottomed out in 2013 and will slowly edge up.

The biggest challenge facing oil companies will be control over escalating costs. With flattening oil prices, this will squeeze earnings margins, so new projects may be put on hold, increasing the risk of a tighter market when the global economy picks up momentum.

OPEC's production capacity is expected to increase. Political unrest in key countries will continue to influence the investment climate, security of supply and production, and the risk of additional supply side disruptions remains high.

Despite the temporary deal over Iran's nuclear programme, the chances of a lasting solution are unlikely, so major changes in Iranian oil exports are not expected. Iraq has the potential to increase production significantly, but growing political unrest, a lack of oil legislation and disagreement about revenues from Kurdistani oil may curb the ambitious plans. If, contrary to expectations, Iran and Iraq increase oil production strongly, there may be a downside risk for price forecasts, but Saudi Arabia will probably cut production to stabilise the market. There is also a downside risk for oil production in Nigeria and Libya due to mounting political unrest.

The need for OPEC's production will be reduced by 2015, leading to a more flexible supply/demand balance and lower pressure on prices. However, with political unrest in key countries, there is a significant risk that we will see supply side disruptions cutting sharply into OPEC's buffer. ■



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Harrier Explorer

2D Solid streamer long offset/Source vessel.

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Munin Explorer

2D long offset/Source vessel.

Equipped with 12,000m of Sercel ALS streamer and 6 gun strings of Bolt 1900 LLXT capable dual source of wide tow configuration.

Hawk Explorer

2D Long Offset/Source Vessel.

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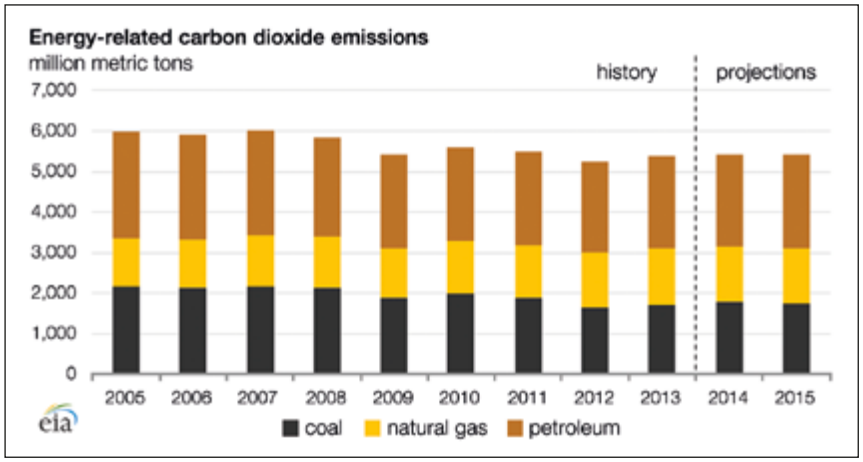
US Energy Emissions Up

According to the Energy Information Administration (EIA), energy-related CO_2 emissions in the **US** in 2013 were about 2% higher than the previous year, probably the result of a small increase in coal consumption in the electric power sector. Overall, however, emissions are about 10% lower than they were in 2005, and this level of reduction is expected to continue, making the government's goal of a 17% reduction in emissions from the 2005 level by 2020 appear feasible.

The reduction since 2005 is thought to be a response to a number of factors, including the recession-led weak economic growth of recent years, as well as power sector decarbonisation since 2010 and continuously improving energy efficiency across the US economy. The abundant and inexpensive supply of natural gas, resulting from the widespread use of new production technologies for shale gas, is obviously a major driver in CO_2 emission reductions. ■



Polish Shale Gas Soon?

Long promised, it would appear that **shale gas** extraction may commence in **Poland** in the not too distant future. According to United Oilfield Services, a provider of seismic data, hydraulic fracturing and modern drilling equipment for shale gas exploration, recent changes in ministerial positions indicate that the Polish government is finally addressing the issue of changes to regulations and taxation affecting shale gas, hopefully opening up the industry.

Poland has reserves estimated to be between 346 and 768 Bcm (12–27 Tcf) – although estimates were originally much higher – and hopes to become less dependent on coal, currently providing around 85% of its energy needs. But the combination of a reduction in reserves estimates and a cumbersome regulation and taxation system has resulted in several high profile companies such as Eni, ExxonMobil, Marathon Oil and Talisman Energy withdrawing from Poland in recent months. ■

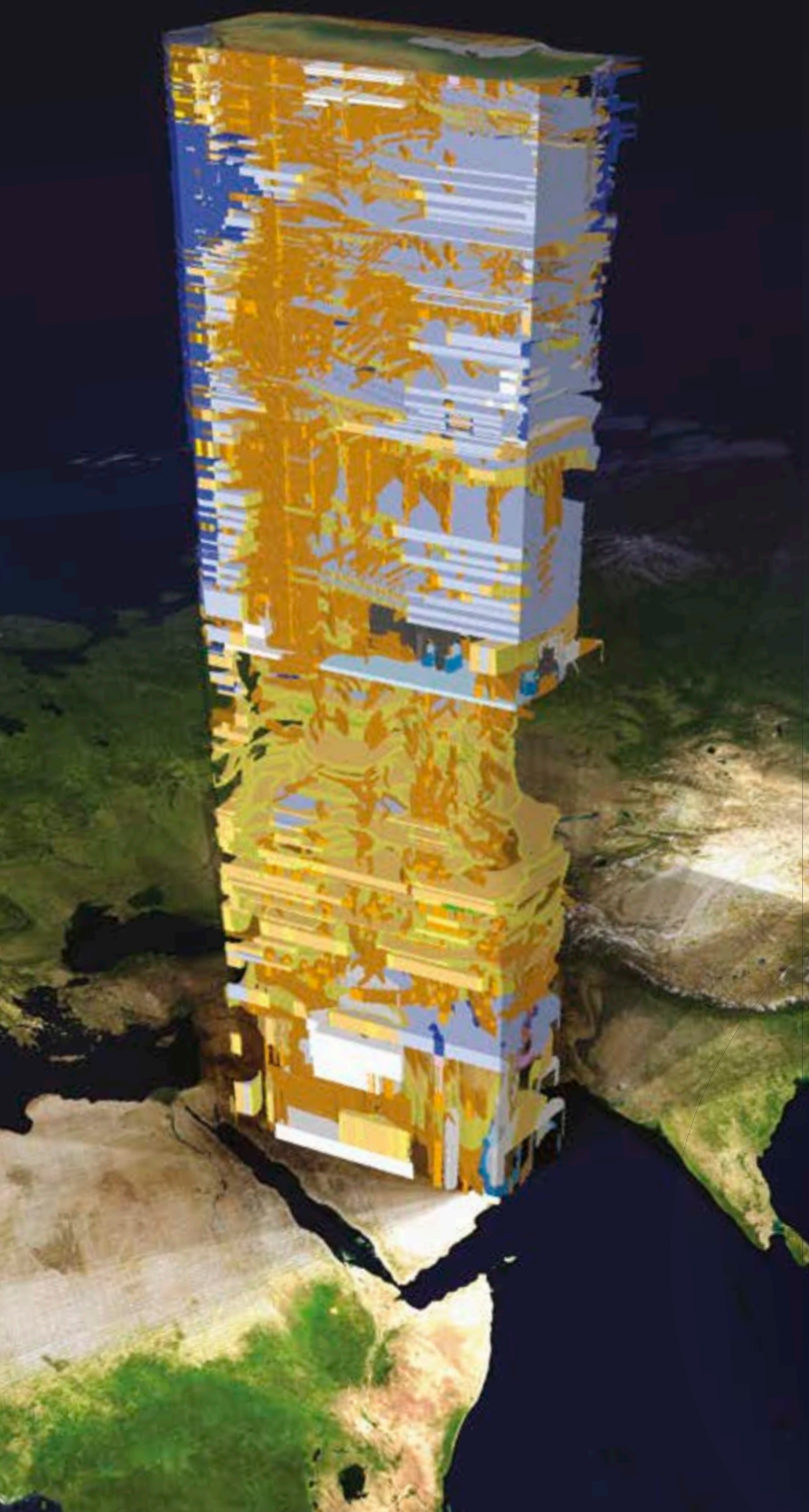
A World of Opportunities

From Morocco to Madagascar, from the Eastern Mediterranean to offshore Namibia, across the expanse of **Africa**, activity is humming. Unfortunately some of the activity is conflict. However, political risk can be addressed. Exploration does continue in troubled regions – the search continues offshore North Africa.

Both on and offshore Africa, major new reserves are proved almost monthly. East Africa continues to be the site for the discovery of thick gas-filled reservoirs; could similar deposits be found across the Davie Fracture zone offshore Madagascar, where new seismic surveys have just been completed? The onshore East African rifts are a developing oil province, with successes in Uganda and Kenya; rifts plays in Chad, South Sudan, Ethiopia, Eritrea and Somalia beckon. The western flank of Africa is also a focus of discussion; much can be learned from the conjugate margins of South America and Africa, and regional studies of several West African basins indicate more possible shelf slope fans.

All these and many other issues will be on the agenda for the annual Africa conference, 9–10 September in **Houston**. This is the 13th in the series of conferences organised jointly by the Houston Geological Society and the PESGB, held alternately in London and Houston. Presentations and posters will address major questions about recent plays, successes and prospects, plus the geology and the application of emerging technologies. Further details on the websites of the two organising societies. ■

New dimensions in exploration



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[photo credit: NASA]

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Ramform Atlas Launched

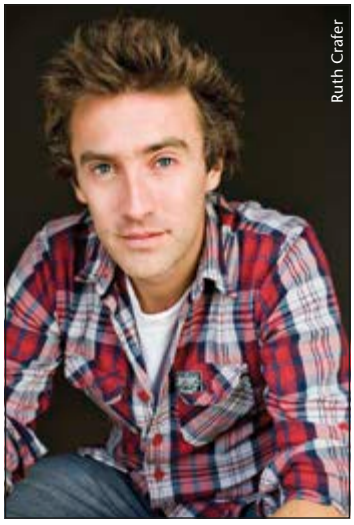

PGS

Claimed as the 'world's most advanced seismic vessel,' **PGS** recently held a naming ceremony for the ***Ramform Atlas,*** the second vessel in the ultra-high capacity **Titan Class**. The ceremony took place in Nagasaki, where the vessel was built.

The Ramform vessels are known for their distinctive and unusual hull shape, with a stern which is 70m across, allowing it to tow up to 24 streamers, each 12 km long. This also gives room for massive amounts of seismic equipment with no compromise to working space or safety, and there is accommodation for 80 crew members. The vessel also allows for extreme fuel capacity, offering survey endurance of 150 days – enough to sail her twice around the planet without refuelling – and this greater operational capacity will result in faster completion of surveys and increased uptime in marginal weather.

Her sister ship, the ***Ramform Titan,*** pictured here, has been operating very successfully since delivery in April 2013. ■

Exploring Mars Via Dallas


Ruth Crafer

Dallas Campbell

The Petroleum Exploration Society of Great Britain (**PESGB**) have announced that the speaker at the Stoneley lecture for 2014 will be broadcaster **Dallas Campbell**, who is well known as the presenter of the popular science programme, 'Bang Goes the Theory', as well as the enormously successful 'The Gadget Show' and 'Supersized Earth'. The title of Dallas's lecture is '**Unlocking the Secrets of the Red Planet**', and he will look at the geological opportunities offered by space exploration, in particular the exploration of Mars.

The **Stoneley Lecture** series, named after the late emeritus Professor of Petroleum Geology at Imperial College, Robert Stoneley, is an annual event open to all, not just PESGB members, and designed to educate and entertain everyone about the benefits of the scientific and technical aspects of petroleum exploration. The event will be held in London on 11 March 2014. Further details and tickets can be obtained through the PESGB website. ■

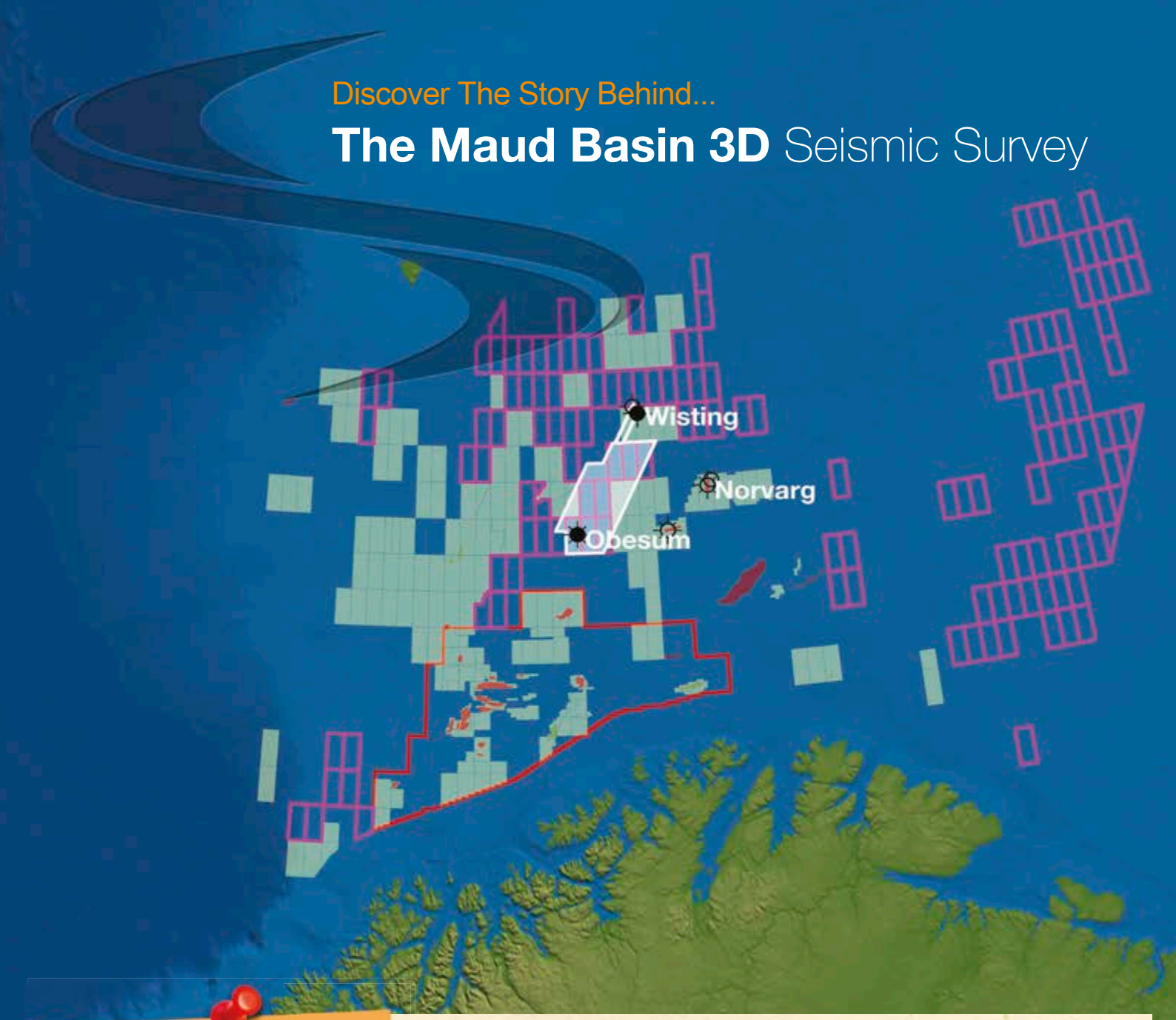
Petroskills Makes Major Acquisition

PetroSkills, LLC, recently announced that it has acquired **Resource Development Company**, LLC (RDC™) of Birmingham, Michigan, a company which has a reputation for excellence and quality in both content and the management of knowledge transfer process. RDC specialises in **e-learning**, and has an e-library containing more than 600 hours of industry-validated content covering operations and maintenance; health, safety and environmental factors; refining; petrochemical; production; and a wide range of other topics. The acquisition of RDC significantly expands the range of products and services available to members of the PetroSkills Alliance and to PetroSkills customers worldwide.

The **PetroSkills Alliance** was created in 2001 by BP, Shell and OGCI to provide 'important but not unique' high-quality, competency-based training. Today it comprises over 30 companies and has successfully evolved into an industry driven, industry-approved programme that spans the value chain. PetroSkills continues to grow as additional organisations join the PetroSkills Alliance at various levels. ■

Discover The Story Behind...

The Maud Basin 3D Seismic Survey



- Barents Sea, Norway
- 3,300 km^2
- Broadband Technology
- Available Q2 2014

Following the Wisting oil discovery in 2013, industry attention once again focused on the possibilities of large commercial oil reserves in the Barents Sea. With the likely source of the oil to be the Jurassic Hekkingen Fm, the untapped potential of the nearby Maud Basin and surrounds quickly became apparent.

Identifying the need for a modern 3D dataset, Searcher proposed and industry agreed, that a broadband 3D seismic survey to extensively explore the basin and surrounding flanks was the best way forward.

With a large portion of the survey area subsequently nominated for the 23rd Bidding Round, this story is just getting started.

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Petroleum Systems in Jordan

DR. MUNIM M. AL-RAWI,
Carta Design Limited

Despite a long exploration history, only two producing fields have been found in Jordan, yet it has proven petroleum systems and reserves of both shale oil and gas. We look at the potential within this long-neglected Middle Eastern country.

Jordan is located within the producing sedimentary basin in the North-West Arabian Plate. Exploration was initiated in the country in 1947 by the Iraqi Petroleum Company, yet to date only two fields, with low production capacity, have been found. According to the NRA and NPC, the estimated reserves are about 1 MMbo and 600 Bcfg and production is only about 22 bopd and 14 MM cfgd.

There are, however, encouraging hydrocarbon shows in different parts of the country, with proven petroleum systems in the Infra-Cambrian, Lower Palaeozoic, and Cretaceous stratigraphic record and potential reservoirs in Triassic carbonates and Tertiary sandstone. A lack of adequate structures may explain the dearth of discoveries. In addition, recent investigations have shown the presence of huge oil shale reserves in the exposed immature Upper Cretaceous source rocks, with shale gas in the widely distributed Ordovician source rocks, and shale oil also in the frequently found Silurian source rocks.

Regional Geology and Tectonic History

Jordan occupies the north-western Arabian Plate, with most of the country located within the shelf part of the plate. Precambrian basement is exposed along the edge of the Arabian Shield in southern Jordan and northern Saudi Arabia and consists of accreted micro continental terranes, overlain by post-tectonic sediments and volcanics.

Extensional, rift-related tectonics dominated the area during late Pre-Cambrian to early Cambrian periods. The Najd Fault System which originated during this time has resulted in the formation of large depressions that were subsequently filled with Palaeozoic clastics.

Passive margin conditions with periods of transgression and regression dominated the area during the Early Palaeozoic, whereas active tectonic movements of deep erosions were dominant in Late Palaeozoic periods. Upper Ordovician glacio-fluvial sandstones and Lower Silurian organic-rich shales were among the most important sediments deposited in this period (Figure 1).

Most of the Palaeozoic basins in Jordan are compartmentalised by Cretaceous-Tertiary

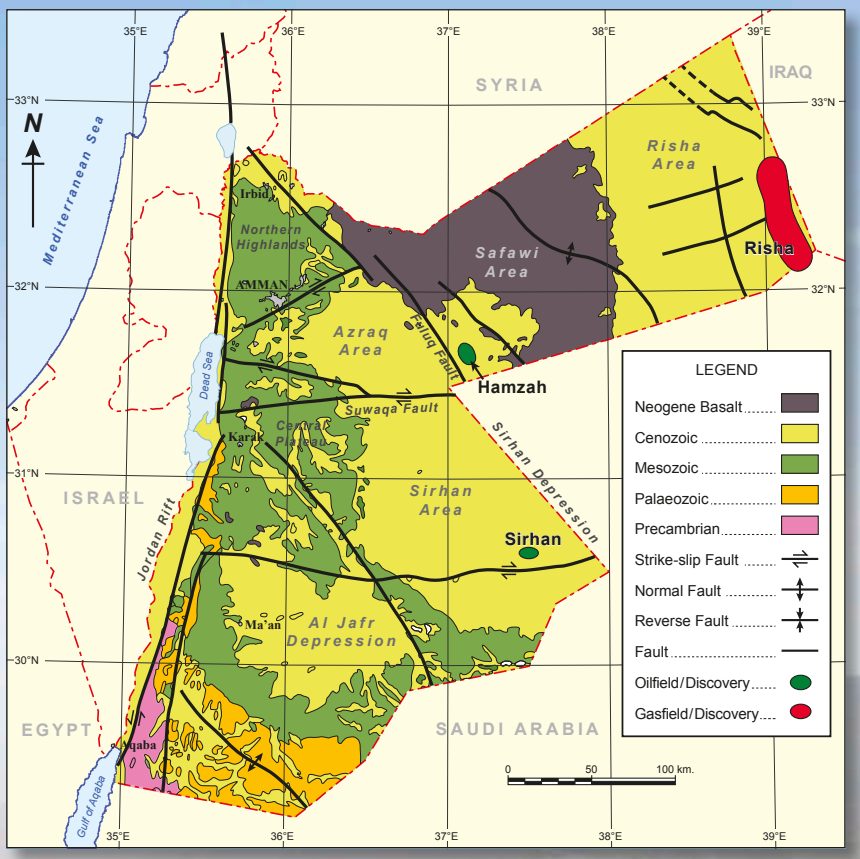


Figure 1. Simplified geological map of Jordan (modified after NRA 2006, in Naylor et al., 2013).

Upper Cretaceous limestones and marls, overlain in places by Tertiary basalt, are exposed in the mountains near the Dead Sea.

Anne Whaley Sousou

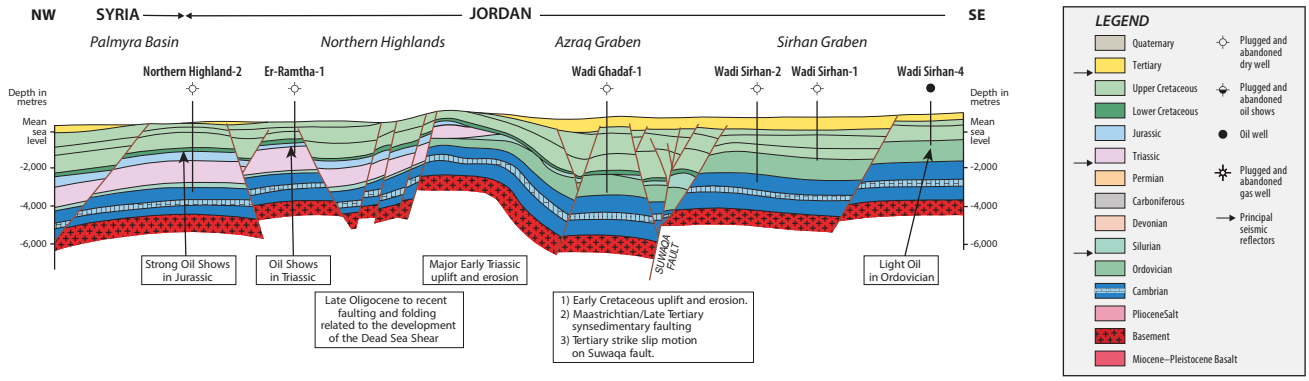


Figure 2. NW–SE regional cross-section from Syria to Jordan. Modified after NRA, 2001.

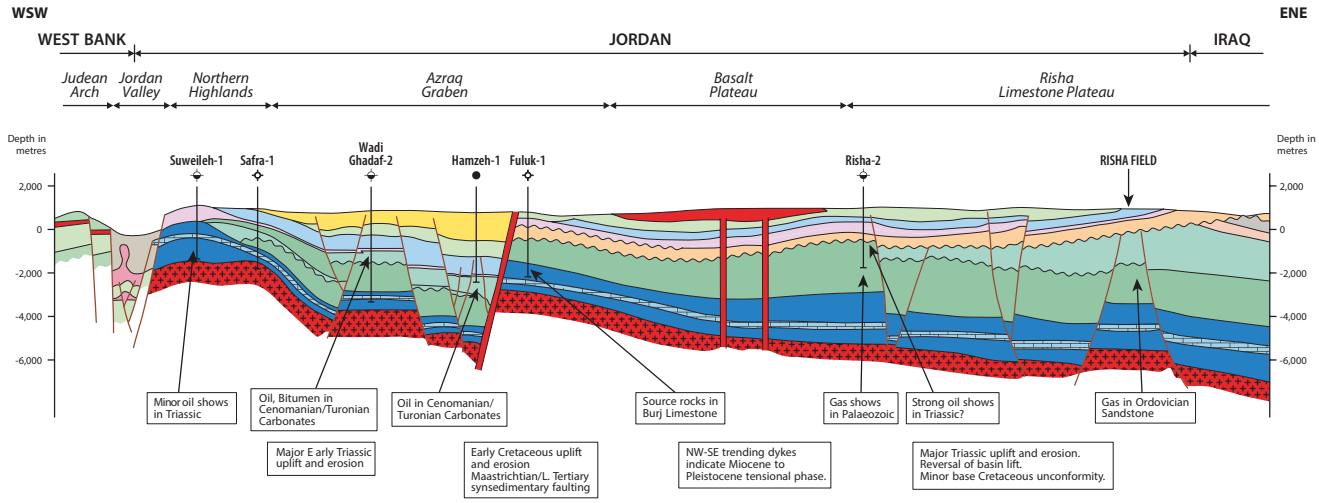


Figure 3. Schematic ENE–WSW regional cross-section from Iraq to the West Bank. Modified after NRA, 2001.

wrench faults related to Late Cretaceous fragmentation of the Arabian Plate. During the Permo-Triassic, extensional tectonics rifted the Arabian Plate from the Turkish-Iranian Gondwanan fragments. Mesozoic-Cenozoic basins in Jordan such as Azraq-Sirhan are dominantly rift-related.

A mid-Tertiary tectonic phase resulted in the opening of the Red Sea and the development of the Dead Sea–Wadi Araba Graben and the Arabian Plate boundary.

Four petroleum systems have been identified in Jordan. Two are within the Infra-Cambrian–Lower Palaeozoic sequences, one within the Triassic-Jurassic sequence and one within the Cretaceous-Tertiary sequence (Figures 2 and 3).

Infra-Cambrian–Cambrian Petroleum System

This system is semi-proven in the Tabuk Basin of northern Saudi Arabia (Kahf field) and is of potential in the Jafr Basin of south-central Jordan. The lack of other discoveries can be attributed to the poor understanding of the system, as well as the relative immaturity of the Infra-Cambrian–Cambrian source rocks and the lack of oil extract to source correlation. The shale of the Infra-Cambrian Saramouj Group and the Cambrian Salib Formation are lacustrine in origin while the carbonates of the overlying Burj Formation are marine. No data are available on the quality of the organic matter and its maturity. In northern Saudi Arabia, however, an Infra-Cambrian–Cambrian source has been postulated for the oils in the Ordovician Sarah Formation reservoir.

The basin architecture in Jordan is characterised by series of asymmetrical half-grabens. Structural highs are step-faulted, uplifted margins of rotated basement blocks. Structural lows are the broad sags of syn-rift infill at the down-faulted margins of the listric fault-bounded basement blocks, as seen in Figure 2. The timing of structural development of the main rift is postulated to be in the Middle to Late Early Cambrian.

The primary reservoir is the porous arkosic sandstone of the pre-rift Salib Formation, sourced from down-dip syn-rift shales or from the limestone and shale of the Middle Cambrian Burj Formation.

Apart from the Kahf field in northern Saudi Arabia, there are no other wells to prove this system. This is an area for future exploration work in the South Jordan Block.

Ordovician-Silurian Petroleum Systems

The Ordovician-Silurian system in Jordan is part of the Tabuk-Nafud Basin covering northern Saudi Arabia and the Rutbah High in western Iraq. It is proven in the Risha gas field in north-east Jordan, and the Sirhan 4 light oil discovery in south-east Jordan, at the Akkas oil, gas and condensate field, western Iraq and most recently, the Jalamid gas discovery in northern Saudi Arabia.

There are several horizons with source rock potential within

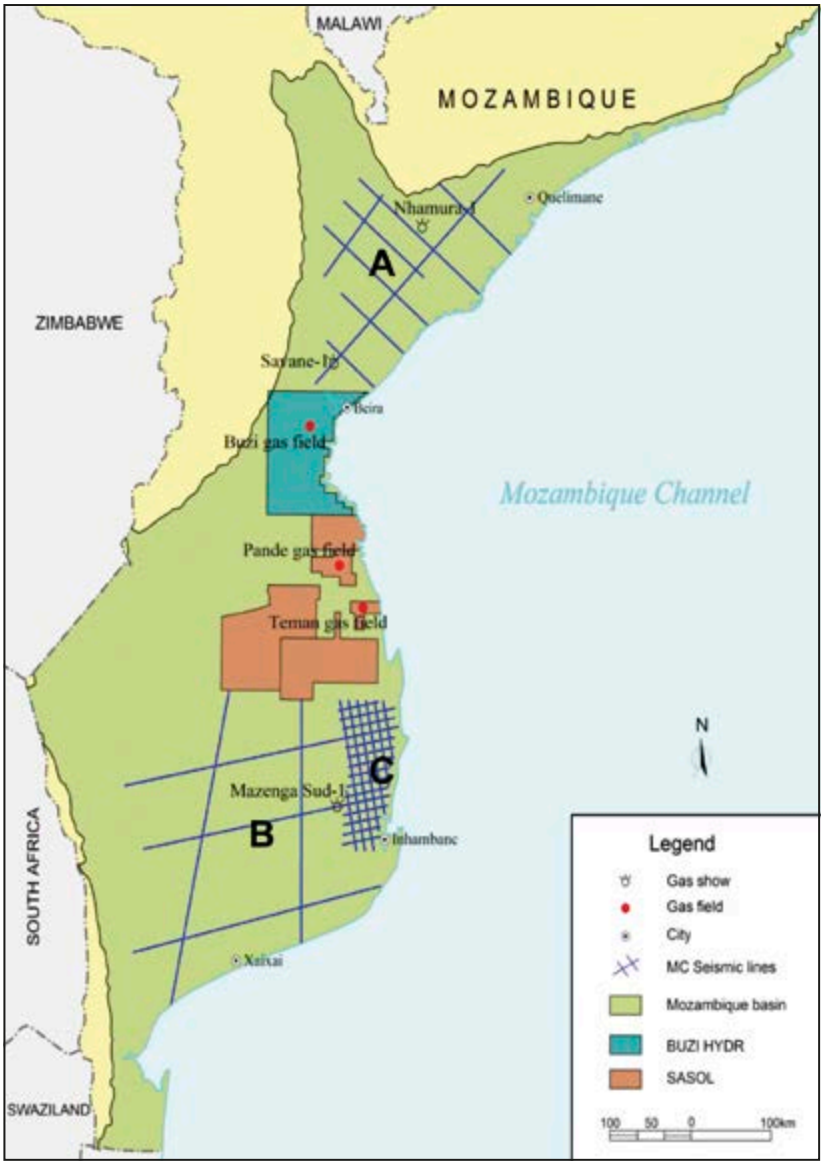
Multi Client Projects in Mozambique Onshore

With the recent large discoveries in the Ruvuma Basin, industry interest is turning again to the Mozambique Basin. Earlier exploration activities and leads suggest a high hydrocarbon potential in passive continental margin sedimentary deposits and rifted grabens/half-grabens systems within the area.

BGP MC has entered into an agreement with the National Petroleum Institute of Mozambique (INP) to exclusively carry out a 2D speculative seismic survey in onshore Mozambique. Covering a very broad area of coastal plain and continental shelf in the Mozambique Basin, the project area is believed to be a very prospective one for hydrocarbon exploration.

Lines are designed to map structure framework, sedimentary formations from ages, and to investigate hydrocarbon potential of the area. BGP will provide clients with high quality seismic data by utilizing powerful resources and state-of-the-art technology.

BGP plans to commence the project in Q2 2014, and a beneficial rate will be offered to early participants. INP is committed to launching a bid round based on the seismic data collected and oil companies should buy the data to apply for the concession blocks in the survey area.



Zambezi (area A): 1170 km
South Mozambique regional (area B): 1520 km
Mazenga (area C): 1775 km

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Figure 4. Bitumen in vuggy crystalline dolomite core at a depth of 478m in well RH-2 (Wadi EsSir Formation, Upper Cretaceous). Photograph by Mark Fitzpatrick in Naylor et al., 2013, with the authors' permission.

the Ordovician and Silurian sequence in Jordan. The shale units of the Ordovician Hiswa and Dubaidib Formations, below the Risha Sandstone Member, are indicated by several independent geothermal studies to be over-mature source for the dry gas in the Risha sandstone reservoir in the Risha field, and may have contributed gas to the Sirhan 4 discovery. The Silurian hot shales are proven to be in the oil window, both in the Risha and Sirhan areas.

The play target is the Ordovician sandstone reservoir in the Dubaidib Formation upper sandstone section, the Risha Sandstone Member in the Risha gas field and its equivalent in several Sirhan wells in south-east Jordan. Prospective traps in the Risha High are low relief anticlines and stratigraphic traps at top Ordovician level, while in the Sirhan area traps are found in numerous roll-overs, horsts and fault blocks. The Triassic carbonate reservoir in north-east Jordan could also be considered a stratigraphic oil play sourced from the Silurian shale. Upper Cretaceous carbonate core was recovered with cavities filled with asphalt oil, shown through geochemical analysis to be Palaeozoic oil (Figure 4).

The base Silurian shale is a proven regional seal for the underlying Ordovician reservoirs, both in the Risha and Sirhan areas. However, for individual sandstone reservoirs, which are interbedded with shales within the Ordovician succession, the shale units are local seals (Figures 2 and 3).

Triassic Petroleum System

This system is proven in oil and gas fields such as the Cheriffe field in the Palmyra area of central Syria. It is very prospective in northern Jordan, where the equivalent of the Syrian Kurra Chine carbonates, evaporates and shales are present. The organic rich layers within the Syrian Triassic Amanus Shale and Kurra Chine formations are similar in composition, consisting of fine-grained limestone and dense calcareous shale, and these sediments are also present in northern Jordan, where oil generation is proved by the existence of oil seeps associated with spring waters flanking the Ajlun Dome. Live oil shows were also observed in a core from the Jurassic limestone obtained from the NH-2 well near the southern Syrian border (Figure 2).

The Triassic and Jurassic carbonates and evaporates are ideal reservoir and seal alternations, with the carbonate reservoirs exhibiting porosities of up to 20% in places. These are interbedded with anhydrites, which form an effective seal. The regional northwards plunge is interrupted by horst blocks, step faults, anticlinal structures and marginal swells. In the East and West Safawi areas in northern Jordan, the plays are mostly in graben-associated structures and stratigraphic pinch-outs. One major stratigraphic anomaly in the Upper Triassic carbonates, presumably associated with reefal build-up, is recognised in the northern part of the Safawi Block which require testing by drilling.

Cretaceous-Tertiary Petroleum System

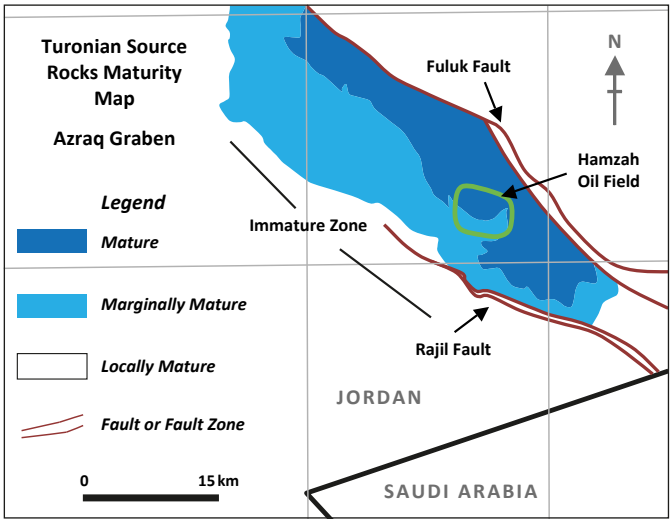
This system is proven in the Azraq Graben, which is located in central Jordan. It is an asymmetrical graben with significant thickening of the Cretaceous and Paleogene sediments, bounded in the east by the north-west to south-east trending Fuluk fault. The area was the site of early exploration drilling activity, where the only producing Jordanian oil field, Hamzah, is located. Source rocks are the interbedded Cenomanian and Turonian Wadi EsSir limestones and marl. All the drilled wells in the Azraq Graben have penetrated the Maastrichtian Ghareb oil shale formation at shallow depths.

In addition to the proven oil accumulation in the downthrown side of the Fuluk fault, there are shallow prospects on the upthrown block, where the structural style is one of rotated fault blocks. Source rocks in the downthrown side of the graben are exothermally mature for oil (Figure 5).

Subsequent to the first oil discovery at Hamzah-1, sixteen wells were drilled in the area, including appraisal and production wells, with another thirteen wells drilled elsewhere in the graben. Several wells produced non-commercial reservoir oil, and others found non-conventional oil from Wadi EsSir source rock formation.

A series of compressional anticlines are found on the downthrown side of the southern east-west boundary fault of the Azraq Graben, the Suwaqa Fault. These anticlines trend in an east-west direction. Several high-level closed anticlines have been mapped at the western up-dip margin of the Azraq Graben, and they represent good targets at shallow depths, since they lie on possible migration pathways from deep basinal areas (Figures

Figure 5. Turonian source rock maturity



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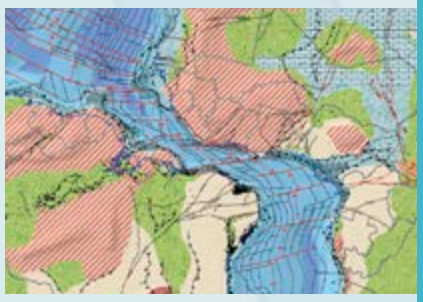

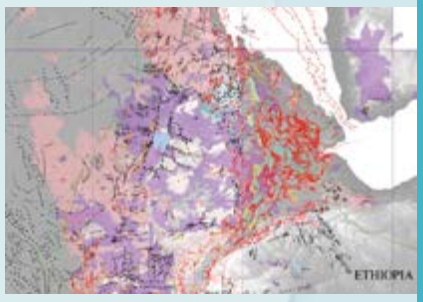

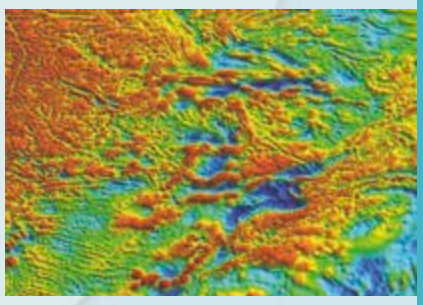

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2 and 3). The source rock Wadi EsSir Formation is also the effective seal for oil accumulations in the Azraq Graben.

In the Dead Sea Graben, the organically rich Upper Cretaceous Ghareb shales and marls are known from both sides of the rift, and have widespread distribution over most of Jordan. Unlike the near-surface positions they hold on the basin margins, these source rocks are thrown into the rift to depths of more than 5,000m. At this depth the source rocks reached the oil window, and the generated hydrocarbons migrated upward and onward to supply traps and seeps on the Jordanian side of the graben. The issue in the Dead Sea area is not source, but the apparent lack of good reservoir rocks, as well as the mobility of salt in the centre of the basin, which prevents wells reaching the Palaeozoic, Triassic, Cretaceous and Tertiary reservoirs.

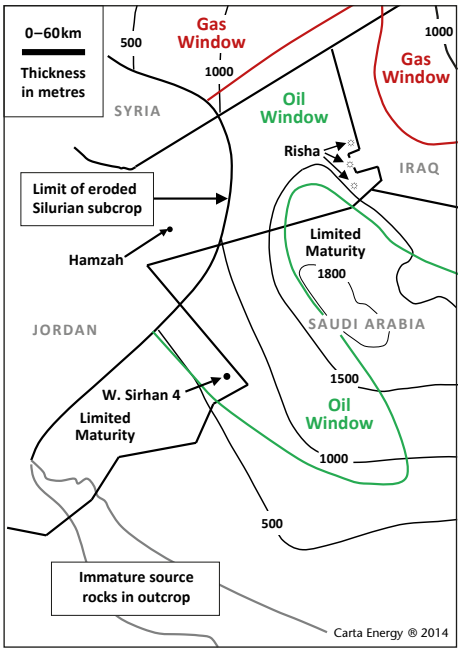


Figure 6. Silurian shale oil in Jordan

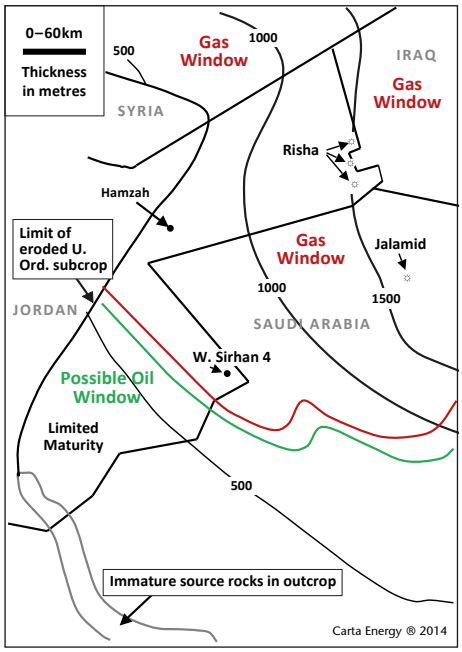


Figure 7. Ordovician shale gas in Jordan

Oil Shale, Shale Oil and Shale Gas Potential

The paucity of adequate structures may explain the lack of many discoveries in Jordan. However, recent investigations have shown the presence of huge oil shale reserves in the exposed immature Upper Cretaceous Ghareb source rocks. Some international oil companies already have licences for the exploitation of the oil shale in Jordan.

Silurian shale oil is another widely distributed source rock in Jordan, both in the 'panhandle' east of Jordan, including the Risha and Safawi areas, and in the Sirhan area, south-east Jordan (Figure 6). Ordovician shale gas is also found in the widely distributed source rocks in eastern and south-east Jordan (Figure 7). This promising unconventional potential should see the acceleration of high-tech hydrocarbon exploration activities in Jordan.

References:

Naylor, D., Al-Rawi, M., Clayton, M., Fitzpatrick, M.J., and Green, P.F., 2013. Hydrocarbon Potential of Jordan. J.P.G., Vol. 36 (3), July 2013, pp. 205-236.

Natural Resources Authority (NRA), 1997, 2000, 2001 and 2004. Petroleum Exploration Opportunities in Jordan. Amman, Jordan.

Looking east from Wadi Rum Village. Cliff-forming Cambro-Ordovician sandstone of the Salib, Umm Ishrin and Disi Formations is resting on the peneplained surface of the Precambrian Aqaba Complex. These same rocks form the steep cliffs at Petra (GEO Expro, Vol. 10, No. 4)

Munim Al Rawi

Looking Down the Wellbore

What is petrophysics, what does it do for the oil industry, and where is it heading?

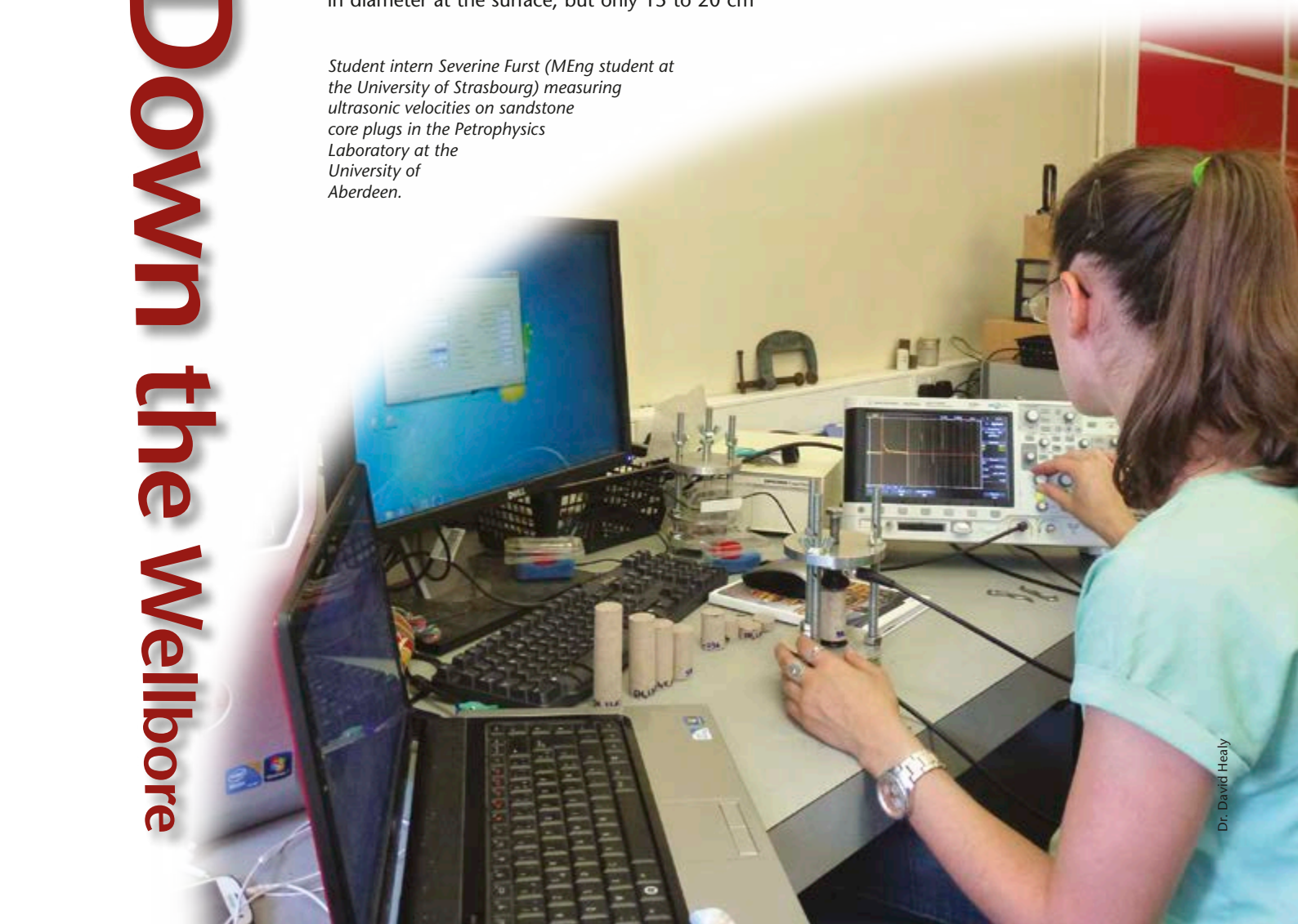
DAVID MACDONALD and **DAVE HEALY**,
School of Geosciences, University of Aberdeen, and
GRAHAM WEBBER, Senergy

What is Petrophysics?

Spindletop was a PR disaster for the oil industry – not just because of the environmental damage, but also because it created a false impression that finding oil was easy. When the Lucas Gusher came in on 10 January 1910, photographs went around the world and a myth was born: if you drill through an oil accumulation, oil will flow to the surface. This myth is still believed by the majority of the general public.

The reality is horribly different. It is perfectly possible to drill through an accumulation of oil or gas and not realise it – particularly if the drillers are keeping the pressure in the wellbore higher than the formation pressure ('overbalanced'). A quick thought experiment shows the problem – you are peering down a hole that is about a metre in diameter at the surface, but only 15 to 20 cm across at the bottom. The big problem is that the hole could be anything from 2,000m to 5,000m long, and you have very little information: just the rate that the drill bit cut through the formations at various times, and the cuttings – gravel-sized chips of rock that have been flushed out of the wellbore by the drilling mud. It is like standing at Piccadilly Circus looking into a pipe that ends at King's Cross Station and trying to count the number of people in the concourse.

So how do you determine what's down there? The blisteringly simple idea that the Schlumberger brothers came up with was to lower an electrical instrument down the wellbore and take regular readings of some physical

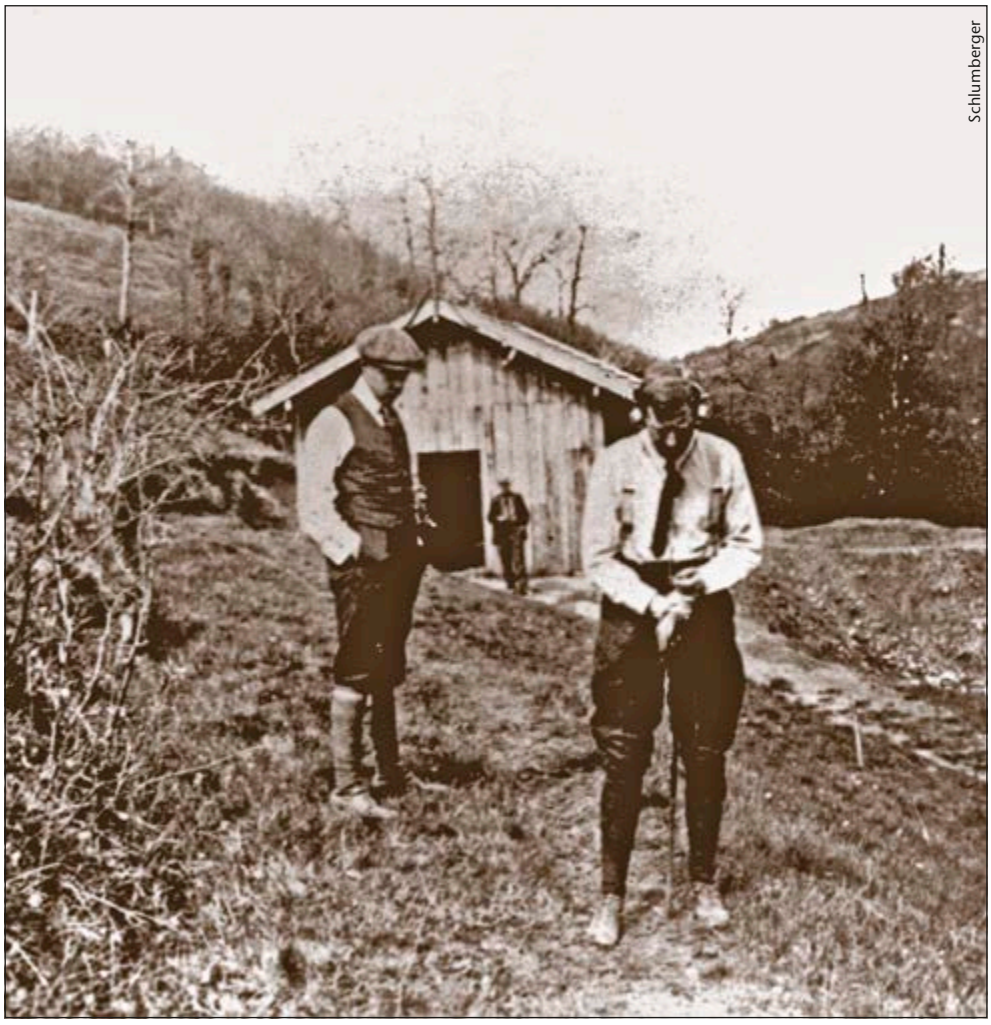


Student intern Severine Furst (MEng student at the University of Strasbourg) measuring ultrasonic velocities on sandstone core plugs in the Petrophysics Laboratory at the University of Aberdeen.

Dr. David Healy

property of the rock. If this was done at regular intervals, then the changes in properties would give a clue as to changing rock layers in the subsurface. On 5 September 1927, the first wireline electric log was run on the Diefenbach 2905 well in Alsace and the science of petrophysics was born. That first log measured the potential difference between each layer and the surface.

Today, Schlumberger and the other service companies such as Baker Hughes and Halliburton have a bewildering variety of tools that can measure natural radioactivity, porosity, density, resistivity, and the dip of layering. Most importantly, these data can be analysed to give us the fluid content of the rock. Petrophysics research in industry and academia is leading to the development of new tools and also to new ways of analysing and interpreting the data. It is a global, multi-billion dollar business.



The Schlumberger brothers experimenting with early geophysical equipment in 1912.

What Does a Petrophysicist Do?

Petrophysics is defined as the study of the physical and chemical properties of rocks and their interaction with fluids, but what do petrophysicists in the oil and gas industry actually do? Petrophysics provides the link between sub-surface disciplines. While the reservoir architecture is defined by geophysics and geology, the reservoir properties (porosity, permeability and fluid distributions) are determined by petrophysical interpretation based on well data. Petrophysicists plan and supervise log and core data acquisition, ensure data quality, assemble databases of all types of well data and make interpretations to address the needs of their sub-surface colleagues, through all stages of oil and gas exploration and production. They provide real time operational support and interpret wells to support exploration prospect evaluation.

In field appraisal and development, they integrate all types of data (including log and core data, fluid sample analyses, formation pressure data, well test and production data) to populate static and dynamic models of the reservoir and determine volumes of hydrocarbons in place. Petrophysicists also advise on alternative production development options.

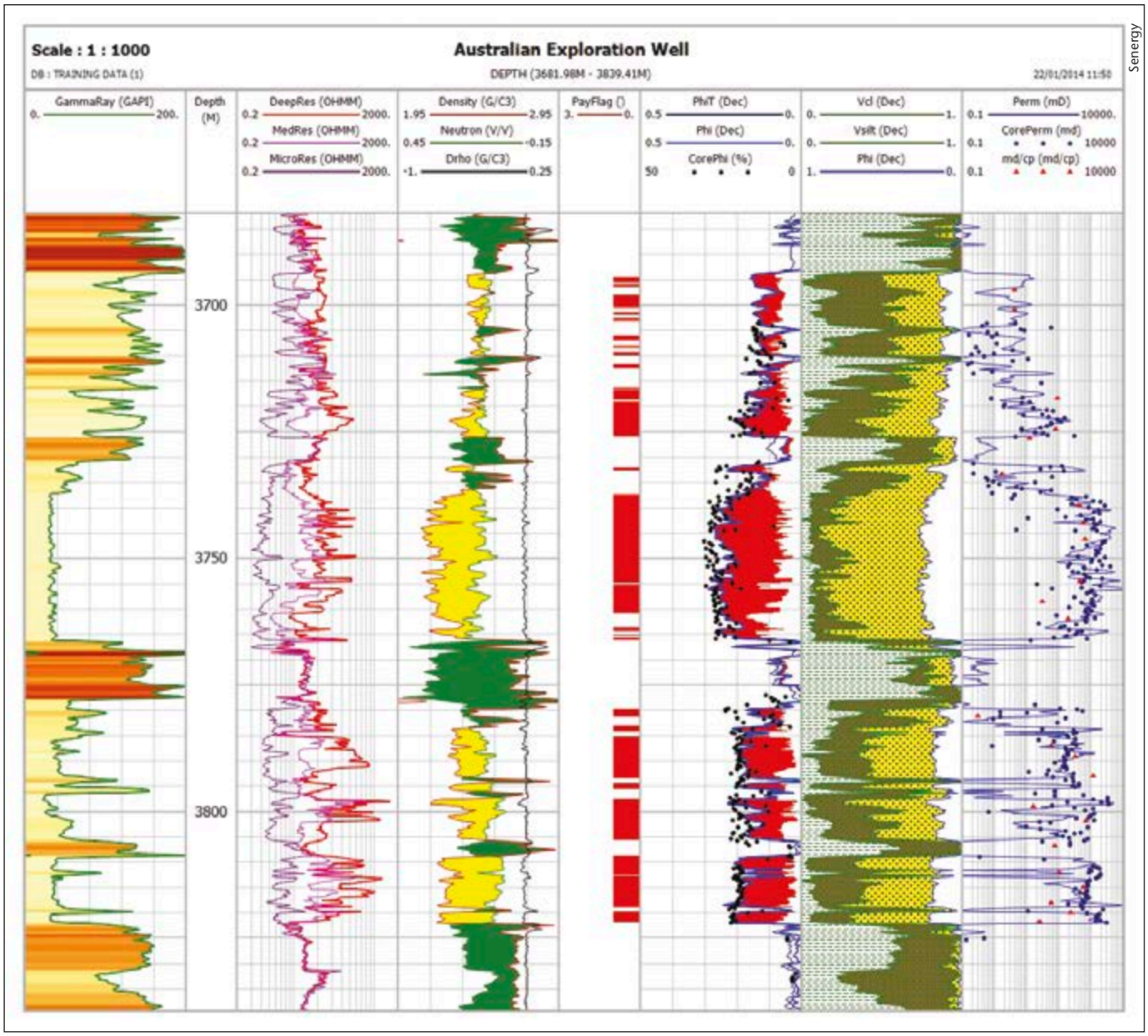
During the development and production phases, petrophysicists plan new wells and interpret logs acquired in producing wells to monitor production and the movement of fluid contacts, supporting reservoir management.

Where Do They Come From?

There is only one problem – there are not enough petrophysicists being trained to support this sophisticated enterprise.

Traditionally, petrophysics has been taught as a small part of postgraduate degree programmes in petroleum geology or engineering, but this is not enough to develop a real specialism in the subject. Working petrophysicists are recruited from a wide range of technical backgrounds: geology, electronics, mechanical engineering, physics, and mathematics. Practitioners commonly start their careers in field operations as logging engineers or mud-engineers before joining operating companies. Petrophysical expertise is then built on the job by a combination of work experience and short courses. Such diversity of experience and technical backgrounds works well to address the wide range of activities and knowledge encompassed by petrophysics and formation evaluation. However the development of experienced petrophysicists this way takes anything between three and eight years, depending on the variety of work experience and peer support that is available.

A fresh approach to training new-start petrophysicists from diverse technical backgrounds is being launched as an MSc programme by the University of Aberdeen's School of Geosciences and Senergy in partnership. The aim is to provide



Petrophysical interpretation of an exploration well based on wire-line logs and other data.

a development route for petrophysicists, where individuals already working in industry will acquire a broad range of skills, knowledge and expertise over a period of two to three years. Candidates will be assessed via assignments, examinations and a dissertation.

Written and interpersonal communication is a key requirement for petrophysicists; this will be emphasised in the programme. Since most of the petrophysical interpretation is performed on software which allows integration and visualisation of data and facilitates mathematical and statistical modelling of reservoir properties, some skill in simple algebra and statistics is required.

The Future of Petrophysics

Specialist petrophysics may involve development of new logging tools or interpretation methods; support for geophysical studies of rock properties; and rock mechanical studies for optimisation of drilling. Such research problems are being tackled by industry-academia partnerships around the world and the lab in Aberdeen University is a good example.

The guiding principle for the research projects in the Aberdeen University Petrophysics Laboratory is to use rock samples from outcrop analogues or core, and integrate the petrophysical measurements with quantitative, predictive subsurface models. Recent projects in the laboratory have addressed:

- anisotropy of permeability in faulted sandstones, using samples from Scotland, and petrophysical variations in carbonates across normal fault zones, with data from Malta. Both projects were funded by Total E&P UK and BG International;
- the petrophysical characterisation of reservoir quality in fold and thrust belt carbonates in Kurdistan, funded by the Ministry of Higher Education and Research, Iraq;
- the seismic anisotropy of evaporites as a function of mineralogy and crystallographic fabric with samples

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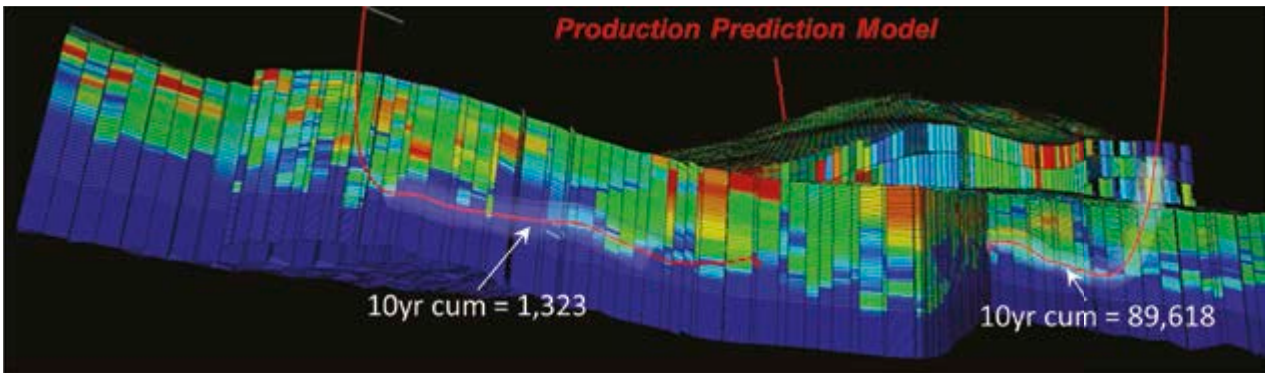

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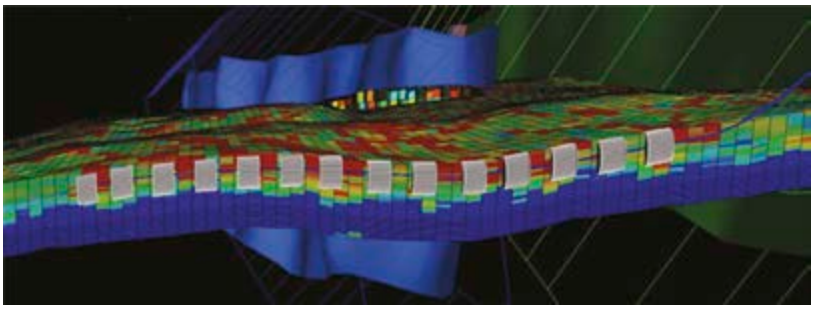
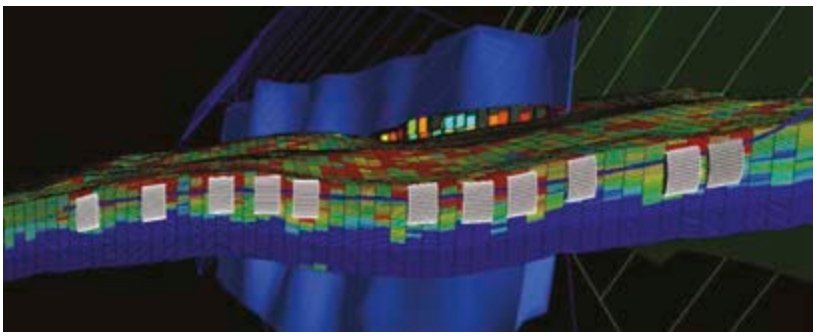


Planned well with maximum number of completion stages (constant spacing)



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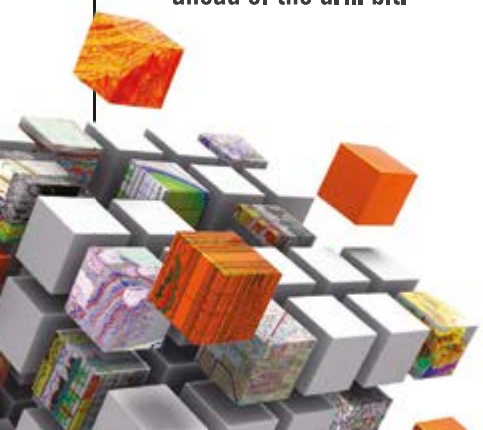

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from Nova Scotia; a project funded by the National Board of Science and Technology and Ministry of Energy, Mexico.

Ph.D. students working on these projects have been trained in experimental measurement methods, statistical data analysis and rock physics modelling. All of their work is either submitted for publication in international peer-reviewed journals, or in preparation for submission.

Future projects scheduled for 2014 include a study of the rock physics of fractured and altered basement reservoir analogues, an investigation into coupled poroelasticity and permeability of fault zones in sandstones and limestones, and analysis of spatial and temporal evolution of porosity around fault zones in granular rocks.

While the inherent length-scale related limitations of core plug datasets are widely known, we believe that repeatable, quantitative laboratory measurements of rock properties provide useful knowledge in our quest to understand, model and predict the behaviour of rocks and fluids in the subsurface. In addition, the practical acquisition and analysis of these data is in itself a valuable training exercise for our students.

In the Petrophysics Laboratory there is equipment for helium porosimetry on core plugs and mercury injection porosimetry on rock chips and powders up to 15 cm^3 in volume, as well as a range of permeameters, using either nitrogen or water as the permeant, and pressure vessels capable of confining pressures up to 250 MPa (equivalent to about 8 km depth). It is possible to measure ultrasonic acoustic velocities, for both P- and S-waves, in dry core plugs. The lab is commissioning a new system to provide fluid-saturated ultrasonic velocity data from up to five 1.5 inch diameter core plugs at confining pressures up to 70 MPa (about 3 km depth). A recent expansion in capability in the laboratory has been funded through Joint Industry Projects (JIPs) with Total and BG, and generous donations from the Aberdeen Formation Evaluation Society (AFES) – a chapter of the Society of Petrophysicists and Well Log Analysts.

An immediate challenge is to fund and purchase a new state-of-the-art scanning electron microscope (SEM) to replace the existing machine. This would be a high vacuum chamber capable of handling large sample sizes (e.g. 10 cm x 10 cm), complete with detectors for cathodoluminescence (CL), electron backscatter diffraction (EBSD) and energy dispersive X-ray analysis (EDX). Integrating laboratory petrophysical measurements with data from the new SEM will produce a step change in the capacity of the Aberdeen petrophysicists to quantify rock properties, with applications from reservoir quality, to rock physics and geomechanics. ■

Oil industry geologists undertaking continuing professional development on a University of Aberdeen CPD course looking at the Clashach Fault in the Permian Hopeman Sandstone Formation near Hopeman, Inner Moray Firth Basin.

Clare Bond (University of Aberdeen)

Dolphin geophysical

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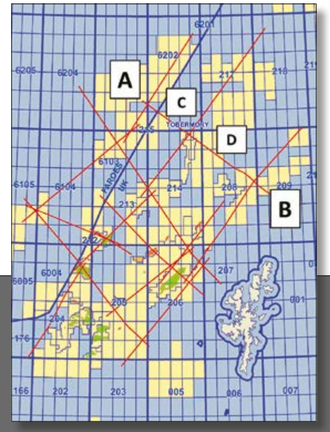
West of Shetland:

SHarp Broadband 2D Regional Well Tie Survey

Improved imaging throughout the entire geological section



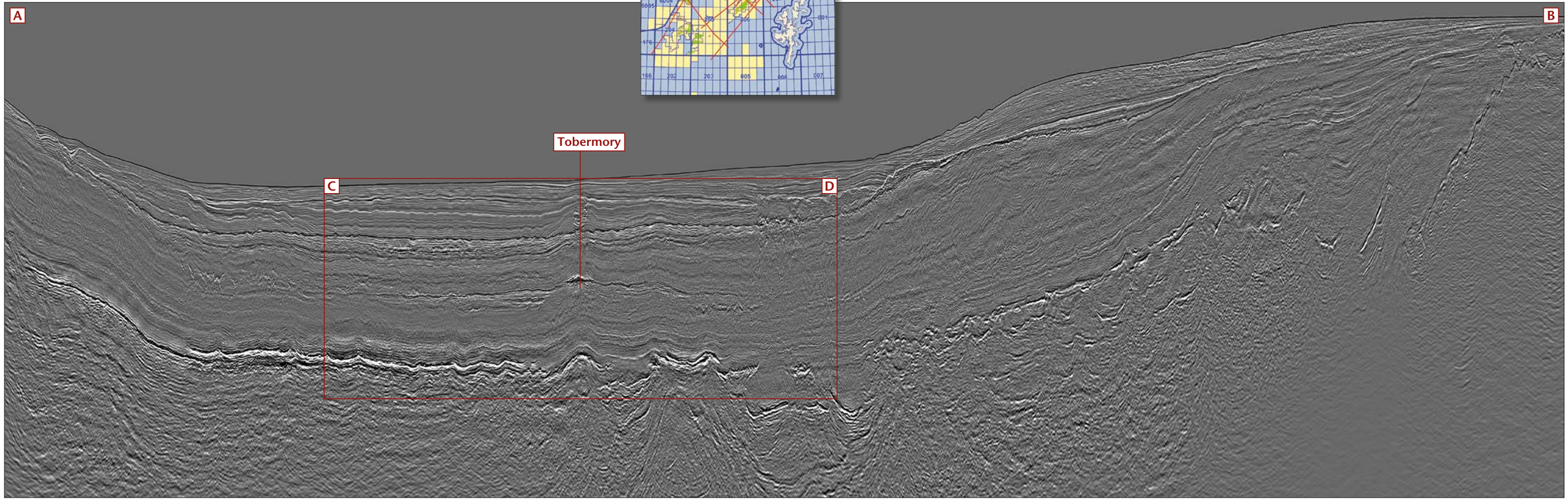
Location of Dolphin Geophysical's SHarp Broadband Regional Multi-Client Well Tie Survey

Dolphin geophysical

In preparation for the expected increase in exploration activity over the Faroe/West of Shetland area, Dolphin Geophysical, using their vessel the *Artemis Arctic*, has completed a SHarp broadband 2D regional well tie survey of approximately 2,135 km. This survey ties recently drilled wells, discoveries and fields.

The results of this seismic survey have been well received by industry due to the improved imaging throughout the entire geological section, but especially with reference to intra-basalt and sub-basalt features.

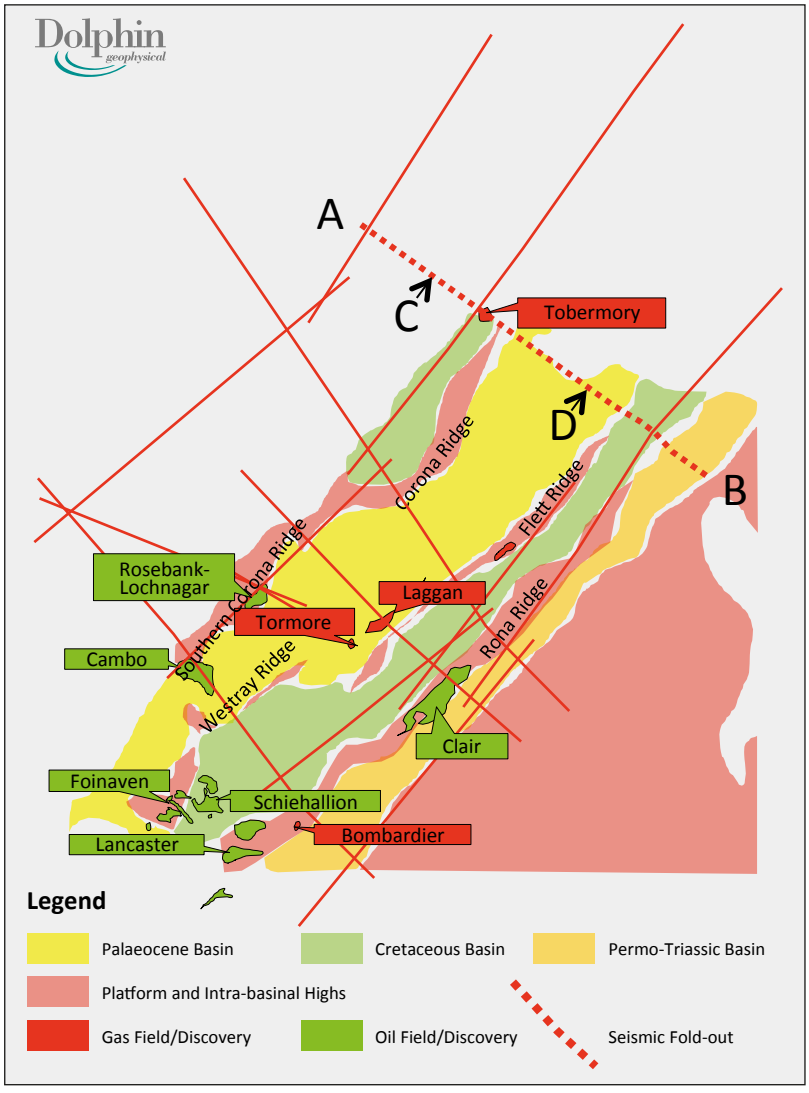
Seismic line from the SHarp Broadband 2D Regional Well Tie Survey, passing through the 1999 Tobermory gas discovery well



A New Regional Dataset for West of Shetland

IAN T. EDWARDS, Global Multi-Client Surveys and New Ventures

The use of deep tow streamers and proprietary processing algorithms has resulted in excellent imaging both above and below the basalt in the West of Shetland region, casting light on this fascinating area where challenges are both technical and operational.



Location of SHarp Broadband Regional Well Tie Survey with simplified geology.

The main West of Shetland Faroe-Shetland Basin was initiated in the Permian period, and progressive tectonic events resulted in subsidence throughout the Mesozoic and Tertiary eras. The location of the SHarp Broadband 2D Regional Well Tie survey is shown (right) overlain onto a simplified geological map of the area. The red dotted line shows the location of the seismic shown in the foldout and also the enlarged section discussed below.

Exploration History

Exploration began in the West of Shetland area in the 1970s, and the Clair field, found in 1977, was the first significant discovery to be made. This is located on the Rona Ridge where oil is trapped in fractured Devonian and Carboniferous reservoir rocks.

During the 1980s and early 1990s exploration drilling continued in the Faroe-Shetland Basin but without significant success, until the Foinaven and Schiehallion fields were discovered in 1992 and 1993 respectively. These fields are in younger Tertiary sandstones, and exhibit good quality reservoir properties.

In 2004 a significant oil and gas discovery was made with the Rosebank/Lochnagar well (213/27-1Z) located in the Faroe-Shetland Channel near the UK/Faroes border in 1,100m water depth. This discovery proved a play system consisting of interbedded fluvial and shallow marine clastics and volcanic strata.

The sedimentary regime governing the deposition of the reservoir sediments in the Rosebank area was discussed by Stonard et al. at the AAPG in 2011. The diagram on the top of the following page shows a volcanic province encroaching from the west-north-west, and the progradation of the Flett Delta from a south-south-easterly direction.

Deep Towing and Processing

Dolphin Geophysical utilised a 10 km offset streamer with SHarp deep tow parameters, coupled with their proprietary in-house OpenCPS Broadband sequence, and believe they have produced a new regional reference dataset.

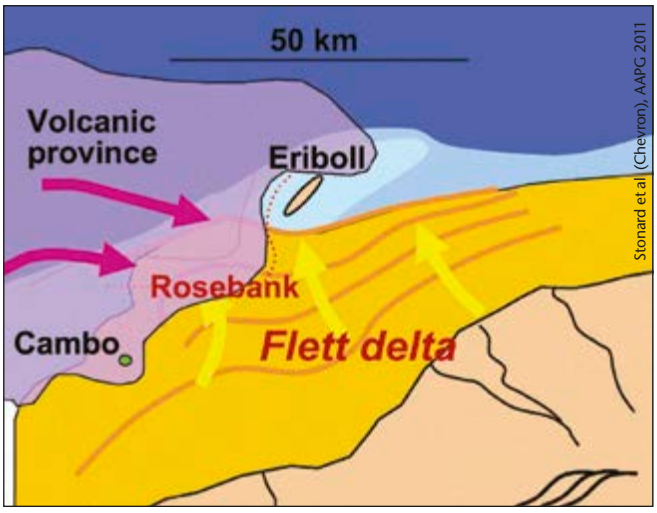
Dolphin's broadband product, SHarp, uses a modified towing geometry and proprietary processing algorithms. Towing the cable much deeper than is conventional provides a much quieter dataset as the hydrophones are well away from the sea surface and vessel noise. Lowering the noise floor improves the signal to noise ratio (S/N) and in itself thus allows a broader bandwidth to be achieved in the final image. In addition, towing deep boosts the low frequency response of the receiver ghost and hence increases the signal strength at ultra-low frequencies. This provides a further boost to the S/N at these frequencies.

The receiver ghost for the deep cable does contain 'notches' in the amplitude spectrum at higher frequencies that are well within the 'conventional' bandwidth, but research has shown that there is not perfect cancellation between the upgoing and downgoing waves. As a result the S/N within these notches is sufficient for Dolphin's proprietary de-ghosting algorithms to recover the full bandwidth – both low and high (Williams et al., *First Break,* November 2012, Grion et al., SEG 2013).

The result for this survey is very high bandwidth and resolution above the basalt and improved low frequency penetration below the basalt. In some areas, clear resolution of intra-basalt layers is observed as well. Unlike some broadband methods, SHarp allows conventional de-multiple techniques and conventional AVO to be applied. This results in more straightforward processing of the data and also lets interpreters use their existing workflows for rock property estimation. The resulting improvement in data quality can clearly be seen in the seismic line below, which is an expanded section of the main foldout line on the previous page.

Technical Challenges

The challenges of exploration in the West of Shetland are both technical and operational. It is classed as a deepwater area with extreme metocean conditions, and due to its location short operational windows are the norm.



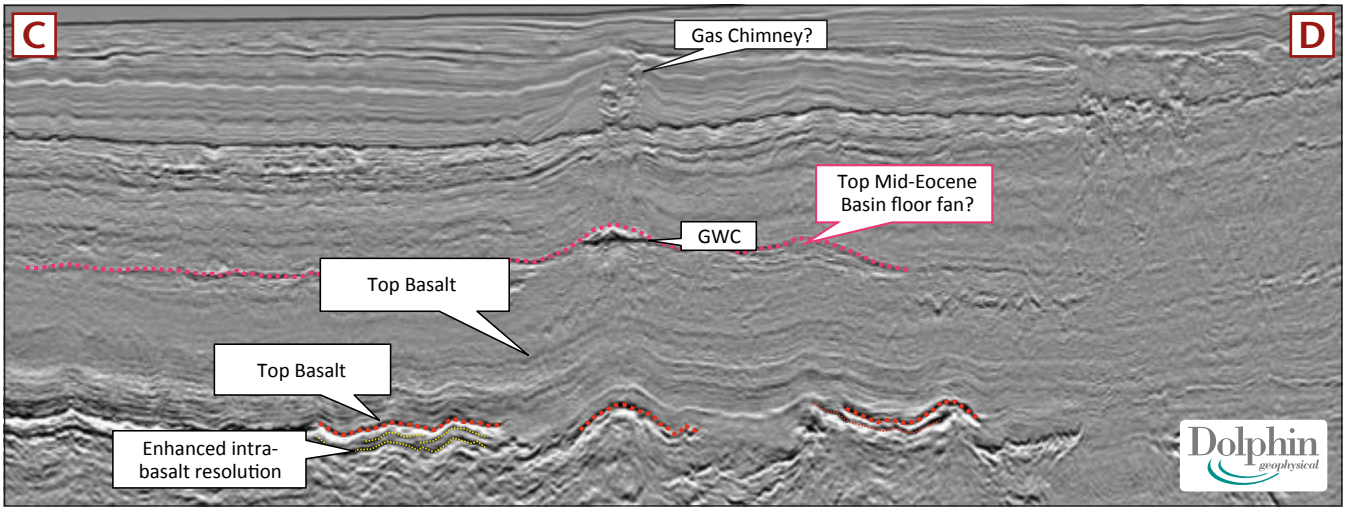
The sedimentary environment in the Faroe/West of Shetland area is dominated by a volcanic province encroaching from the west-north-west, and the progradation of the Flett Delta in the south-east.

The geological setting is one where the petroleum reservoirs are interbedded with intrusive and extrusive igneous rocks. This environment is problematic for many aspects of the exploration process including seismic imaging, drilling, and petroleum systems analysis, which has to account for the thermal effects of igneous activity, and also the possible effects upon migration and trapping. A recent paper by Rateau et al. (*Petroleum Geoscience*, Vol.19) provides an excellent overview of the role of igneous intrusions on the migration of hydrocarbons in the West of Shetland area.

For discoveries such as Rosebank the volcanics are interbedded with the reservoir sediments, and hence enhanced imaging as that obtained in this latest broadband survey offers the subsurface personnel another tool with which to explore and develop this difficult but promising area.

For further Information please contact:
Ian T. Edwards,
Vice President, Global Multi-Client Surveys & New Ventures
E ian.edwards@dolphingeo.com | M +44 (0)7920 713587

Detail from main foldout line, looking at the Tobermory discovery.



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Premier awarded three deepwater blocks in Brazil.

2012
Acquisition of 60 per cent of Rockhopper Exploration plc's licence interests in the Falkland Islands.

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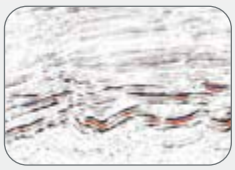
Discovery of the Catcher field in the UK North Sea.

2009
Acquisition of Oilexco.

2006
Discovery of the Chim Sáo oil field in Vietnam.

1992
Premier discovers giant gas field in Myanmar, Yetagun.



1971
Premier acquires first interest in the UK North Sea.

1936
First listed on the London Stock Exchange as Premier (Trinidad) Oilfields.

1934
Premier Oil founded as the Caribbean Oil Company.

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How Much Oil in the Middle East?

"No such galaxy of fields of the first magnitude over such a wide area has been developed in the history of the oil industry."

Everette Lee DeGolyer, *Oil in the Near East*, 10 May 1940, Texas

RASOUL SORKHABI, Ph.D.

Current estimates place the Middle East's conventional oil at about 800 Bbo, or nearly half of the world's proven recoverable crude. What makes the Middle East so unique is the concentration of numerous giant fields in the region. With only 2% of the world's producing wells, the Middle East's output is over 30% of the world's crude, highlighting its prolific fields. In addition, the Middle East holds 40% of the world's conventional gas reserves. Despite our best estimates, it is not exactly known how much oil and gas exist in the Middle East and how much of it can be recovered in the future, but there is probably more to Middle East petroleum than what we currently know.

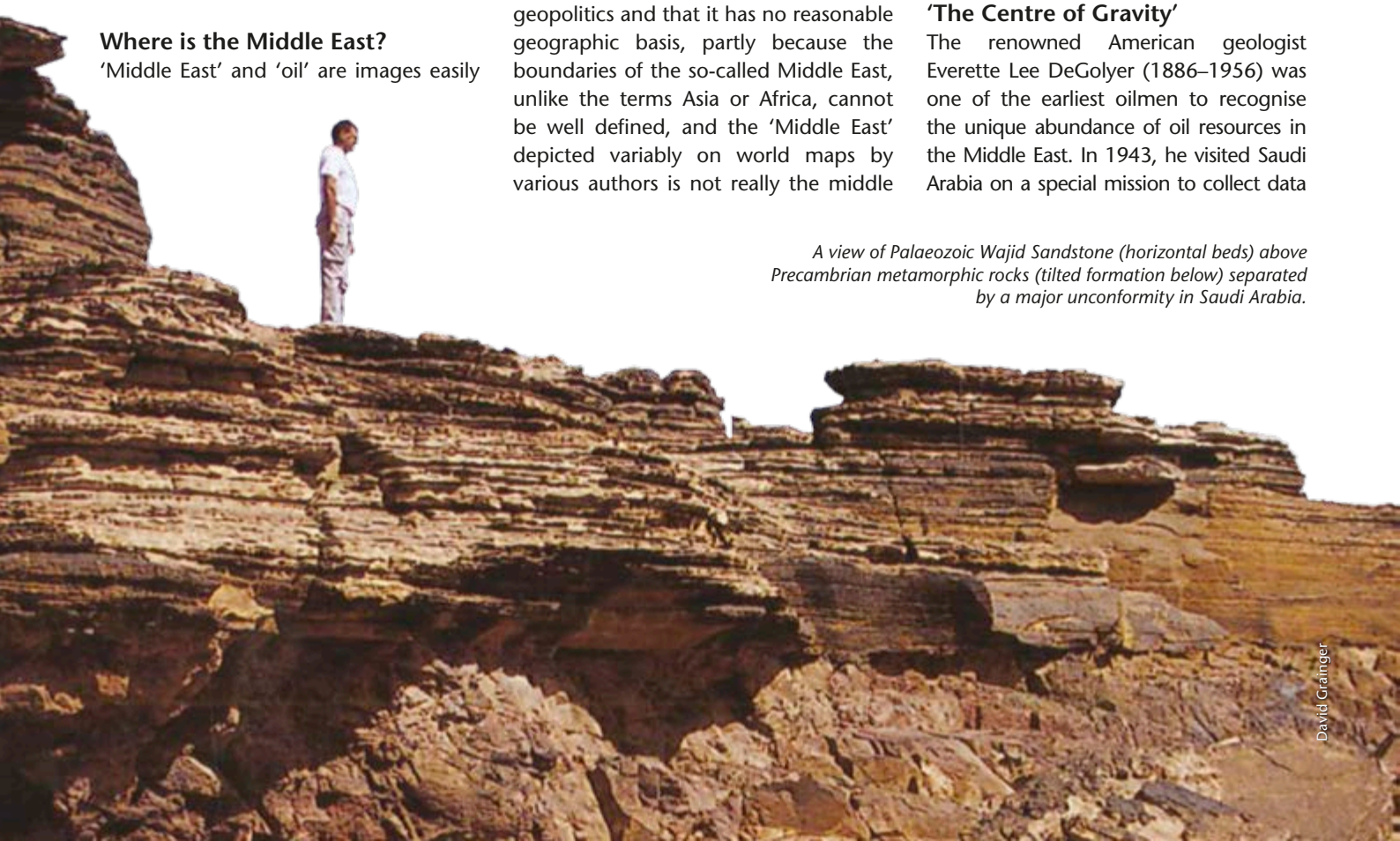
Where is the Middle East?

'Middle East' and 'oil' are images easily connected in the public mind. It is also commonly agreed that Middle East oil reserves and production have huge relevance for the global economy. Estimation of oil and gas reserves is usually a task threaded with many uncertainties. In the case of the Middle East, the problem is even more severe, not only because petroleum data are treated with secrecy by the Middle Eastern governments but also because it is not easy to define the Middle East. In a 2012 book *Is There a Middle East?*, a group of historians and geographers have argued that the term Middle East is simply a 20th-century geopolitical concept born out of British imperial geopolitics and that it has no reasonable geographic basis, partly because the boundaries of the so-called Middle East, unlike the terms Asia or Africa, cannot be well defined, and the 'Middle East' depicted variably on world maps by various authors is not really the middle of the East (whatever 'East' means).

With this qualifying statement, for the purpose of this article, we define the Middle East as consisting of ten oil-producing countries in what is geographically South West Asia: Iran, Iraq, Syria, Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates (UAE), Oman, and Yemen. These countries together cover an area of 5.4 million square kilometres (or about 3.6% of the Earth's land surface) but their significance for the world's oil economy is second to none. Of these countries, Iran, Iraq, Kuwait, Qatar, Saudi Arabia and UAE are also members of OPEC.

'The Centre of Gravity'

The renowned American geologist Everette Lee DeGolyer (1886–1956) was one of the earliest oilmen to recognise the unique abundance of oil resources in the Middle East. In 1943, he visited Saudi Arabia on a special mission to collect data



A view of Palaeozoic Wajid Sandstone (horizontal beds) above Precambrian metamorphic rocks (tilted formation below) separated by a major unconformity in Saudi Arabia.

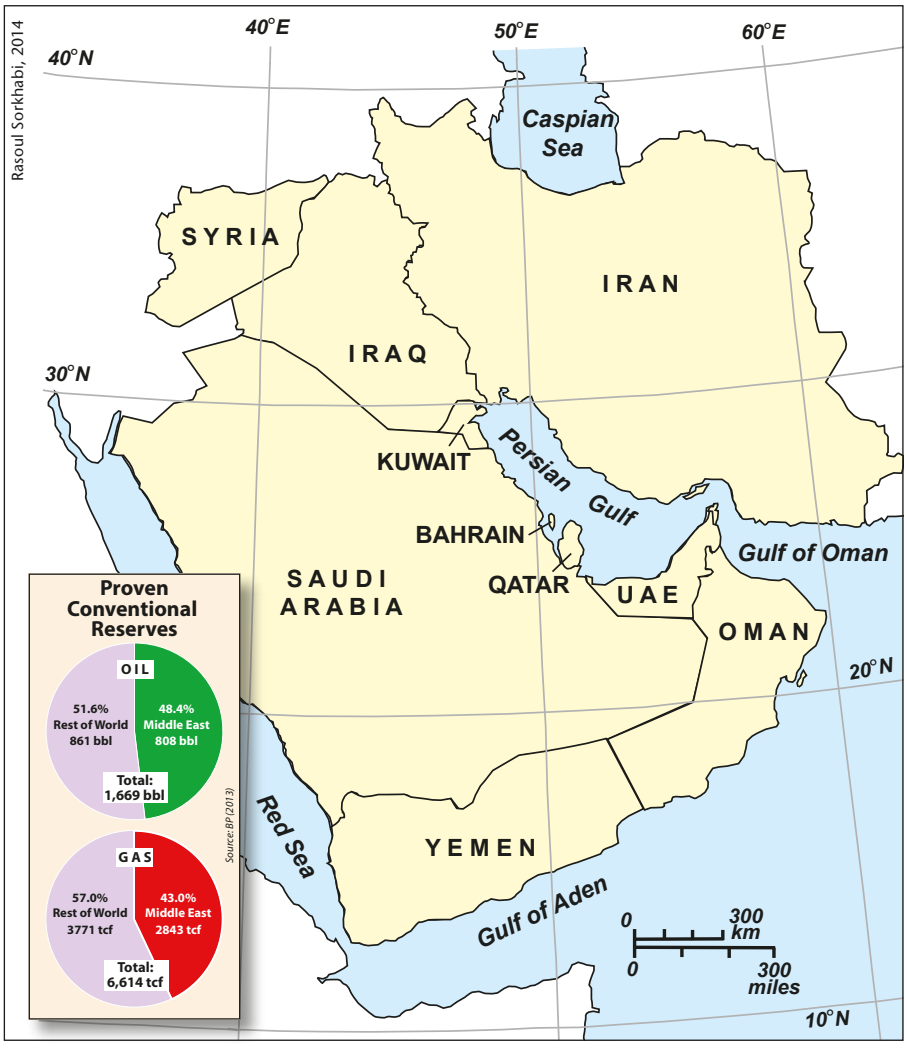
David Grainger

for an assessment of Middle Eastern oil. In his report (published in *AAPG Bulletin*, July 1944), DeGolyer estimated the oil reserves of Iran, Iraq, Kuwait, Saudi Arabia, Bahrain and Qatar to be about 27 Bbo but also suspected that 'reserves of great magnitude remain to be discovered.' He concluded: 'The centre of gravity of world oil production is shifting from the Gulf-Caribbean areas to the Persian Gulf area.' This, indeed, has been a reality for the past six decades. Geological reasons for the abundance of oil in the Middle East has been discussed in a previous article, 'Why So Much Oil in the Middle East?' (*GEO ExPro*, Vol. 7, No. 1). Here we look at the patterns of petroleum reserves in the region.

Each year, several organisations such as British Petroleum, Oil & Gas Journal, OPEC, and US Energy Information Administration (EIA) publish estimates of oil and gas reserves for various countries. According to their latest reports, the Middle East as a whole contains 808 Bbo (BP, 2013), 802 Bbo (EIA, 2013), 799 Bbo (OPEC, 2013) or 797 Bbo (Oil & Gas Journal, 2013). This accounts for nearly one half of the world's total reserves of about 1.5 to 1.7 Tbo. Note that these data are given for geo-statistically 'proven', recoverable (with current technology and economy), conventional oil reserves.

A very interesting fact emerges when we consider oil production and the number of producing wells globally and in the Middle East. In 2012, there were 893,249 producing wells around the world and their total output was 74,680 MMbpd; that averages 30,515 barrels per well in a year. In the Middle East, only 18,659 wells produced 23,130 MMbopd, which translates to oil production of 452,459 barrels per well per year (or 15 times the global average).

The Middle East is also home to abundant natural gas resources. Conventional gas reserves of the region are currently estimated to be 2062.5 Tcf (43% of world's total) (BP, 2013), 2822.7 Tcf (41%) (OGJ, 2013), 2880.3 Tcf (41%) (OPEC, 2013) or 2823.3 Tcf (41%) (EIA, 2013).



A map of the oil-producing Middle Eastern countries and pie diagrams showing estimates of proven, recoverable, conventional oil and natural gas resources in the Middle East compared to the rest of the world.

Patterns of Reserves Distribution

The distribution of oil fields and reserves is not uniform throughout the Middle East for a variety of reasons, partly because of the size of each country. For instance, Saudi Arabia, with an area of 2.1 million km^2 or almost five times the size of Iraq (400,000 km^2), is home to oil reserves of 265 Bb or nearly twice the volume of Iraq's oil reserves (140 Bb).

A more important factor is the location of each country with respect to the optimal petroleum geology of sedimentary basins. For instance, although Kuwait has an area of only 18,000 km^2, less than one-tenth the size of Syria (187,000 km^2), its oil reserves of 101.5 Bb far exceeds Syria's reserves of merely 2.5 Bb. Finally, we should also consider the non-uniform nature of oil exploration activities in various parts of the Middle East or across the spectrum of stratigraphic levels from shallower to deeper rocks.

In terms of geology, there is a finite volume of petroleum in a given reservoir and basin. However, 'reserve' estimates are always in a state of flux because of changes in our knowledge of basin geology, exploration activities, drilling and recovery technology, and assessment methodology. Utilising these factors thus lead to 'reserves growth' through time. For instance, in 1960 (when OPEC formed), the Middle East oil reserves were estimated to be 183 Bb (or 60% of the world's total) which increased to 343 Bb in 1970 (55%), 362 Bb in 1980 (53%), 661 Bb in 1990 (53%), 697 Bb in 2000 (55%), and 766 Bb in 2010 (47%). These data (from BP sources) indicate that Middle Eastern oil reserves have accounted for about one half of the world's proven oil in the past six decades.

Ideally, changes in the reserves should reflect our science, technology and exploration, but it is also conceivable that political and economic considerations may influence the reporting of reserves. Colin Campbell and Jean Laherrere ('The End

PROVEN OIL RESERVES (BILLION BARRELS)

	BP (2013)	OGJ (2013)	EIA (2013)	OPEC (2013)	% of World	R/P ratio
BAHRAIN	-	0.12	0.12	-	-	-
IRAN	157.0	157.3	154.6	157.3	9.4	-
IRAQ	150.0	140.3	141.4	140.3	9.0	-
KUWAIT	101.5	101.5	104.0	101.5	6.1	89
OMAN	5.5	5.5	5.5	5.5	0.3	16
QATAR	23.9	25.2	25.4	25.2	1.4	33
SAUDI ARABIA	265.9	265.9	267.9	265.9	15.9	63
SYRIA	2.5	2.5	2.5	2.5	0.1	41.7
UAE	97.8	97.8	97.8	97.8	5.9	79
YEMEN	3.0	3.0	3.0	-	0.2	45
WORLD	1669	1645	1526	1478	100	53

Sources: *BP Statistical Review of World Energy* (2003); *Oil & Gas Journal* (Dec. 2, 2013); *Energy Information Administration (EIA, DOE/USA) website*; *OPEC Annual Statistical Bulletin* (2013)
Notes: The data are for proven, recoverable, conventional oil reserves. Data on Share (%) of world and Reserves/Production (R/P ratio in years) come from BP (2013).

Proven recoverable conventional oil reserves of the Middle East in 2013 according to various sources.

OIL PRODUCTION (1,000 BARRELS/DAY)

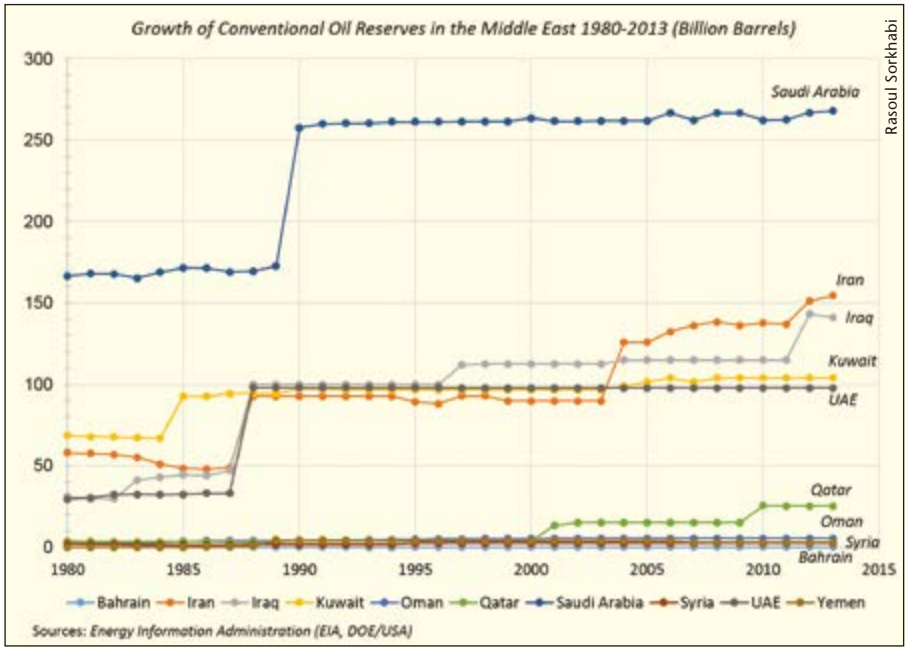
	BP (2013)	OGJ (2013)	EIA (2013)	OPEC (2013)	Oil Wells
BAHRAIN		41	55	168	496
IRAN	3,680	3,000	3,589	3,740	2,074
IRAQ	3,115	2,918	2,987	2,942	1,526
KUWAIT	3,127	2,454	2,797	2,978	1,286
OMAN	922	919	924	814	4,918
QATAR	1,966	741	1,579	734	513
SAUDI ARABIA	11,530	9,513	11,726	9,763	2,895
SYRIA	164	168	176	182	146
UAE	3,380	2,651	3,213	2,653	1,458
YEMEN	180	184	171	161	2,578
WORLD	86,152	74,680	89,344	72,859	893,249

Sources: *BP Statistical Review of World Energy* (2003); *Oil & Gas Journal* (Dec. 2, 2013); *Energy Information Administration (EIA, DOE/USA) website*; *OPEC Annual Statistical Bulletin* (2013)
Notes: Number of producing oil wells from OGI (2003).

Oil production in Middle Eastern countries according to various sources.

of Cheap Oil,' *Scientific American*, March 1998) noted that between 1985–1990 six members of OPEC (including Saudi Arabia, Kuwait, Iran, Iraq and UAE) increased their reserves by 287 Bb, possibly because of their desire to increase their production-export quota as OPEC members. This kind of practice, if true, makes the world's oil reserves data less reliable because the annually published data by various agencies largely rely on the data reported by oil companies. Another uncertainty is that estimation of oil reserves is not made annually; therefore, a country's oil reserves may remain unchanged in annual reports for years although the country would produce from its oil fields all through those years.

Oil reserves growth in the Middle East 1980-2013.



Future Plays: Frontiers and Unconventionals

Early oil discoveries in the Middle East were made in Jurassic, Cretaceous and Oligocene limestone reservoirs. Indeed, these reservoirs are still the major plays in the Middle Eastern basins. Given its decades of prolific production, the Middle East is often thought of a 'mature' petroleum province. However, promising oil and gas prospects do exist in the region.

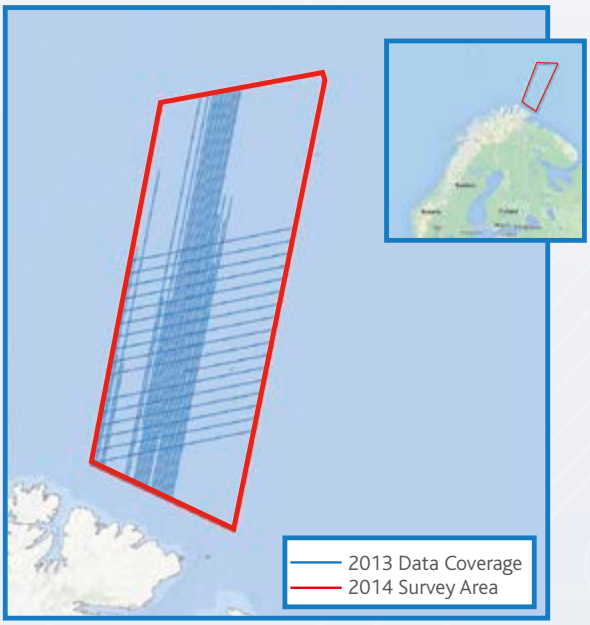
Future plays that would drastically increase the Middle East's oil reserves and production can be categorised into the following:

1. Frontier Areas: Some parts of the Middle East remain poorly explored. One notable example is Iran, where oil production has traditionally come from the Zagros Basin in south-west Iran, while the central and northern parts of the country remain virtually untouched.

2. Deep Plays: Although Permian and Silurian rocks have been drilled in some parts of the Middle East, the Palaeozoic section in deeper parts of the basins has not been explored thoroughly.

3. Unconventional Resources: With such abundant conventional reserves, it is probably less attractive economically for the Middle Eastern countries to tap into

SE Barents Sea - Multi-Client Gravity Gradiometry



2013 Gravity Gradiometry Data

In 2013, ARKeX began acquiring a multi-client airborne Full Tensor Gravity Gradiometry (FTG) survey in the South Eastern Barents Sea. Initial results from this survey are very promising. Data is already being used to help delineate basement ridges and potential hydrocarbon-bearing basins, as well as aiding in the mapping of prospective hydrocarbon-trapping structures. ARKeX will complete the survey in the spring of 2014.

ARKeX are offering the data acquired in the 2013 survey to licence on a non-exclusive basis and are also seeking participation for the 2014 acquisition program.

2013 Data Available

Line km	9,609.34 km
Contiguous data available	3,823.53 km²

2014 Total Coverage

Line km	27,404 km
Total Square km	45,700 km²

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unconventional resource plays such as shale gas, oil shale, tight sandstone and coal-bed methane. Nevertheless, these resources exist in the region although comprehensive studies and exploration have not been made. For example, Jordan (not included in this article for its insignificant conventional oil and gas) sits on one of the largest oil shale (immature kerogen) plays in the world (see page 22). Interestingly, the theme of GEO 2014 to be held this March in Bahrain is 'Taking Geoscience Beyond the Conventional,' and is expected to focus on shale plays in the Middle East. Indeed, the Middle East stratigraphy contains several major regional shale plays, both in the Palaeozoic and the Mesozoic sections, which are excellent candidates as self-sourced shale reservoirs.

In 2012, the United States Geological Survey released its 'Assessment of Undiscovered Conventional Oil and Gas Resources of the Arabian Peninsula and Zagros Fold Belt,' in which it estimates 86 Bb for yet-to-discover conventional oil and 336 Tcf for yet-to-discover conventional natural gas. The report recognised several petroleum systems in the Middle East with the following source rocks: Huqf (Precambrian-Cambrian); Silurian-Ordovician; Palaeozoic-Triassic in Euphrates Graben of Syria; syn-rift Triassic-Jurassic sediments in the Palmyra and Sinjar areas; Madbi-Amran-Qishn system (Upper Jurassic) in Yemen; Middle Cretaceous Natih Formation in Oman; and Jurassic-Cenozoic systems distributed in much of the Arabian platform and Zagros Basin, accounting for 92% of the estimated yet-to-discover oil reserves in the region.

Finally, improvements in recovery technology can also boost the Middle East's reserves and production. Assuming a recovery efficiency of 50%, almost one-half of oil-in-place still remains underground in conventional reservoirs. ■


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Further Reading:

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Alsharhan, A.S., and Nairn, A.E.M. (2003) Sedimentary Basins and Petroleum Geology of the Middle East. Elsevier, Amsterdam.

Beydoun, Z.R. (1991) Arabian Plate Hydrocarbon Geology and Potential: A Plate Tectonic Approach. AAPG Studies in Geology 33.

Halbouty, M.T. (Ed.) (2003) Giant Oil and Gas Fields of the Decade 1990-1999, AAPG Memoir 78U.S.

International Energy Agency (1995), Middle East Oil and Gas. Paris.

Middle Eastern Giant Fields

A giant petroleum field is defined as one having more than 5 MMb of recoverable oil; a supergiant contains more than 5 Bbo. The Middle East's oil riches are partly due to the largest concentration of giant and supergiant oil fields in the world. A recent study of the world's giant oil and gas fields was conducted by Paul Mann, Mike Horn and Ian Cross. They compiled 932 giant fields, which account for 40% of the world's proven oil reserves. About one-fourth of the world's giant and supergiant fields are located in the Middle East.

A map of giant oil and gas field in the Middle East

Mike Horn

Ultimate recoverable conventional oil and natural gas reserves for selected supergiant fields in the Middle East.

Field	Country	Year	Oil[1] (Bbl)	Oil[2] (Bbl)	Gas[1,2] (tcf)
Ghawar	Saudi Arabia	1948	75.0	66.1	186.2
Abqaiq	Saudi Arabia	1941	18.7	10.3	14.2
Berri	Saudi Arabia	1964	18.5	9.1	12.2
Zuluf	Saudi Arabia	1965	20.2	12.2	5.2
Manifa	Saudi Arabia	1957	23.1	16.8	4.8
Safaniya	Saudi Arabia	1951	55.6	21.1	3.9
Burgan	Kuwait	1938	60.0	31.8	42.8
Aghajari	Iran	1936	17.4	5.8	9.9
Ahwaz	Iran	1958	25.6	13.4	23.3
Marun	Iran	1963	22.0	12.6	75.3
Gachsaran	Iran	1928	16.2	11.8	31.1
Fereidoon	Iran	1966	4.3	10.0	
Azadeghan	Iran	2004	4.6	6.0	2.0
Pars South	Iran	1971	1.3	1.3	350.0
Rumaila S & N	Iraq	1953 1970	30.0	22.0	20.0
Kirkuk	Iraq	1927	25.0	17.0	8.2
Majnoon	Iraq	1975	13.0	12.0	11.0
North Field	Qatar	1971			9.0 + 10.7 condensate
Zakum	UAE Abu Dhabi	1965	21.7	17.2	12.4
Bab	UAE Abu Dhabi	1953	11.6	10.3	29.3

1. Mike Horn, "Giant Fields" (2013)
2. Mann, Caghagan and Gordon (2003) "Tectonic Setting of the World's Giant Oil and Gas Fields" in AAPG Memoir 78

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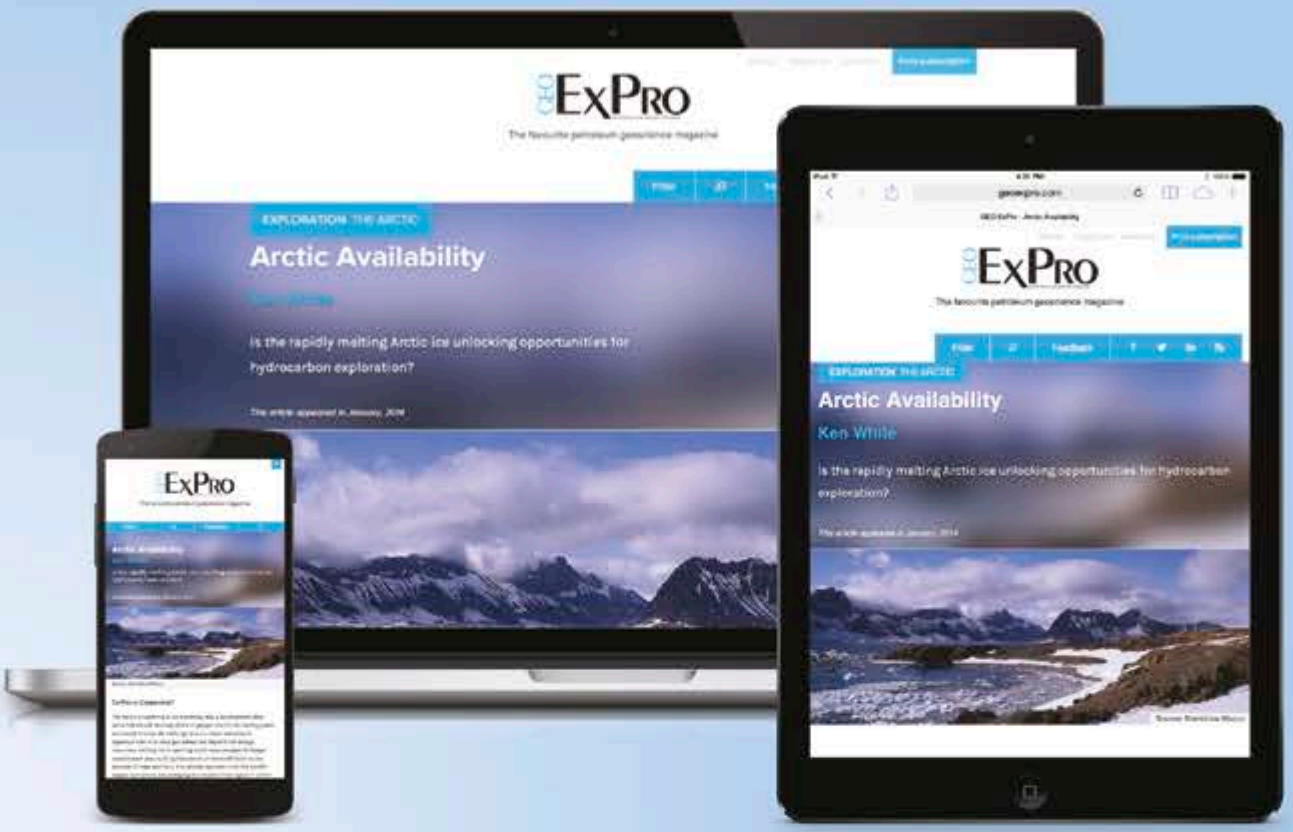

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Broadband Seismic Technology and Beyond

PART VII: CGG's BroadSeis – A Change of Thinking

Our brain is substantially shaped by what we have learnt and by the experience of daily life. As geophysicists, we learnt and believed that seismic deghosting through ghost notches in pressure-only recordings in towed streamers was impossible when the sensors were deep. CGG changed that way of thinking. Instead of fighting the ghost in acquisition, they made a different set of rules, deliberately taking advantage of the fact that the ghost notch varies along the cable. This 'notch diversity' can be fully exploited in data processing and imaging.

"Gonna change my way of thinking
Make myself a different set of rules
Gonna put my good foot forward
And stop being influenced by fools"

Bob Dylan (1941–)

LASSE AMUNDSEN, Statoil and
MARTIN LANDRØ, NTNU Trondheim

Over the years, considerable efforts have been put into improving the bandwidth of marine seismic data. In 2010, CGG responded to broadband technology development by launching a simple, elegant and step-change solution: BroadSeis™. Using proven, readily available equipment that could be put into operation immediately, BroadSeis is a combination of three distinct parts: deep-towed low-noise Sercel Sentinel® solid streamers; unique variable-depth streamer acquisition techniques; and deghosting and high-end imaging.

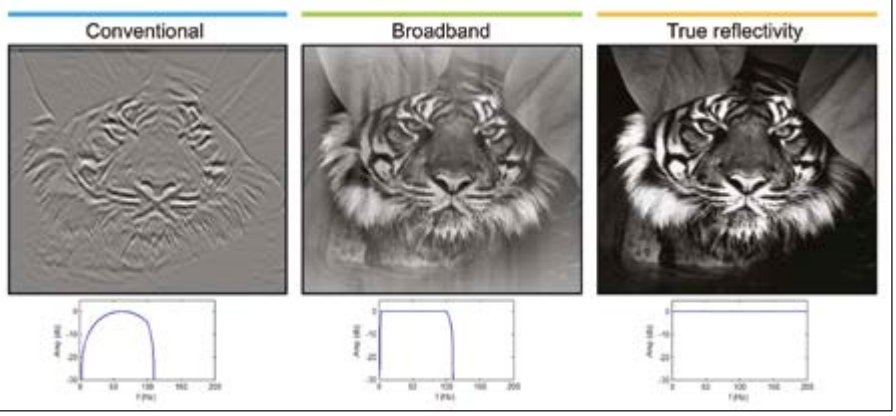
Acquiring variable-depth streamer data is not more complex than acquiring conventional streamer data because the main change is to tow the streamer at pre-defined variable depths. BroadSeis takes advantage of towing solid streamers at depths that are currently considered extreme to benefit from the improved low-frequency response of the hydrophones and reduced sea-state noise. Control of solid streamers to variable depths has proved to be robust and stable, even down to 50m.

In previous issues of *GEO ExPro* we have addressed the benefits of broadband seismic. Both low and high frequencies are required for high-resolution imaging of important features such as thin beds, small sedimentary traps and shallow drilling hazards. In addition, high-fidelity, low-frequency data provides deeper penetration for the clear imaging of deep targets, as well as providing greater stability in seismic inversion.

Flat or Slanted Streamer Acquisition?

In conventional seismic acquisition, a vessel tows a number of streamers that are normally positioned horizontally at an approximately constant depth relative to the sea surface. It is then necessary to tow the streamer quite close to the sea surface so that the second ghost notch occurs beyond the frequency range required for imaging; the first notch occurs at 0 Hz. Thus, in the past, the ghost notches dictated the depths at which streamers were towed. However, shallow streamer depths result in attenuation of the lower

Image courtesy of CGG



The picture analogue to broadband seismic. The right picture has all frequencies, allowing us to see all the features and the 'true amplitude' response, while the middle one has no high frequencies and also lacks the very low frequencies, reducing the resolution and absolute amplitude response. The left picture has been affected by ghosts and lacks both low and high frequencies, severely affecting the resolution and leaving us with only a relative understanding of the interfaces. Broadband seismic fills in frequencies on the low side and adds more high frequencies, which has a big effect on resolution. The small graphs below each picture show the frequency content of each image.

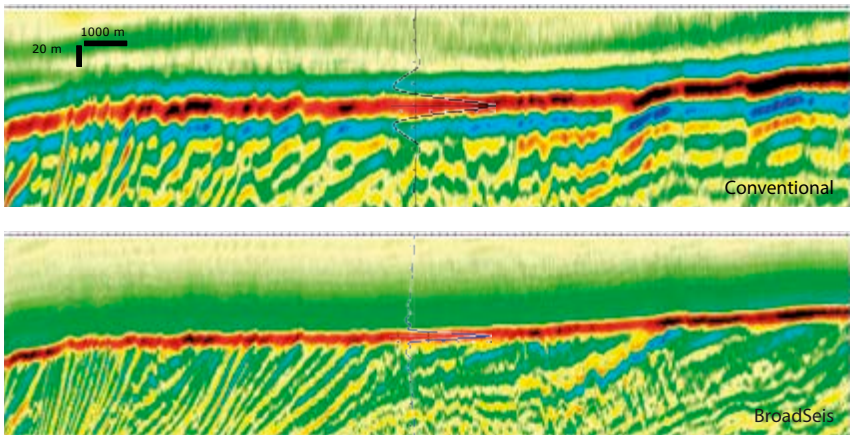
frequencies due to the ghost effect. Furthermore, towing the streamers close to the sea surface increases the noise recorded at the low-frequency end.

As the streamers are moved deeper, a better low-frequency response is obtained, with a lower sea-state noise level, but the ghost notches in the amplitude spectrum come in at lower frequencies as the cable gets deeper: 100 Hz at 7.5m streamer depth and 50 Hz at 15m. In the past, this has led to a choice between recording at shallow depth to obtain the high frequencies, or deep for noise-free lower frequencies. For low frequencies, and especially for deep penetration in challenging geological environments, such as basalt or very deep layers, it is beneficial to tow the streamer at depth. However, unless the notches are removed, the higher frequencies will suffer, which is undesirable. In cases where only low frequencies are of interest, for example up to 25 Hz, and it is acceptable to sacrifice the high frequencies (e.g., all the frequencies above 25 Hz), a tow depth of 25m could be used.

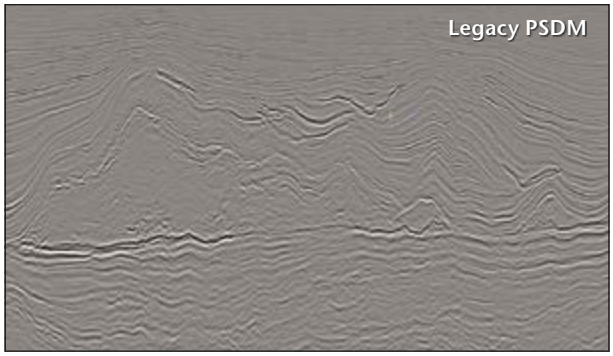
This problem of towing deeper but with fewer frequencies in the recorded signal has led to compromises in the bandwidth recorded for most surveys. Different acquisition techniques have been proposed to overcome this problem, including deep-towed dual sensor streamers (*GEO ExPro,* Vol. 4, No. 4), with the up-going waves recorded by the geophone being used to fill in the notch in the hydrophone data, or towing pairs of streamers at different depths to yield a fuller frequency range by combining the streamer measurements into deghosting (*GEO ExPro,* Vol. 3, No. 1).

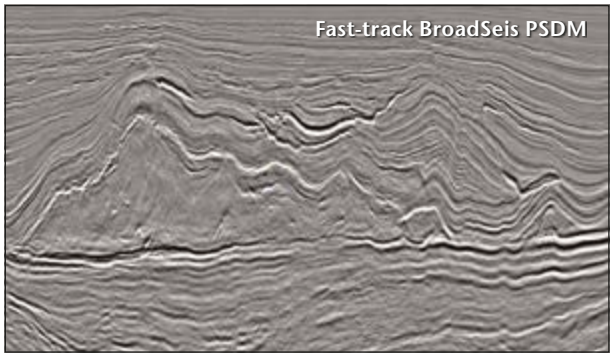
One early proposition was that the streamers could form a constant angle (i.e., they may be slanted) with respect to the sea surface. However, the slanted streamer has a major limitation, which may make it impractical. Current streamers have a typical length of about 6 to 10 km. Using a slanted streamer, with, for example, a slope of 2% (i.e., 0.02) relative to the sea surface, would lead to a depth of about 280m

This zoom over the water bottom offshore Gabon clearly shows the benefit to be gained from broadband wavelets without side lobes, making it possible to resolve a huge amount of detail. In this case the dipping sediments can be traced right up to the water bottom on the BroadSeis section. The wavelet extracted over the water bottom event demonstrates the characteristic BroadSeis wavelet with minimal side lobes due to excellent low-frequency content.



Courtesy of Total, Cobalt and the Republic of Gabon





BroadSeis provides additional low-frequency content for better subsalt imaging. In both the post-salt and intra-salt basins the full bandwidth provides great resolution and texture to aid interpretation. Courtesy of CGG Brazil Data Library.

Variable-Depth Streamer

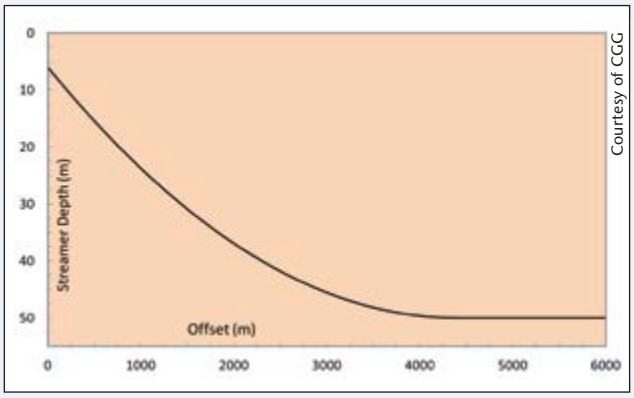
The streamer does not typically have a variable-depth profile over its entire length. Typically, the first portion is curved and the second portion is flat. One example of a variable-depth streamer is described by the following equations:

$$z(x) = z_0 + s_0 x\left(1 - \frac{x}{2x_C}\right) \quad \text{for} \quad x \le x_C$$

$$\text{and...} \quad z(x) = z_0 + s_0 \frac{x_C}{2} \quad \text{for} \quad x > x_C$$

This curved profile of the streamer is defined by three variables: z_0, s_0 and x_c. In these equations, depth z is measured along the Z axis and offset x is measured along the X axis. The first of the equations provides the curved profile, while the second equation provides a straight line (constant depth).

As illustrated in the figure, the first parameter z_0 indicates the depth of the first sensor in the streamer. This parameter may have a value in the range of metres to tens of metres; a typical example is z_0 = 6m. The second parameter s_0 is related to the slope of the initial part of the streamer relative to a horizontal line. As an example, the value of the slope s_0 may be between 1 and 3%.



Schematic diagram of curved streamer. Parameters are z_0 = 6m, s_0 = 2% and x_C = 4,400m.

The third parameter x_c indicates a horizontal length (distance along the X axis) measured from the first detector of the streamer's curved portion to the end of the curved portion. This parameter may range from hundreds to thousands of metres. In other words, the streamer may have a curved first portion and a second portion that is flat, differently curved or slanted. The parameter x_c defines the first portion.

for the last sensor, but in reality current marine sensors are designed to operate in water depths up to about 50m. Thus, for current streamers, the slant streamer approach could require detectors to be located in water depths beyond their current capabilities, although as sensor technology improves, these ranges may of course increase. Furthermore, the water depth is often a limitation and for water depths less than 100–200m, a slanted streamer approach might be impossible.

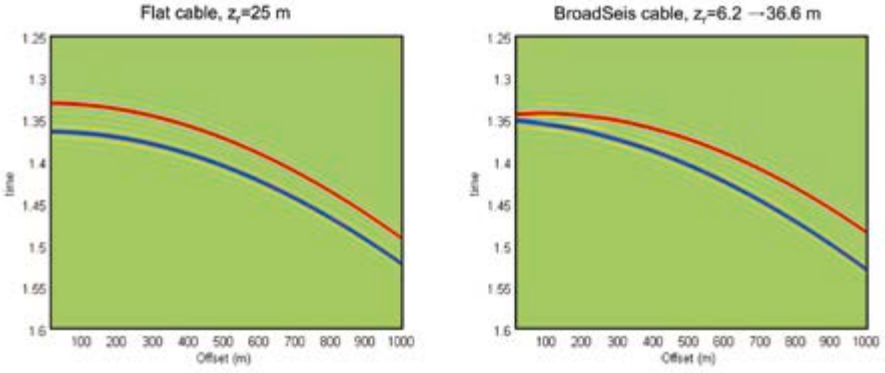
Clever, Simple Solution

Spurred by the initial industry developments within what is now broadband seismic technology, Robert Soubaras of CGG came up with a clever and simple solution to the deghosting problem called BroadSeis. It is capable of acquiring both low and high frequencies with the same set of streamers by utilising a variable-depth towing configuration, i.e. the cables have an optimally curved geometry to maximise the receiver ghost-notch diversity. With this novel configuration, the receiver ghost notch varies along the cable and this 'notch diversity' is exploited by deghosting and imaging techniques for generating a high-quality final image with sharp and clean wavelets for easier interpretation. BroadSeis delivers an elegant solution with an improved bandwidth and, thus, a sharper image of the subsurface.

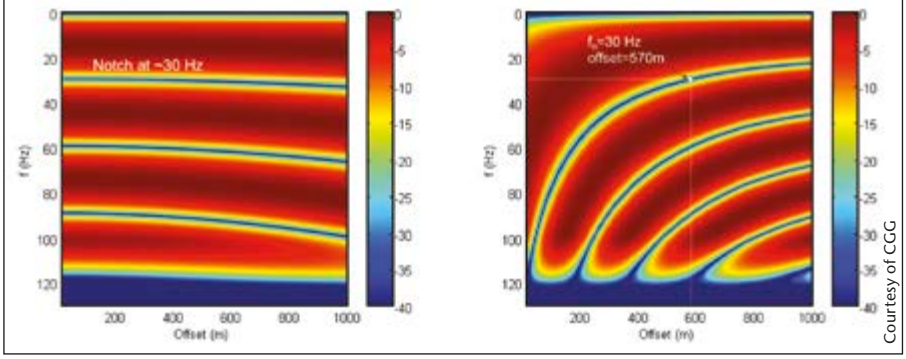
The notch diversity is designed and optimised for exploration and production targets, to deliver the best possible resolution to interpreters. The profile of the cable depth can be tuned for different water depths, target depths and desired output spectra of the wavelet.

We refer the reader to the box on

Reflected upgoing event (red) and associated receiver ghost (blue) for deep flat streamer (left) and BroadSeis streamer (right). The wavelet is high frequency so that the events are well separated.



Associated frequency spectra of data with offset. The blue lines show the notches in the spectra caused by the ghosts. For the BroadSeis streamer (right) the notches in the spectrum vary more significantly with offset. This is often referred to as notch diversity.



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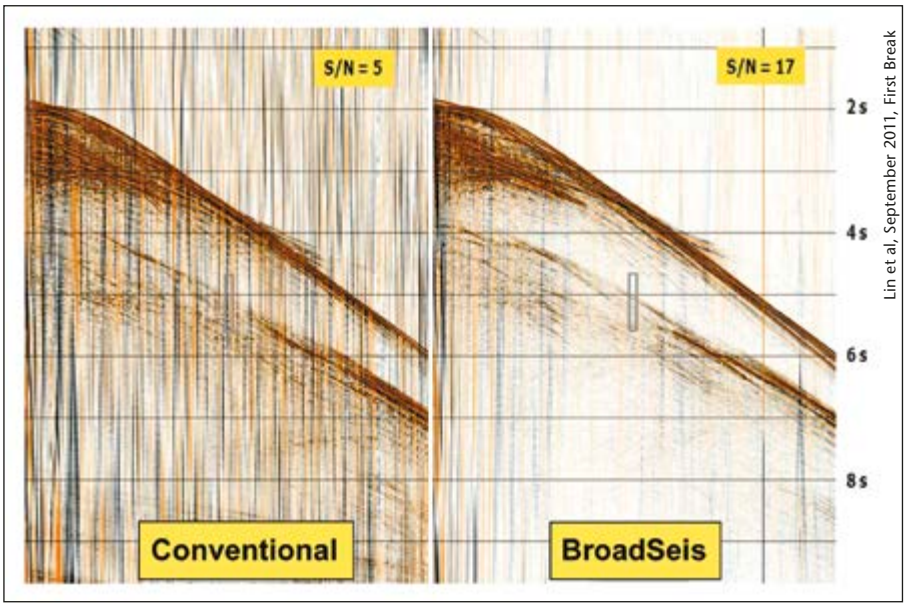
page 52 to see an example of a variable-depth streamer.

Deghosting

BroadSeis, therefore, is a data acquisition technique that widens the seismic bandwidth at both ends of the frequency spectrum by using a single spread of Sentinel cables towed with a variable-depth configuration. Starting from the nearest channel, the receiver depth increases with offset, introducing diversity in the receiver ghosts. This diversity enables CGG to remove the receiver ghost. One advanced method developed by Soubaras (2010) is normal plus mirror imaging followed by joint deconvolution that produces a broadband wavelet with high signal-to-noise ratio.

The issue of receiver ghosts is long-standing in the seismic industry. We are starting to see a range of solutions which are helping to overcome this challenge, and a number of alternative pre-imaging deghosting algorithms have been developed. Such solutions are offered by Wang (2013) and Poole (2013) who describe pre-migration processing approaches. Of particular interest in these methods is the derivation of a surface datum ghost-free model of the data. This model may be used to receiver-side deghost and re-datum data so that conventional flat streamer algorithms can be used.



Shot gathers, acquired in marginal weather, show how BroadSeis' deep tow reduces weather-related noise and so extends the weather window.

Acknowledgement:
The authors would like to thank Vetle Vinje of CGG for assistance with this article.

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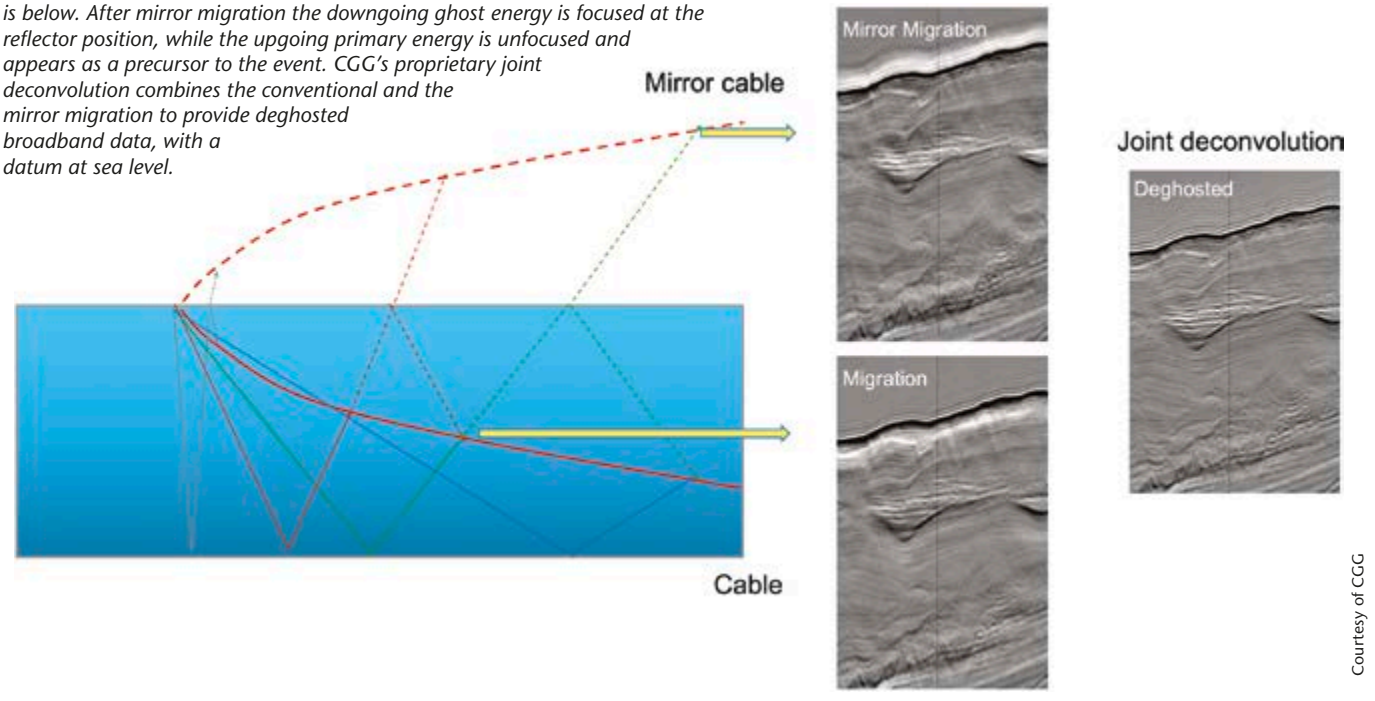
Deghosting by joint deconvolution. After conventional migration, the upgoing primary energy is focused at the reflector position while the downgoing ghost energy is unfocused, appearing as a fuzzy, polarity-reversed event after the reflector. Mirror migration treats the data as though they had been recorded at a mirror cable, positioned as far above the sea surface as the real cable is below. After mirror migration the downgoing ghost energy is focused at the reflector position, while the upgoing primary energy is unfocused and appears as a precursor to the event. CGG's proprietary joint deconvolution combines the conventional and the mirror migration to provide deghosted broadband data, with a datum at sea level.



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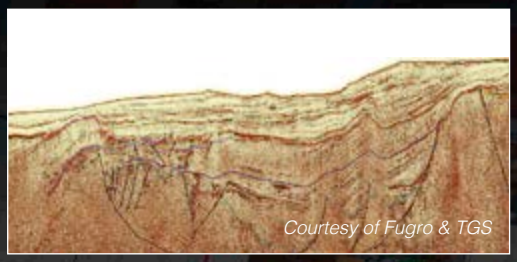

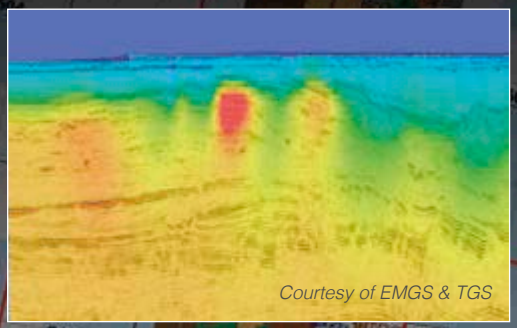

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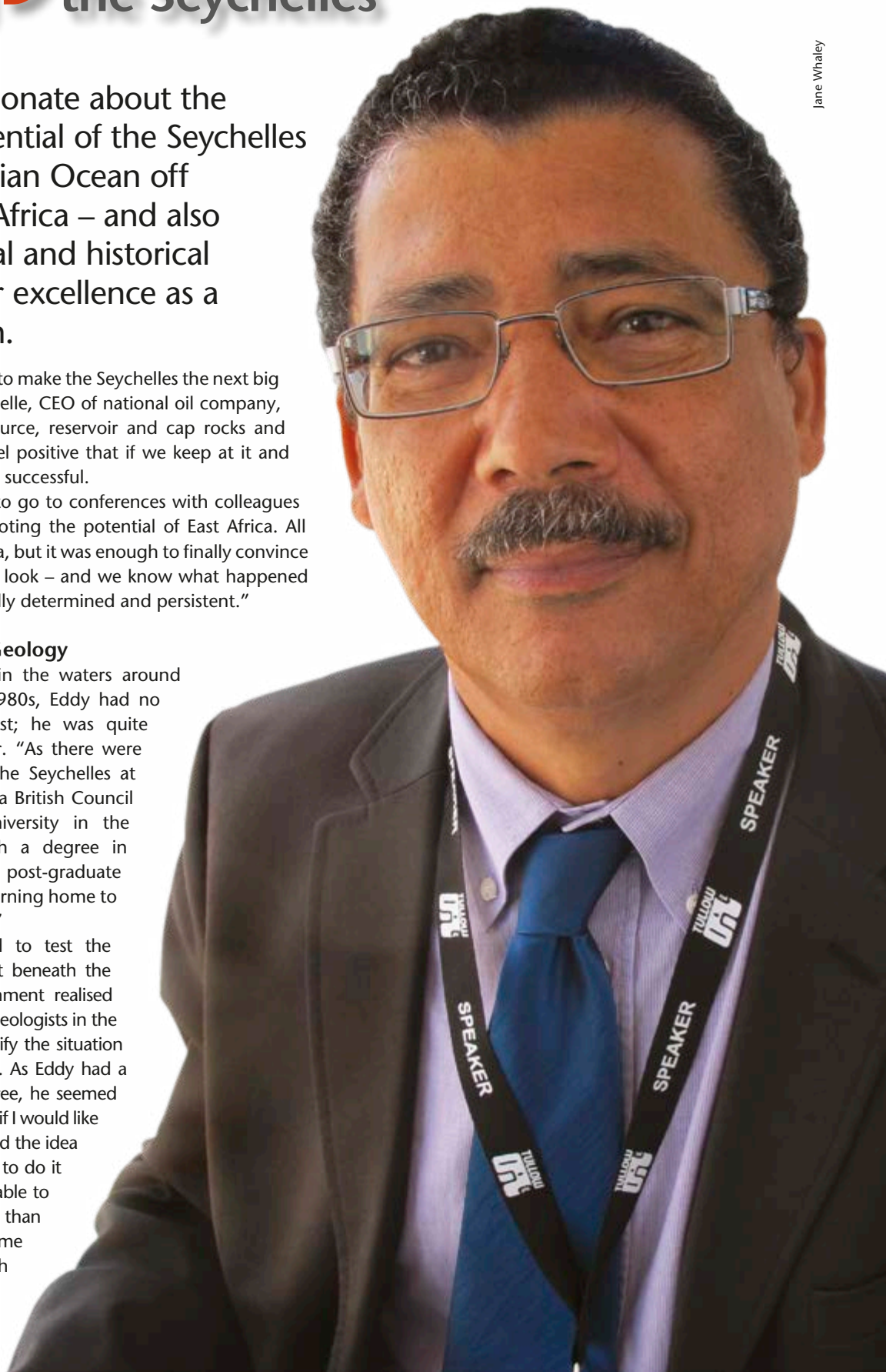
Eddy Belle
Promoting the Seychelles

JANE WHALEY

Eddy Belle is passionate about the hydrocarbon potential of the Seychelles Islands, in the Indian Ocean off the coast of East Africa – and also about their natural and historical heritage and their excellence as a tourist destination.



Jane Whaley

"We have everything we need to make the Seychelles the next big oil province," exclaims Eddy Belle, CEO of national oil company, PetroSeychelles. "We have source, reservoir and cap rocks and we have good structures. I feel positive that if we keep at it and continue exploring, we will be successful.

"I remember when I used to go to conferences with colleagues from Uganda, together promoting the potential of East Africa. All they had was some gravity data, but it was enough to finally convince Heritage and Tullow to take a look – and we know what happened then! We just have to be equally determined and persistent."

Chemistry to Petroleum Geology

Until Amoco began to drill in the waters around the Seychelles in the early 1980s, Eddy had no thought of being a geologist; he was quite happy as a chemistry teacher. "As there were no tertiary level colleges in the Seychelles at the time, I had been sent on a British Council scholarship to Lancaster University in the UK, where I graduated with a degree in Chemistry, following it with a post-graduate teaching certificate before returning home to commence a teaching career."

But when Amoco decided to test the extent of the continental crust beneath the Seychelles Plateau, the government realised that there were no Seychellois geologists in the country, so they looked to rectify the situation by rapidly training some locals. As Eddy had a first class honours science degree, he seemed an ideal candidate. "I was asked if I would like to study petroleum geology, and the idea interested me – but I was keen to do it somewhere where I would be able to actually see some rocks, other than the granite which surrounds me in the Seychelles. In 1985, with

the help of a US Government scholarship, I went to the University of El Paso in Texas to take a masters degree in Petroleum Geology; since I knew nothing of the subject, I first did an intensive three-month introductory course in Tulsa, Oklahoma. I had to work very hard, but I really enjoyed the course, and returned home two years later to join the newly-created Petroleum Office of the Seychelles. At the time, this consisted of just three people: an exploration geologist on loan from the Indian ONGC, a petroleum engineer who had worked with Amoco, and me.

"In 2012 the government created PetroSeychelles to be the national oil company with the remit to promote exploration in the country, and I was asked to head it up. Until then, Seychelles Petroleum Company had been the arm of the government overseeing the petroleum upstream sector, but as it also had shares in companies exploring offshore, it was in a difficult situation, so the new organisation was formed. It is still a very small company – only nine people including support staff – but we are the arm of the government that oversees oil exploration and, hopefully, eventually also production offshore the Seychelles."

Unique Islands

"Interest in the hydrocarbon potential of the waters of the southern Indian Ocean had started back in the 1950s and '60s with a series of research voyages," Eddy continues. "Scientists realised that since the Seychelles Islands consisted of granite, which is of continental origin, rather than the oceanic volcanic material usually found at mid-ocean islands, there was a chance that the continental crust extended around the islands. And, as we all know, continental crust means the possibility of hydrocarbons."

Oil companies had begun to look at exploring for oil in the Seychelles in the 1970s, when Mobil included the Seychelles Plateau in a regional survey which extended from East Africa to Sri Lanka, while Burmah Oil shot reconnaissance lines across the plateau in 1973. These found a block-faulted sequence overlain by flat-lying sediments, comparable to a rift-drift succession, with the sedimentary section reaching at least 6 km in thickness. The Petroleum Mining Act was established in 1976, allowing companies to seek acreage, and a number of them shot seismic and other geophysical data, before Amoco took the plunge and drilled three wells in 1980 and '81.

"The Amoco wells did not find commercial hydrocarbons," says Eddy, "but they did prove that a working hydrocarbon system was present in the Seychelles. However, since that time only one more well has been drilled in our territory, by Enterprise in 1995. It was testing the hypothesis that a thick pre-Tertiary sedimentary sequence would lie below thin Tertiary carbonate and volcanic layers, but what they found was two kilometres of carbonates underlain by a kilometre of volcanics, and they abandoned the well. VSP measurements indicated that there were indeed sedimentary rocks below the volcanics – but by that time Enterprise had moved on. Because we are relatively remote and everything has to be brought in to the islands, it is expensive to set up and to explore here, which is an issue we are looking at."

Promoting Tourism

In 2001, Eddy's career took a surprising twist for a petroleum geologist; he was asked to become Principal Secretary at the Ministry of Tourism. "It seems an interesting jump, but actually, it was very logical, as it was basically another management role," he explains. "Tourism is the main pillar of our economy, but the government felt that it was not performing as well as it could be doing. The Ministry asked me to set up a new tourist board for the country, on similar managerial lines as the Seychelles National Oil Company, the predecessor of PetroSeychelles, which I had successfully headed up for a number of years.

"I really enjoyed that job, as I am very passionate about my country," he adds. "I come from Takamaka, which is a beach area on the main island of Mahe, but because the Seychellois population is so small – less than 90,000 – everyone seems to know everyone else. People communicate with one another – you can't sit in a bus without striking up a conversation with the person beside you. It is a real racial melting pot, with people having African, European, Indian and Chinese backgrounds, but everyone gets on together and treats each other with respect and we have no racial or religious tensions. In addition, we have a lovely safe climate, with no cyclones or other traumatic weather conditions, 115 beautiful and primarily uninhabited islands, wonderful beaches and scenery – and no dangerous snakes or spiders!

"We promote the Seychelles as a high-end destination, giving the visitor an experience not to be found elsewhere," Eddy explains with passion. "We don't want mass tourism, which would put pressure on our fragile ecosystems, so it is important that our tourism is sustainable. For example, we limit the number of hotel beds allowed on each island, and don't want to develop beyond these limits – but we do like to encourage our visitors to discover new areas, and maybe spend a little extra money during their travels. We have become a favourite holiday spot for royalty, celebrities and politicians, as we value their privacy – and do not tolerate the paparazzi.

"So my spell in the tourism ministry was a fascinating break from the oil industry. I was looking at different issues, but faced similar managerial, growth and promotional challenges. After four years I had successfully set up the new Seychelles Tourist Board and felt I had accomplished my mission, so I returned to my old job in the petroleum sector in 2005."

Renewed Interest

This proved to be a very timely move, as after a ten-year lull during which no

acreage was held, interest in the potential of the Seychelles was developing. US company Petroquest International took a concession in that year, followed by Dubai-based East African Petroleum, a subsidiary of Black Marlin Energy, in late 2008.

"Much of this renewed interest was sparked by geochemical work, particularly by Chris Machette Downes," Eddy explains. "In Houston he found the original 1980s cores obtained by Amoco, and he discovered that they still had hydrocarbons in them, which he could correlate to the natural seepages found in a number of areas of the Seychelles (see *GEO ExPro,* Vol. 4, No. 5). There is a very positive story about sources and the potential for oil as well as gas here. Petroquest has since been taken over by WHL Energy and East African Petroleum by Afren, and both these companies are undertaking seismic surveys at the moment and are planning to move into the drilling phase in 2014 or 2015, showing their level of commitment to the region."

Eddy thinks that new technology, particularly in the seismic arena, could prove to be the key needed to unlock the geology of the region. "Fugro undertook a survey in the Seychelles EEZ in 2010–2011, and more recently, in August last year in fact, the Japanese company JOGMEC signed an agreement to conduct geological and geophysical surveys in order to evaluate further the hydrocarbon potential of the region. The thick carbonate and volcanic layers absorb seismic waves, preventing the underlying pre-Tertiary sediments from being clearly imaged, but new seismic techniques such as long offset streamers and low frequency recording, plus developments in data processing, mean that we can now begin to visualise these underlying sediments where hydrocarbons are thought to be trapped."

Since his basic geology degree, Eddy has not had much time for "seeing rocks", and most of his subsequent training has been in the field of management. This has included stints in the US and in Norway, where he spent time with Farouk al-Kasim, a previous *GEO ExPro* profilee (Vol. 8, No. 3). "We have very good ties with Norway," he explains, "and would like to emulate their methods and set up a Petroleum Trust if we find oil. This is not exactly because we need to build a huge, sustainable infrastructure, but because we want to ensure that some revenue is kept aside for future generations."

National Monuments and Conservation

Eddy enjoys the international travel that comes with his work promoting the Seychelles, admitting that living on a small island can be a bit claustrophobic if you cannot occasionally escape. But he is always pleased to return home, often taking a break from geology to explore some of the many old monuments to be found on the islands.

"I have always been very interested in the history and nature of these islands; I was previously Chairman of the National Monuments Board and am currently Treasurer of the Island Conservation Society", he says. "I think it is very important that we ensure the unique systems of the Seychelles remain unchanged and protected, and I also think that a country must preserve both its cultural and natural heritage. In addition, people visit our country to enjoy these things and don't want them to change, so we must make sure we protect them.

"While my career path hasn't been straightforward, it is strange how one thing has led to another and everything I have done has proved relevant. Take, for example, my early teaching training and experience. This taught me many things which have contributed to success in my later work, including presentation skills and how to plan, as well as the importance of psychology when dealing with a variety of people. It proved an unusual but invaluable foundation for my managerial tasks.

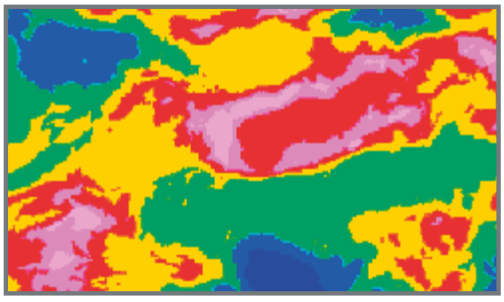
"My life has been good and interesting, as I have managed to do so many things," Eddy concludes. "I feel very lucky." ■

Eddy Belle relaxing in his beautiful country.

Eddy Belle

The Neuquén you never knew

Uncovering the hidden secrets of one of the world's largest shale plays



Using predictive analytics, NEOS GeoSolutions combined hyperspectral, magnetic, electromagnetic (EM), gravity, and seismic datasets to determine optimal drilling locations. Warmer colors indicate higher prospectivity.

Argentina's Neuquén Basin is one of the world's most dynamic and underexplored hydrocarbon systems. Its two principal shale targets – Los Molles and Vaca Muerta – have been rich source rocks for the conventional reservoirs that have been produced in the basin for more than 50 years. With new technologies available for unconventional asset exploration and development, producers are taking a second look at these extremely thick oil- and gas-charged shales. While several seismic and non-seismic datasets have been acquired, the coverage lacks uniformity, and no one has been able to integrate the data into a single, actionable interpretation — until now.

NEOS GeoSolutions has acquired high-resolution, airborne geophysical data over 30,000 square kilometers of the Neuquén Basin. Using innovative, multi-measurement methodology, the company has integrated these new measurements with existing well, geological, geochemical, and seismic data available in the public domain, from third parties, and from the project's underwriters. NEOS designed the Neuquén survey to provide the project's underwriters with an enhanced basement-to-surface understanding of the basin and its potential.

Initially, high-resolution hyperspectral imaging was acquired to map the regional lithology, the total organic carbon (TOC) of the target shales, and oil seeps and indirect hydrocarbon indicators on the surface. A second work stream generated 3-D models constrained by the structural aspects of existing seismic lines, available well data, and newly acquired gravity and magnetic measurements. These models provided useful exploration insights by depicting isopachs, burial depth, depth-to-basement, and proximity-to-intrusives for all target shale horizons.

The team also developed a new hydrocarbon maturation model by combining the 3-D model, existing basin TOC models, and surface samples. This analysis identified new areas of opportunity previously considered to be overmature. By interpreting the locations of volcanoes and intrusives from airborne magnetic data, a new thermal gradient model was developed, refuting the misconception that intrusives had terminally degraded regional opportunities.

Finally, NEOS combined all datasets using a geostatistical data mining technique called predictive analytics. By analyzing key attributes – including shale thickness, a set minimum amount of overburden over the objective, a minimum of faults and fractures along the drill path or near the bottom-hole location, the potential for generated and retained liquid hydrocarbons, and a relatively flat topographic area for drilling – NEOS and client geoscientists highgraded acreage to identify optimal drilling locations and reveal the lucrative secrets of the Neuquén.

▶▶▶ To learn more about this project or others in the *Unlock the Potential* series, visit: www.ThePotentialUnlocked.com

HIGHLIGHTS

KEY TECHNOLOGIES:

- MAGNETIC
- GEOCHEMISTRY
- GRAVITY
- HYPERSPECTRAL
- PREDICTIVE ANALYTICS
- SEISMIC REINTERPRETATION

AREA: Neuquén Basin, Argentina

CUSTOMER: Supermajor

FOCUS: Regional Mapping

TYPE: Unconventional

KEY INTERPRETIVE PRODUCTS:

- Regional 3D subsurface models
- Horizon-specific isopach maps
- Estimates of gas-in-place on an areal basis, developed using multi-variate analysis

CUSTOMER BENEFITS:

Reveals new prospectivity in the frontier portion of an established basin by integrating new airborne geophysical measurements with existing seismic, well, and geological and geophysical (G&G) data.

Petrophysics in *High Angle* and Horizontal Wells

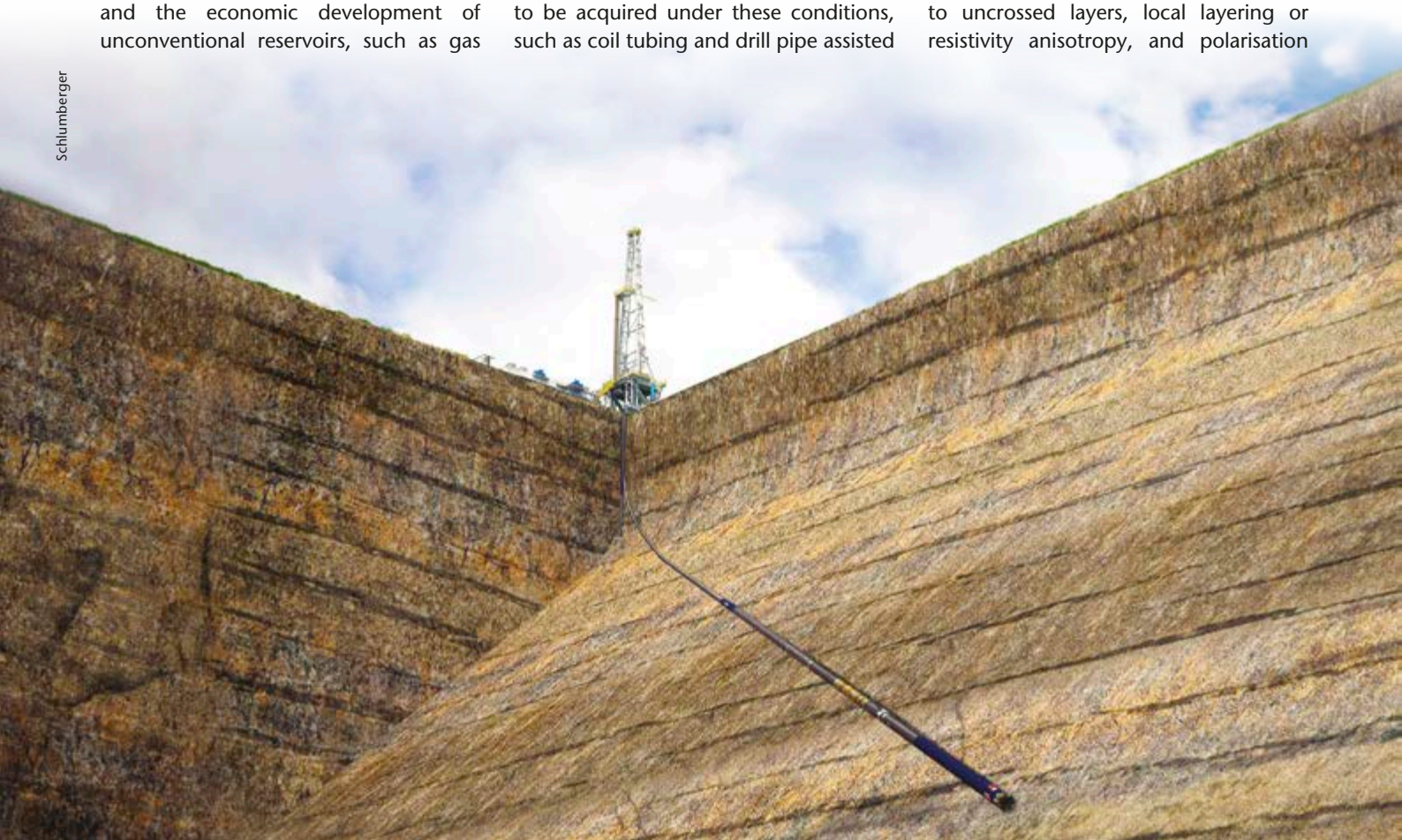
DAVID MAGGS, SILVIA LATTUADA, ROGER GRIFFITHS, Schlumberger;
MAURICIO MELE and ANTONIO VALDISTURLO, Eni E&P

The benefits of directional drilling are widely known – increased reservoir exposure and greater production. However, the practice can pose formation evaluation challenges in high angle and horizontal wells, making traditional petrophysical interpretation techniques harder to apply because of geometric effects on the data. Modern wellbore software can provide a viable solution.

Increasing numbers of wells are drilled horizontally or at high angles for a number of reasons – to improve reservoir exposure, avoid or target particular features, and in relief-well scenarios. The practice has been proven to significantly increase production; even the first commercial horizontal well delivered twenty times the expected production in a vertical heavy oil well (Bosio, 1986). Modern drilling technology, geosteering, and logging while drilling (LWD) tools allow high angle and horizontal (HaHz) wells to be routinely undertaken and the economic development of unconventional reservoirs, such as gas and oil shales and tight sandstones, would not be possible without the extensive use of horizontal wells.

Directional drilling presents a number of formation evaluation challenges, however. In HaHz wells it is often difficult to apply the traditional petrophysical interpretation techniques used in vertical wells, particularly the resistivity logs, due to geometric effects on the data. A well is said to be horizontal if it deviates more than 80° from vertical (Passey et al., 2005). Modern technologies allow standard petrophysical measurements to be acquired under these conditions, such as coil tubing and drill pipe assisted logging, and the development of LWD tools and assemblies which have become the primary means of acquiring logging data in HaHz wells.

The difficulty begins with the fact that LWD data acquisition strategies in horizontal wells are often designed for geosteering purposes and can be unsuitable for petrophysical evaluation. Even when full LWD logging suites are available in HaHz wells it is often difficult to apply vertical well petrophysical interpretation techniques because of bed boundary effects and proximity to uncrossed layers, local layering or resistivity anisotropy, and polarisation



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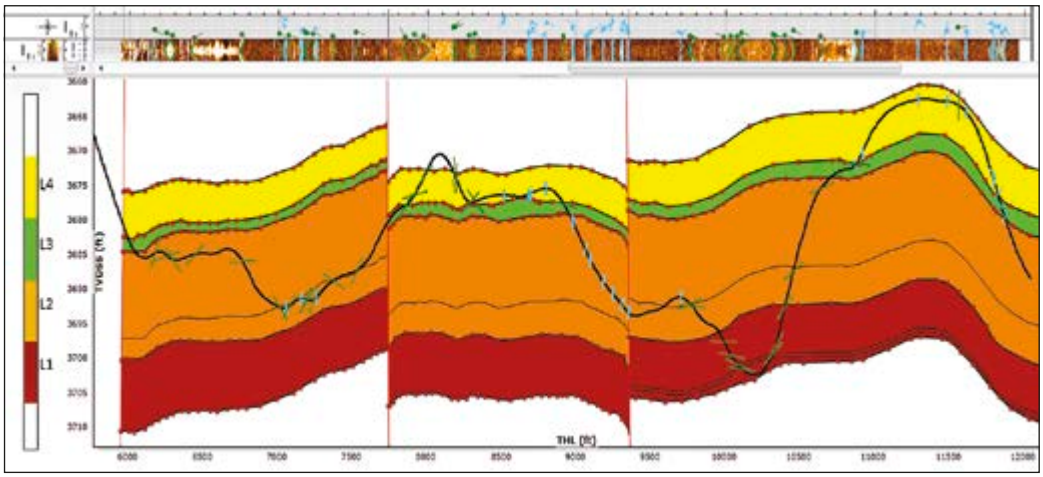


Geological section of example well A showing the target layers and faulting. Note the extreme vertical exaggeration: 50 ft TVDSS (true vertical depth sub-sea) vs. 6,000 ft THL (true horizontal length).

horns on the resistivity measurements (Griffiths et al., 2012). Other effects complicating the borehole environment include asymmetric invasion profiles, the presence of cuttings beds and drilling mud segregation (Passey et al., 2005).

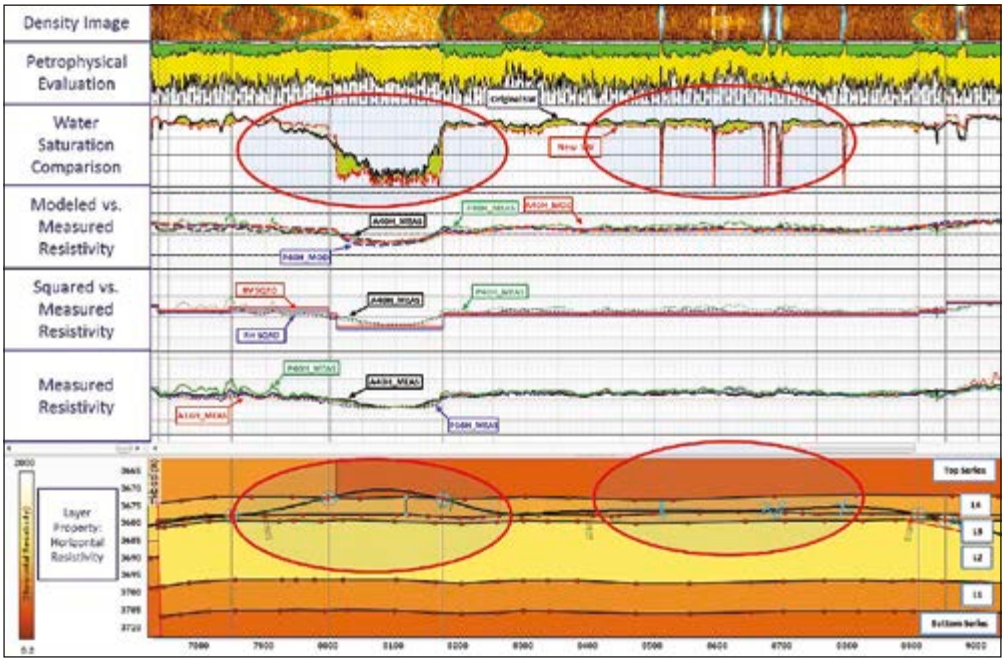
Many operators therefore now find themselves in the situation of being able to land HaHz wells inside a challenging target in the desired stratigraphic position, but less able to interpret the acquired logs to obtain a correct petrophysical evaluation of the well data.

A Digital Solution

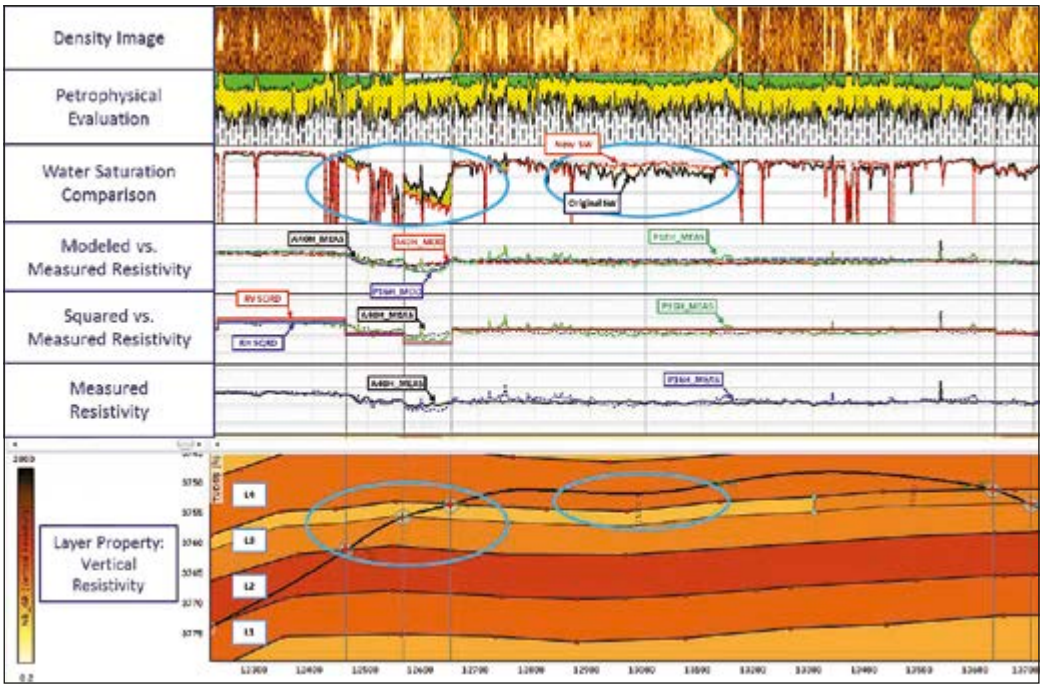
It is possible, however, to improve the LWD data prior to analysis using modern E&P software. A recent project outlined how the most common effects in horizontal wells can be addressed using a new workflow within the Techlog wellbore software platform, from Schlumberger (Valdisturlo et al., 2013). The project focused on wells in a developmental field in North America. The reservoir consisted of a few tens of feet of thick, silty sand beds, interbedded with siltstone and local alignments of carbonate concretions, deposited in a shelfal environment. Extended reach wells used in the development of the field had long lateral sections: between 5 and 10,000 ft (1.5m–3.5 km). Due to the geological complexity of the area, the wells often crossed multiple layers and faults and were actively steered to optimise reservoir contact. The workflow was applied on two complex horizontal wells to improve delineation of the formation properties and aid standard petrophysical evaluation. The workflow built a layered geological model which simulated log responses in a continuously updated loop to obtain corrected physical properties for each layer, taking into account the influence of nearby layers on the log response.

The workflow checks LWD logs and compares them with existing vertical wells to assess reliability. Sections from the geological model are then used to build the formation model in the proximity of the well. If available, LWD image logs are also used to calculate formation dip and azimuth along the trajectory. The formation model is then verified, refined, and updated. Each layer of the formation model crossed by the well is populated with formation properties based on selected well logs. For layers not crossed by the well, properties are manually entered based on offset well responses. If necessary, lateral property boundaries are inserted in the layers, allowing for property variations to exist in a layer which the well intersects more than once. Forward model simulations of the logs are then compared with the measured logs, and the layered model and layer properties are manually refined until the best agreement between simulated and acquired logs is reached.

Validated layer properties from the workflow form the basis for the new petrophysical evaluation, which is compared with the original evaluation performed using raw acquired data. Substantial differences are evaluated and understood, before final validation and updating of the geological model. Lastly, a final hydrocarbon-in-place calculation update is performed.



Example well A showing bed boundary effects where the well drills up into the overlaying shale and then back down into the L4 reservoir (left red ellipse).



Example well B displaying the effect of thin beds (highlighted by the left blue ellipse) and proximity effect (highlighted by the right blue ellipse).

Analysis-Ready Data

In one of the wells, where it crossed three thin layers at a high angle, extended shoulder bed effects are observed. The resistivity measurements responded to the multiple layers within their volume of investigation, causing the measured resistivities to read higher than they would in a single layer. Consequently the standard interpretation would deliver a water saturation which was too low. By accounting for these shoulder bed effects, the new interpretation delivered higher and more precise water saturation in the thin shaly beds, avoiding undeliverable hydrocarbon volume in a substantial non-reservoir section. In this interval the effect of the carbonate-cemented concretions was clearly observable on the density image.

Two further effects were observed. The standard petrophysical analysis delivered a water saturation which was too low, as the input geometrically uncorrected resistivity was affected by a combination of the nearby thin bed which was shaly and conductive, and an underlying high resistivity reservoir layer. In this case the density image suggested that the wellbore just touched the layer. The resistivity response is affected by a combination of the layers, all of which lie within the resistivity volume of investigation. The contributions from each can only be determined from a tool-specific response equation, available in the Techlog software platform. The overall result indicated that the apparent resistivity is slightly higher than would be recorded. The new water saturation calculated with the geometry-corrected resistivity was slightly higher in comparison with the original water saturation, because it was based on real layer resistivity properties.

The effect of extended bed boundaries and an associated blurring of the resistivity response were evident. The use of the layer properties and a fine geological model sharpened the bed boundaries, and took them, and the surrounding layer resistivities, into account when the resistivity fast forward model was computed. Use of the geometry-corrected layer resistivity in the petrophysical analysis indicated water saturation of almost 100% in the shale (as expected in this area) and revealed higher hydrocarbon saturation in the layer near the exit and entry points. This resulted in improved water saturation determination.

Optimised Analysis

Although bringing a number of significant benefits, the increasing prevalence of HaHz wells has highlighted some of the limitations of traditional petrophysical interpretation techniques in these wells, due to geometric effects on the data. This challenge calls for new approaches and modelling workflows to improve the reliability of interpretation results. Digital drilling and interpretation technologies will form part of a wider theme to be discussed at the 2014 SIS Global Forum, in Barcelona on April 15–17. This biennial industry conference will focus on the future of digitally mitigating E&P risk, using simulation and software technology.

The workflow in the above project efficiently confirmed and refined the geological environment from the static reservoir model, and provided true formation layer properties for use in the petrophysical analysis. The comparison of log responses between vertical and deviated wells was helpful for quality control, and in the well log modelling phase to assess the correct record of petrophysical properties for the input logs and the model ling results. Log measurements were updated and a resulting improvement in petrophysical answers was observed. ■

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Premature Predictions for LNG?

For an industry that is used to long-term contracts and guaranteed markets, changes in the gas market are proving unsettling. Will predictions of a future glut in liquefied natural gas prove premature? **NIKKI JONES**

The trade in liquefied natural gas (LNG) has risen almost without interruption for thirty years, doubling since 2000. However, 2012 saw an unexpected 'blip' in the upward trend and in 2013 investment in several major gas projects was delayed. The cause? The market is complex and changing, demand has become uncertain while supply is strong. The result is that analysts now appear divided on whether there will be a supply glut by the 2020s, or a supply shortage resulting from the current wait-and-see approach to long-term investment.

A Changing Market

Gas acquired a new status when the commodity super-cycle took off in the early 2000s. Companies began searching for the fuel in its own right, causing gas reserves to achieve parity with oil. Investment in infrastructure that can liquefy gas, transport it and regasify has allowed previously disconnected and remote reserves – notably in Australia, the Arctic and Africa – to be linked to markets. The high cost of such infrastructure has been justified by rising demand plus the industry convention of negotiating long-term bilateral contracts, indexed to oil, usually with at least 60% of production sold in advance.

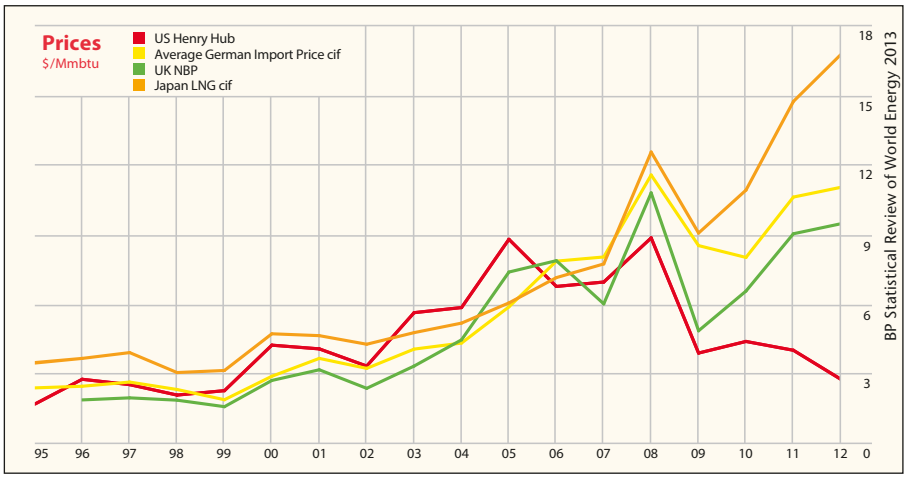
However, a great deal of the early investment was based on an assumption that the US would be the primary market. It is almost humorous to remember now that as late as 2003 the US Energy Department was predicting that the country would run out of domestic gas supplies within two decades and Alan Greenspan was urging Congress to fast-track the construction of LNG *import* terminals. US shale production has, of course, completely reversed this scenario, with the US overtaking Russia to become the world's biggest gas producer in 2010. In 2012, oversupply caused the Henry Hub benchmark to crash to a low of less than $2 per million British thermal unit (mBtu).

Suppliers have reacted by shifting their focus to East Asia – specifically to China which is expected to use at least 75% more energy than the US within 20 years and which doubled its gas consumption between 2007 and 2012, and to Japan

The Karratha Gas Plant, North West Shelf Project, Western Australia. Australia is set to overtake Qatar by 2020 as the world's largest supplier of LNG.

which became the highest importer of LNG following the Fukushima disaster of March 2011. However, both markets lack certainty: Japan's imports of LNG are reported to have cost an unsustainable $33 billion in the first half of 2013, fuelling the government's determination to return to nuclear power and to investigate further its own methane gas deposits; and China has its own shale reserves, estimated by the Energy Information Administration to be approximately 1.275 Tcfg. Although difficult geology, water shortages and lack of infrastructure appear to be hindering Chinese shale development, the possibility remains that global investments based on this one market may, as with the US, backfire. Gas is a small proportion of China's current energy mix (approximately 11%) and given the country's economic slow-down, its massive development of renewables and its reported reluctance to invest in gas turbines, there is room to doubt whether China will fulfil the potential envisaged by all its would-be suppliers.

Sharp falls in demand in Europe are adding to the 'buyer's market' scenario.



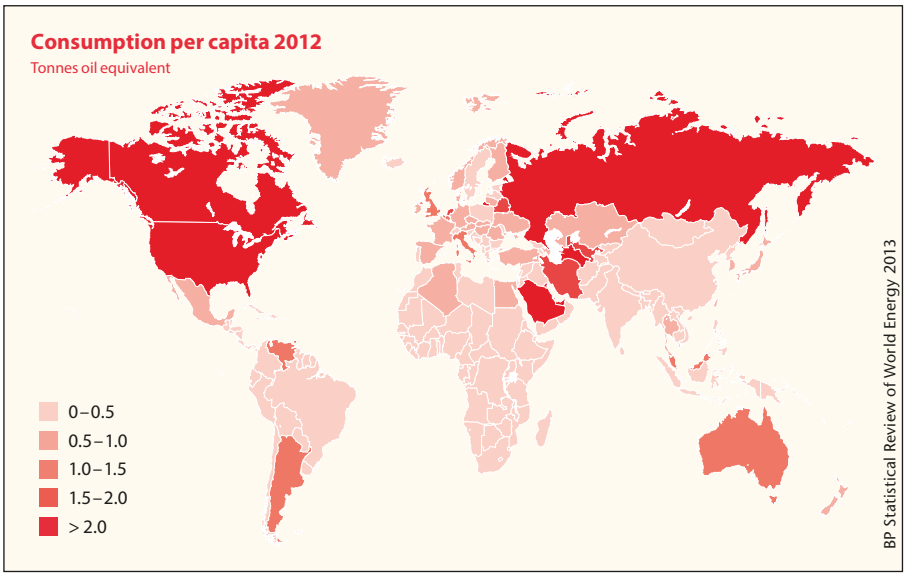
Changes in world gas prices since 1996 (in US$/mBtu)

Although the continent has been searching for alternatives to gas sourced from Russia and the North Sea, weak energy demand generally plus a move towards cheap coal and renewables has made it difficult to attract new investment for expensive infrastructure. Utility companies, which account for more than a third of gas demand, have been cancelling or delaying investment in gas-fired power plants, arguing that they need government guarantees to counter the low carbon price that has made coal particularly attractive, as well as subsidies for renewables. For LNG suppliers, the possibility that Europe will exploit its own shale reserves further complicates the investment picture, as do new pipelines bringing gas from the Caspian and possibly from the so-far unexploited deepwater finds in the Levantine Basin (*GEO ExPro,* Vol. 10, No. 3).

Woodside Energy Ltd

Lowering the Bar

For companies involved in exploiting expensive stranded reserves in Australia, Africa and the Arctic, among others, investment decisions have been further complicated by the question of whether the US will start to export its shale gas, not only increasing global supply but vastly under-cutting the typical Asian price of $15–18 mBtu and European price of $12 mBtu. Up until 2013, in order to keep domestic prices low and fuel its own economic recovery, the Obama administration had been holding back on export licences to any country with which it does not have an explicit free trade agreement. However, in late 2013 several licences were given consent with the potential that if all are granted, the US could be exporting over 40% of its production – more than 28 Bcfgpd. An example of an early deal that has lowered the bar for other purchasers is the contract agreed between the UK's Centrica and Cheniere Energy in Louisiana – 89 Bcfg every year for 20 years at a fixed fee of $3 per mBtu plus 115% of the fluctuating Henry Hub price (currently less than $4 per mBtu). Asian buyers in particular are seeking similar deals.



Worldwide natural gas consumption increased by 2.2%, rising in every region except Europe and Eurasia; the US recorded the largest national increase, while EU consumption fell to the lowest level since 2000.

Not only is US shale offering a particular 'carrot' to buyers but it has added impetus to calls for a more liberalised gas market, specifically a break with oil indexation and an end to 'take or pay' contracts that commit buyers to a certain quantity for years ahead. Statoil, which supplies much of northern Europe, has said that it expects 50% of European consumption to be priced off gas indices by the end of the year. Although at present LNG is still more likely to be indexed to oil, an LNG spot market is developing. With high price arbitrage across the globe, this is currently to the advantage of large producer-traders such as BP and Shell who find that trading can be more profitable than actual production. For example, cargoes originally bound for Europe can be diverted to higher paying Asian customers and cheaper supplies bought on the spot market to satisfy original customers. However, the lack of certainty is clearly a barrier to smaller upstream companies faced with high – and rising – capex; moreover, marked price arbitrage between Asia, America and Europe is unlikely to continue should the market become fully liberalised.

Feast or Famine?

Lack of security with regard to cost recovery is holding up investment. The nascent LNG spot market which by 2011 was accounting for a quarter of all supplies is now reported to have days with no trading at all. According to research by consultants Wood Mackenzie, the only LNG projects to reach Final Investment Decision (FID) in 2013 were all in the US and together they will only add 9 million tonnes per annum (mtpa) (86 MMboe) of LNG capacity, a notable slowdown from the 14.1 mtpa (134 MMboe) added in 2012 and the 26.8 mtpa (262 MMboe) in 2011. High among the postponements are the gasfields off the coasts of Mozambique and Tanzania, additional trains from Australia, and Chevron's Kitimat export facility on the west coast of Canada. Despite several years of impressive gas finds it seems that predictions of a 2020s global gas glut may have been premature: too many market uncertainties prevail. ▶

Rig floor of a drillship exploring for gas off Mozambique

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Qatar – Biggest Supplier of LNG

Since 2006 Qatar has been the world's biggest supplier of LNG – by a very wide margin. Qatari annual exports of almost 80 million tonnes (mt) (764 MMboe) dwarf those of its nearest competitor, Malaysia, with its mere 23 mt (217 MMboe). However, Australia is set to overtake Qatar by 2020 and although currently secure in its long-term contracts, Qatar is unlikely to be able to re-negotiate them on the same terms in the future.

Qatar's massive wealth – it has the world's highest per capita income – comes from the 'North Field', the world's biggest gas reserve, a 9,700 km^2 offshore structure shared with Iran. Although Qatar ranks twelfth in terms of world oil reserves, these are declining. Since 2005 there has been a moratorium on further development of the North Field in order to prevent damage, but exploration has continued and a significant new find (544 km^2) was announced in 2013. Although Qatar only began gas production in 1991 and LNG exports in 1997, the country has moved fast to develop several gas-related industries such as petrochemicals and aluminium production. Qatar also produces 140,000 b/d of gas-to-liquid products at its Shell-built GTL plant, the world's largest.

Qatar has had to adapt fast to the loss of the US as its main market. Most of its long-term contracts are now with East Asian and some European buyers. These appear to be cushioning the state from current upheavals in the market but even Qatar will not be immune to market uncertainties, including the move away from fixed term contracts towards a liberalised spot market.

However, Qatar has been using its wealth to diversify its economy and invest in human capital projects at home, as well as buy its way to a new international status with a highly independent foreign policy. Qatar has come to the world's attention, not just through Al Jazeera, its support for Libyan and Syrian rebels and its provision of a base for the US Central Command – all while maintaining good relations with Iran – but also through the deployment of its massive cash surplus, via its highly active sovereign wealth fund, into infrastructure projects and banking in the Global North. In a further attempt to diversify its economy, in 2013 the Qatari stock exchange was upgraded to 'emerging market' status, a move expected to attract in capital flows of approximately $430m. Whether such developments will adequately insulate Qatar from its dependence on LNG is unclear but, in the short term, there appear to be few clouds on the Qatari horizon. ■

Pearl GTL plant at night. This is one of the largest and most sophisticated plants ever built in the energy industry

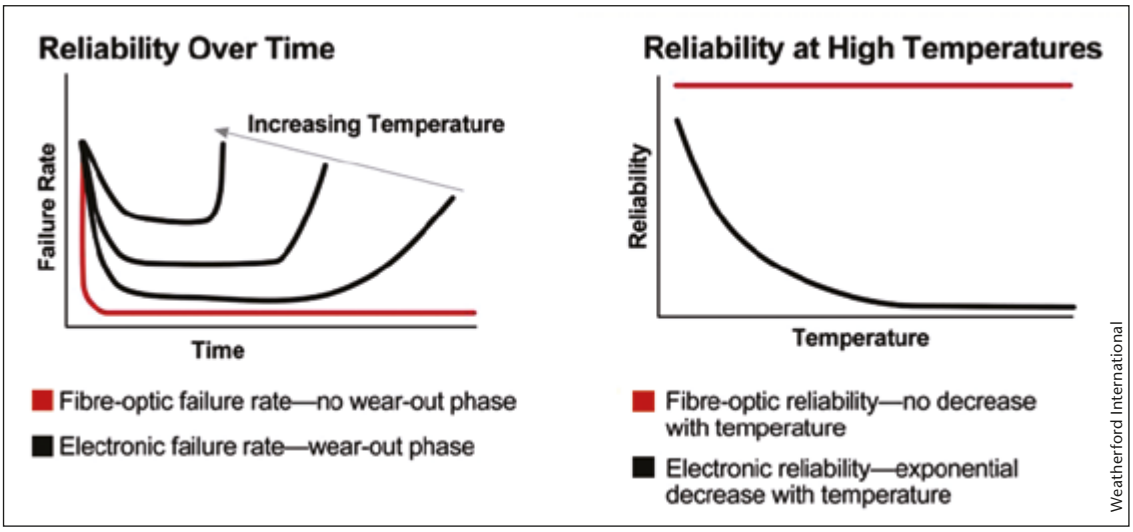
Real-Time Data = Proactive Field Decisions

THOMAS SMITH

Recent developments in permanent downhole monitoring provide accurate and stable measurements even in extreme high pressure/high temperature reservoir conditions. The integration of multiple measurements as they happen allows operators to make field decisions for production and reservoir management.

International engineers preparing the fibre optic cable during an installation of the OmniWell™ second generation pressure/temperature (P/T) sensor in the Middle East-North Africa region. A key installation of this sensor took place in 2011 in North Kuwait and featured long term reservoir monitoring of the downhole pressures and temperatures in an extremely high temperature/high pressure gas well where electronic sensors have previously proved unreliable.

Weatherford International



Fibre optic sensors have proven to be stable over time at increasing temperatures, allowing accurate downhole monitoring in much more extreme P/T wells than electronic sensors.

'Permanent' downhole well monitoring is nothing new, as pressure gauges have been installed in wells since the 1960s. Just like commercial communication and remote sensing satellites that are deployed in a very harsh environment and are usually inaccessible for repair, well monitoring systems must be engineered to last. The technology has grown from just monitoring downhole pressures to integrating multiple measurement solutions for activities such as flow profiling, fracture monitoring, production surveillance, and thermal profiling. These data are sent to the surface using a downhole cable and processed through a scalable data-management platform. Simply put, this allows the operator, through integrated software, to simultaneously visualise dynamic, multi-parameter data under changing well conditions.

From Standard to Extreme Conditions

One technology developed to address these issues is Weatherford's OmniWell™, a unified family of pressure, thermal, flow and seismic products that provide an accurate view of well conditions. These systems have now been installed worldwide in reservoir conditions that range from conventional to extreme. All types of well and development activity can be monitored, including both electronic and optical sensing technologies for conventional and unconventional oil and gas fields. Past monitoring systems relying only on electronic pressure/temperature (P/T) sensors were found to be not dependable under extreme conditions such as high temperature (HT), high temperature/high pressure (HT/HP), high vibration/shock or complex deviated wells. Bearing this in mind, Weatherford International has developed optic sensing technology as part of the OmniWell Production and Reservoir Monitoring solution. This has proven reliable in the most extreme temperature and pressure downhole environments, including maximum reach (MRC) smart wells, multilateral horizontal wells, ultra high temperature/high pressure deep gas wells, and ultra- high temperature heavy oil steam wells.

These systems are providing added value in the form of key continuous real-time production and reservoir data to the Middle East and North African (MENA) countries, whose economies depend on the hydrocarbon industries despite recent efforts to diversify. The MENA region holds more than half of the world's proven oil reserves and a significant percentage of the world's gas reserves (see *How Much Oil in the Middle East?*, page 42). With recent developments in tight and unconventional hydrocarbons, it has become more important for operators in this area to find new resources, cut costs and optimise production for their existing resources.

New oil and gas projects for this region total in the hundreds, and the OmniWell monitoring solution is being used in 11 MENA countries with fibre optic monitoring being deployed in extreme downhole conditions in Kuwait, Oman, Saudi Arabia and Algeria. The technology has proven reliable and useful in understanding the structural, dynamic, and geological behaviour of the region's complex reservoirs.

Success in North Kuwait

Relying on over 19 years of experience with optical gauges deployed in oil and gas wells, with thousands of sensors, and over a spectrum ranging from conventional to some of the most challenging downhole environments, Weatherford and the Kuwait Oil Company put their fibre optic sensor technology through a pilot test programme in 2011. They selected a deep, HT/HP gas well in the Raudhatain Field in North Kuwait.

Ridha Abid, Weatherford International Regional Product Line Manager, had this to say about the pilot project: "The purpose of this pilot programme was to test our fibre optic sensor technology in a deep, HT/HP gas well. Reliability of electronic systems used under these conditions tends to fall off dramatically with increasing temperatures over time. Optical systems have numerous advantages over electronic systems in that there are no electronics downhole and no moving parts. They can withstand continuous, combined high temperature, pressure and vibration downhole from flowing gas wells and can work at temperatures exceeding 230°C and pressures exceeding 20,000 psi. Optical systems can also withstand the high vibration levels associated with gas wells. Add to these advantages a longer reach capable of tens of kilometres of cable

versus the shorter distances available for quartz gauge systems, and it becomes no contest between the technologies."

For the pilot project, an optical P/T gauge rated to 175°C and 20,000 psi was installed in the well above the production packer at a depth of 4,115m in a 4,785m wellbore. The gauges were to provide continuous measurement of tubing pressure and temperature. The equipment was subject to downhole temperatures up to 138°C and pressures up to 9,500 psi during the test.

"We consider the all-optical approach for monitoring these extreme gas wells attractive," Ridha Abid continues. "The system installed in Kuwait is a second-generation optical P/T gauge that is the product of many years of industry optical experience. The first optical P/T gauge was installed in the Gulf of Mexico in 2000 to monitor long-term reservoir pressure and is still operational. This technology is based on very simple concepts: generating light rays from a light source, transmitting the rays through the fibre to the optical sensor and receiving back the reflected light by a receiver. The receiver decodes the information riding the light waves.

"The OmniWell fibre optic pressure and temperature gauges installed in 2011 have survived the HT/HP downhole environment and are continuously providing reliable, real-time pressure and temperature data to operations personnel on site and to engineers in the Kuwait Oil Company office. The data have proven valuable in monitoring the well intervention and production programmes, determining initial reservoir pressure, managing well drawdown, diagnosing completion problems, building wellbore hydraulics, inflow performance models, and providing pressure build-up data – all without the need for well interventions and the resulting loss in production volume. In addition, a much better understanding of the structural, dynamic, and geological behaviour of these complex reservoirs has been obtained. To maximise the benefit from permanent downhole gauges, it is being recommended that such devices be installed in more future wells of North Kuwait fields."

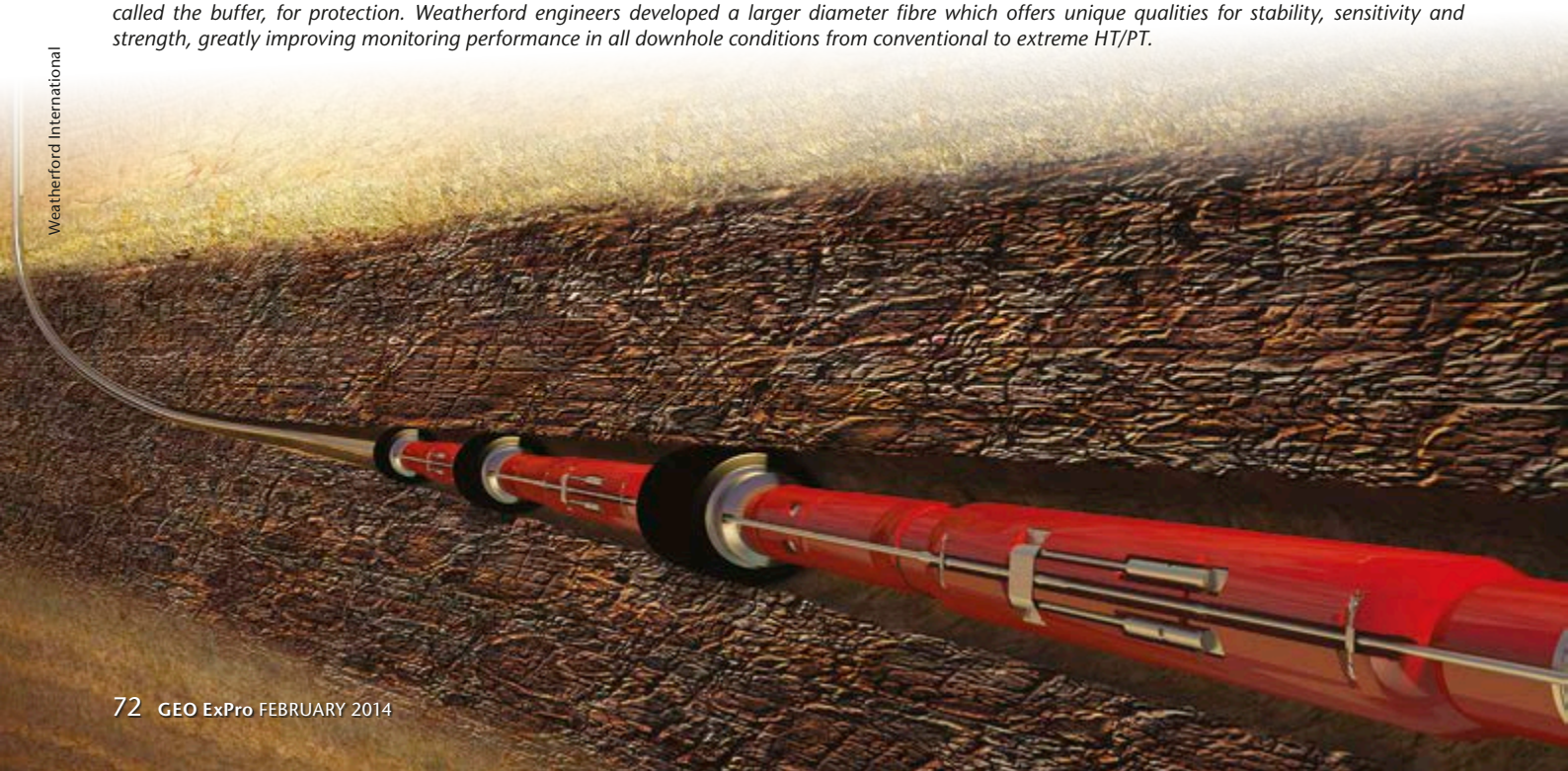
More Than 'Just' New Tools

"Weatherford has not only developed a fibre optic system that can operate reliably in just about any downhole environment, we are also bringing an approach that simplifies and unifies integration and workflows for reservoir solutions for all well types in today's broad range of production environments," says Tad Bostick, Vice President of Reservoir Monitoring for Weatherford. "This is a shift from the tool-based or fragmented data collection approach to a more unified solution where various streams of critical data are transferred to an operator from multiple downhole sources. This unified system allows the operator to make better production and asset management decisions."

Along with the successful testing programme in North Kuwait, Weatherford's optical systems are being installed across the Middle East and North Africa. In Oman, for example, this monitoring system has been installed in HT/HP gas wells to gather data during hydraulic fracturing operations. The P/T gauges were manufactured specifically to withstand the pressures generated during the hydraulic fracturing process. In addition, their surface equipment was solar powered in the remote location. The client was provided with real-time monitoring that allows the optimisation of hydraulic fracture operations. The accurate and stable P/T data from the appraisal wells has enabled management to fully evaluate the field.

The real-time data collected across the Middle East and North Africa is helping keep the region in the fore-front of hydrocarbon production by providing management with the means to maximise field development while lowering overall costs. ■

OmniWell Production and Reservoir Monitoring solutions for flow, temperature, thermal and seismic applications provide actionable data to the operator for better decision making. Improved optical systems feature two sections of glass known as core and cladding, which are covered with a third section, called the buffer, for protection. Weatherford engineers developed a larger diameter fibre which offers unique qualities for stability, sensitivity and strength, greatly improving monitoring performance in all downhole conditions from conventional to extreme HT/PT.



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The conference, which alternates annually between London and Houston, is organized by the Houston Geological Society (HGS) and Petroleum Exploration Society of Great Britain (PESGB). The HGS-PESGB African Conference covers all aspects of African E&P, with particular emphasis on new ideas for plays and prospects, the geology of the continent and its conjugate margins, and application of emerging technologies.

Abstracts (~200 words) should be submitted as soon as possible but no later than March 15, 2014 to the technical committee, Africa2014@hgs.org. The program will be finalized by the end of April.

Currently, volunteers are being sought to be proactive Session Chairs and anyone interested should contact the Technical Committee as soon as possible.

Details of sponsorship opportunities and display booths are available from the HGS office. To become a sponsor or inquire about exhibit space, contact sandra@hgs.org

Registration will be available from April 2014and Early Bird benefits will apply for a few weeks.

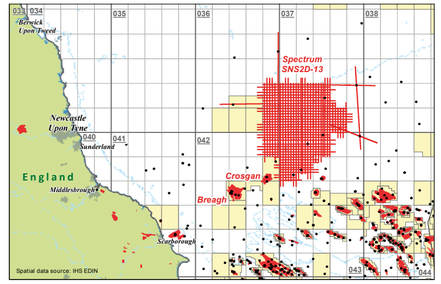
Further details will appear in the HGS and PESGB bulletins and on their websites, www.hgs.org and www.pesgb.org.uk.

Conference Committee for 2014

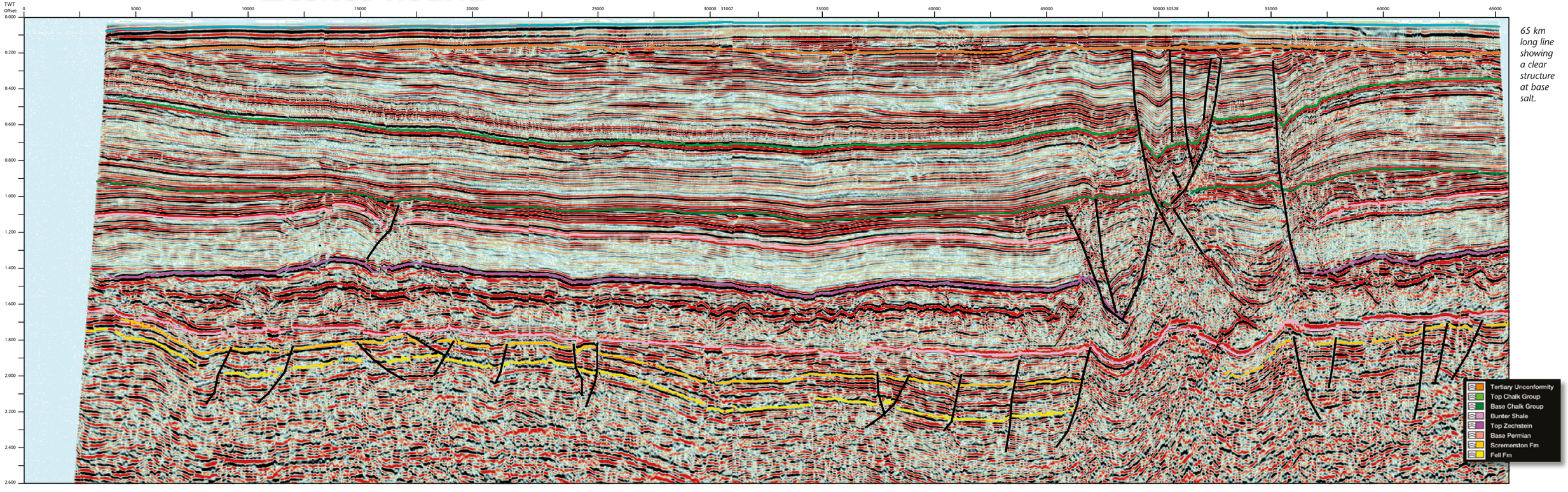
Martin Cassidy (chair), Al Danforth, Ian Poyntz, Donna Davis and Sandra Babcock (HGS)
Ray Bate and Duncan Macgregor (PESGB).

Early Carboniferous Battleground for the UKCS 28th Licence Round

In autumn 2013 the first gas production from the Breagh Field heralded the coming of age of the Dinantian (Early Carboniferous) play on the northern margins of the Southern Gas Basin. This threw down the gauntlet for explorers to chase this new play into open acreage within this mature and infrastructure-rich basin. In 2013 a dense 2D seismic programme was acquired to define the Dinantian play fairway that extends over a large swath of open acreage with yet-to-find potential that dwarfs that of the Carboniferous and Permian plays to the south. For the first time both intra-Carboniferous and pre-Permian unconformity potential can be mapped with confidence, energising this acreage to be the site for fierce competition in the imminent 28th UKCS Licence Round in Q1 2014.



Spectrum



65 km long line showing a clear structure at base salt.

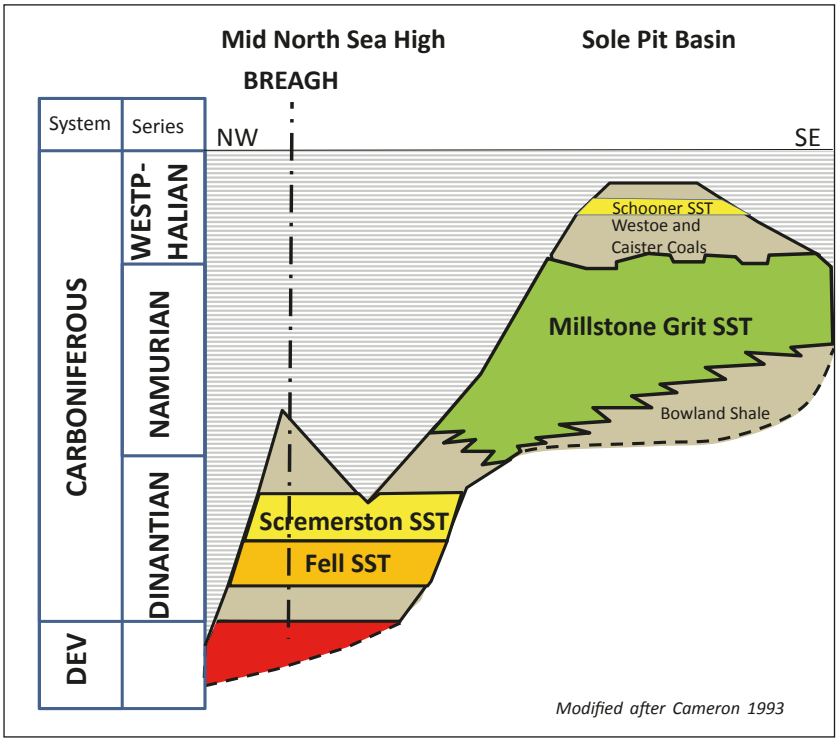
New Data Reveals Potential

NEIL HODGSON, RICHARD WRIGLEY and KARYNA RODRIGUEZ

The northern parts of Quads 42 and 43 in the UKCS Southern North Sea have received limited exploration to date. New data in open acreage north and east of the Crosgan and Breagh fields images the geology clearly and has allowed promising structures to be mapped.

Lying north and east of the Permian Rotliegend Sandstone play fairway in the UKCS Southern North Sea, the northern parts of Quads 42 and 43 have had cursory inspection in the past, usually by explorers seeking either Triassic plays adjacent to gas migration pathways through the Permian evaporites, similar to the Esmond and Forbes fields (about 20 km to the east), or Late Carboniferous Westphalian or Namurian delta-front plays such as the Cavendish and Trent fields. However, due to the geometry of the Base Permian unconformity, the Carboniferous is increasingly eroded to the north and the section encountered here is the sandstone-rich Dinantian (Early Carboniferous) Yoredale Formation (YF), Scremerston Formation (SF) and the Fell Sandstone Formation (FSF). The SF comprises reservoir quality channel sandstones up to 10m thick (42/13-3) with interbedded shales and thin coals. The underlying FSF is a more sand-rich reservoir comprising thick, high net-to-gross sandstones, with individual units up to 40m thick and an average porosity of 17% (43/5-1).

Simplified carboniferous stratigraphy, Southern North Sea, UKCS



New Play Fairway

The first well into the Breagh field (42/13-2), drilled by Mobil in 1997, encountered just such an SF section – finding 20m net pay in a 120m column and testing at non-commercial rates (3 MMcfg/d). However, interpreting the low flow rates to be due to drilling-induced reservoir damage, in 2007 Sterling Resources drilled the 42/13-3 appraisal well that encountered 23m of net pay in a 90m column, and without damaging the formation they tested at commercial flow rates (17 MMcfg/d). Subsequent appraisals reported up to 26 MMcfg/d flow rates (from a horizontal completion), and the field was brought on production in Q3 2013. The adjacent Crosgan field was discovered by Total with well 42/15a-1 in 1990, and awaits appraisal prior to development as a satellite to Breagh. The Breagh 2P reserves are reported at 604 Bcf and P50 contingent resources for Crosgan are 101 Bcf respectively, establishing the potential of this new play fairway for significant discoveries.

Regional depth mapping of the base Permian in the northern gas basin reveals a generally simple south-dipping monocline, except over the Breagh-Crosgan area, which stands out as a broad high. Little progress could be made in identifying valid structures on trend to the north-east as legacy seismic data in the region is widely spaced, multi-vintage and generally poor quality due to the geological complexities of the section. In 2013, to facilitate exploration of the SF and FSF play fairways, 3,736 km of new 2D multiclient data was acquired by Spectrum over open acreage north-east of the Breagh-Crosgan fields. These data were collected with an 8 km cable, nominal 160 fold with 10 second record length.

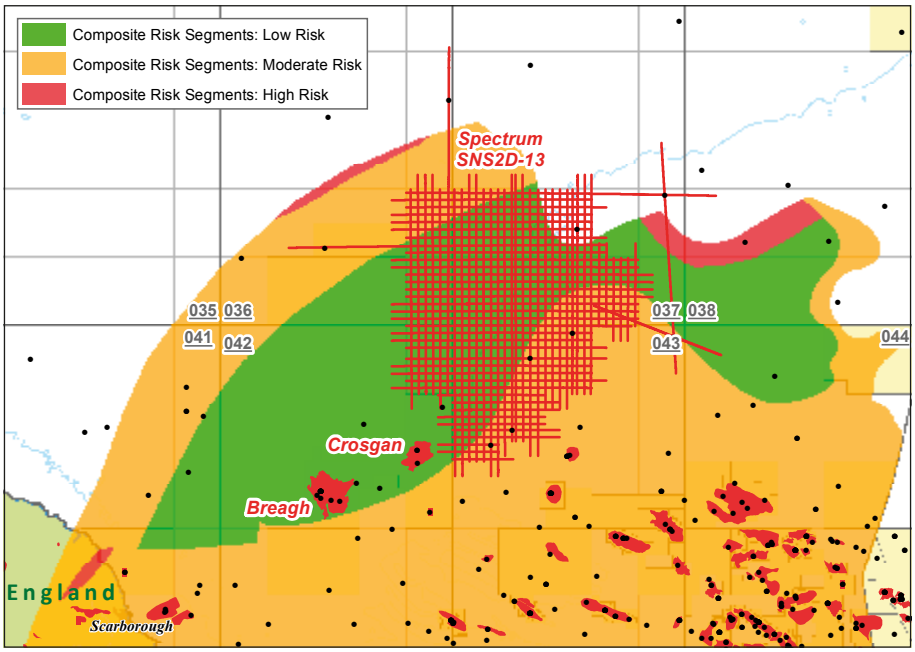
This has enabled a dataset of extraordinary seismic quality to be assembled over the area, which images the Triassic, Permian and intra-Carboniferous sections with great clarity and has allowed base

Permian structures (similar to Breagh field) to be mapped in open acreage and intra-Carboniferous fault block potential to be assessed.

Early Carboniferous Play

Reservoir play-fairway mapping can now identify where SF (and in places FSF) lies at the base Permian unconformity as the new seismic images the intra-Carboniferous reflectors for the first time with confidence. The Dinantian play comprises the following key elements:

Reservoir: SF or FSF sub-cropping the base Permian or in fault block structures. Reservoirs range from interbedded sandstones and coals to thick, stacked delta top channel sequences. Evaluation of the new seismic data is only preliminary and yet already suggests that intra-formational facies mapping may be possible for the first time, highlighting channel belts and reservoir sweet spots.



Composite risk segments, Southern North Sea, UKCS. Analysis shows that the SF/FSF play fairway can be seen as a band extending north-east from Breagh-Crosgan into open acreage.

Charge: The Early Carboniferous play relies on gas sourced from Westphalian Caister and Westoe Coal Formations in the Sole Pit Basin to the south, migrating laterally up-monoclinal dip below the Zechstein salt seal. One of the more intriguing applications of the new data is to map the location of welds in the salt where gas migration may be possible into the Triassic system and top seal may be locally challenged. Sub-Permian plays further north on the Dogger High are likely to have top seal issues due to thin Zechstein, and this is complicated by local halokinesis.

Trap: SF/FSF play top-seal is provided by Zechstein salt, above four-way dip closed structures, potentially with a stratigraphic erosional unconformity component. The 2013 seismic allows detailed facies mapping within the Zechstein sequence, clearly differentiating the halite and anhydrite dominated sequences. Interbedded shales provide intra-Carboniferous seal potential for tilted fault blocks and anticline structures.

The SF and FSF plays can work if intra-Carboniferous shales provide top-seal for Carboniferous structures or if the SF/FSF subcrops the base Permian Zechstein evaporite seal and there is no lower Permian Silverpit or Rotliegend Formation waste zone. Although relatively few wells have penetrated the SF and FSF, mapping the base Permian subcrop of the Dinantian across the northern margin of the Gas Basin has been attempted using published well data (Maynard and Dunay, 1999). This work has been verified by Spectrum in a study of 42 released wells in the area, many of which (for example 41/10-1, 42/10b-2, 42/13-3 & 42/15a-2, 43/5-1) demonstrate the key play elements. A broad north-west to south-east trend of Early Carboniferous subcrop to base Permian extends through and to the north-east of the Breagh area into open acreage. The limit of the play fairway is defined by wells in the south of Quad 42 and 43 which encountered younger mudstone-prone (Westphalian and Namurian) units that are characterised by sandstones with poor visible porosity and low permeability.

These key play elements were mapped using conventional play-fairway analysis. Combining these three play elements indicates that the low-risk common risk segment of the SF/FSF play fairway extends in a band spreading north-east from Breagh-Crosgan into open acreage.

With over 750 Bcfg of resources discovered to date in this play-fairway, the yet-to-find based on Spectrum's preliminary structure mapping of the new dataset is over 1 TCF. As yet unquantified Triassic potential is a secondary target. This potential dwarfs that of the remaining exploration potential of the mature Permian and Carboniferous basins to the south.

Following first gas production from the Breagh field in September 2013, the commerciality of the Early Carboniferous play on the northern margins of the Southern Gas Basin is proven. New, high quality, dense 2D seismic is available to high-grade the prospectivity of these plays previously unimaged on poor legacy seismic, providing a new tool for explorers to use to aggressively compete for acreage in the 28th UKCS Licence Round in 2014. ■

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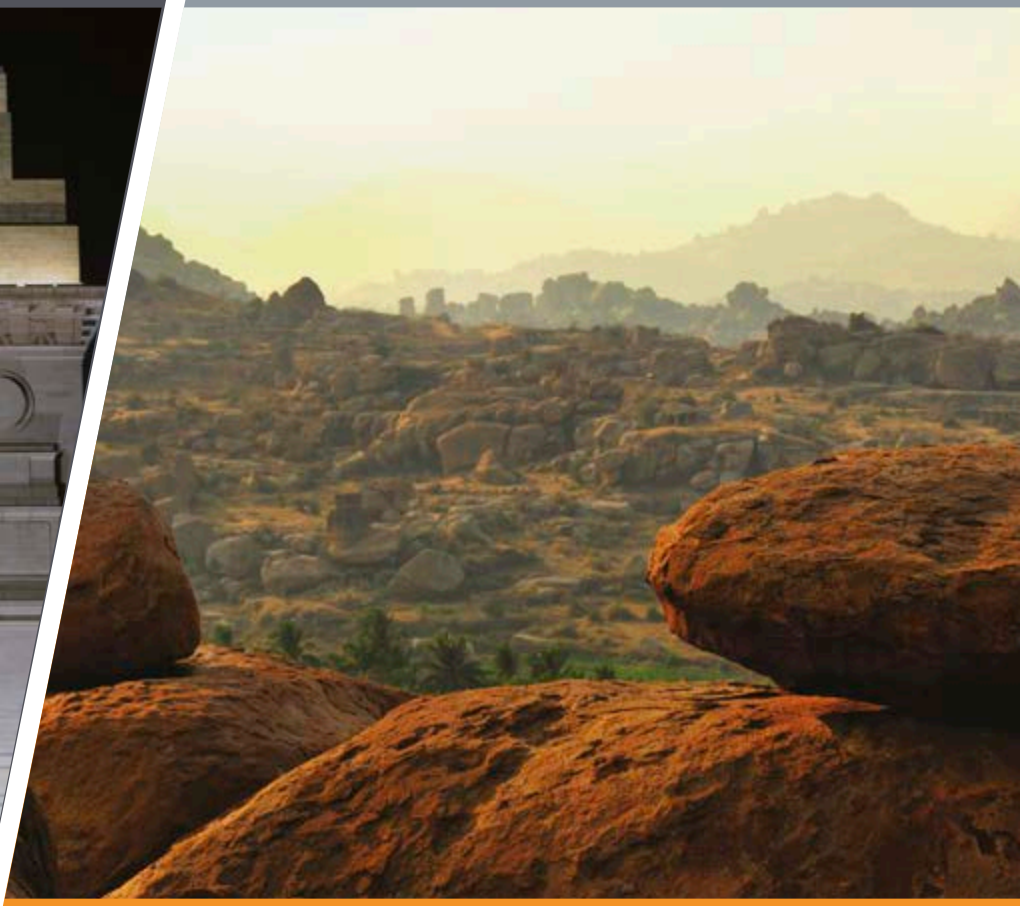

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The Predictive Power of Palynology

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Microfossils are key to understanding the evolution of life on earth. Demand in the petroleum industry for palynologists – experts in the study of these minute fossilised organisms – is suddenly running hot.

DAVID UPTON

In a major turnaround for a profession that fell out of favour in the 1980s, a number of palynology consultancies are growing rapidly and struggling to meet the demand for skills.

Palynology's demise in the 1980s coincided with the arrival of electric well logs. Many petroleum geologists believed downhole instruments told them all they needed to know and arcane reports based on microfossil contents of drill cuttings were no longer necessary. In a decade when cost-cutting reigned, palynologists were routinely among the first to be laid off. But microfossil experts – who are now in critically short supply after decades of underinvestment by the oil and gas industry – are having the last laugh.

Solving Exploration Problems

The revival is being led by a new breed of palynologists such as Perth-based Jeff Goodall, who have a keen focus on applying their science to the problems of petroleum discovery.

UK born and educated, Goodall migrated to Australia in 1999 to take up an in-house palynologist position with Santos. The Adelaide-based independent had bucked the 1980s shift from palynology and maintained a sizeable department under the leadership of Geoff Wood. Goodall left three years ago to join a consultancy founded some 30 years earlier by an icon of the industry, Roger Morgan, who is now phasing into retirement. The new partnership known as Morgan Goodall Palaeo (MGP) has grown from two palynologists in 2011 to more than a dozen today, servicing Australasia and the South East Asian region. It is within striking distance of laying claim to being the largest consultancy of its kind in the world.

Goodall says the growth of MGP and the revival of palynology more generally is due to a number of factors. "There is growing awareness among petroleum

MGP's Daniel Mantle and John Lignum discussing palynological data at the computer.

MGP

How Palynology Adds Value

Palynologists can tell the wellsite geologist the position of a drill bit within a rock unit to an accuracy of between five and ten metres, according to MGP's Jeff Goodall.

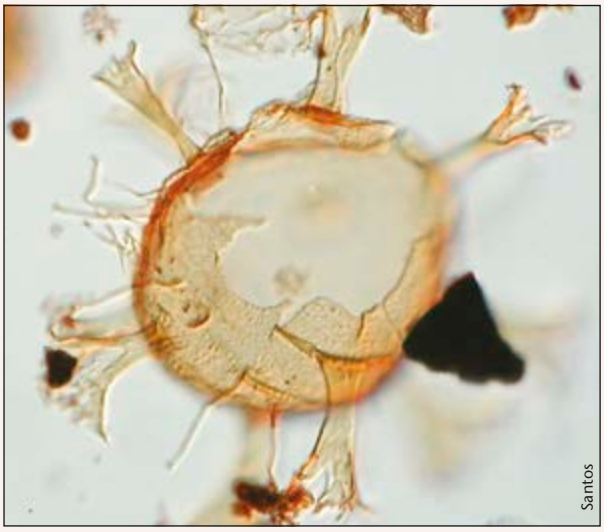
"The palynologist provides a means of checking the progress of the drill bit relative to the interpreted geology. More than that, we can give the well site geologist an accurate prediction of how many metres the bit is located above a seal/reservoir contact. This can be very important with shale gas targets, which are often highly pressured. We can tell the client when to stop drilling and to start running casing ahead of the contact between the shale and the overlying rocks."

This remarkable predictive power comes entirely from monitoring changes in the microfossils, which include plant spores, pollen, algal remains from land areas and plankton from marine environments. Microfossils can be shaken out of the cuttings or cores by using hydrofluoric acid to dissolve silicates and carbonates, and then studied under a microscope.

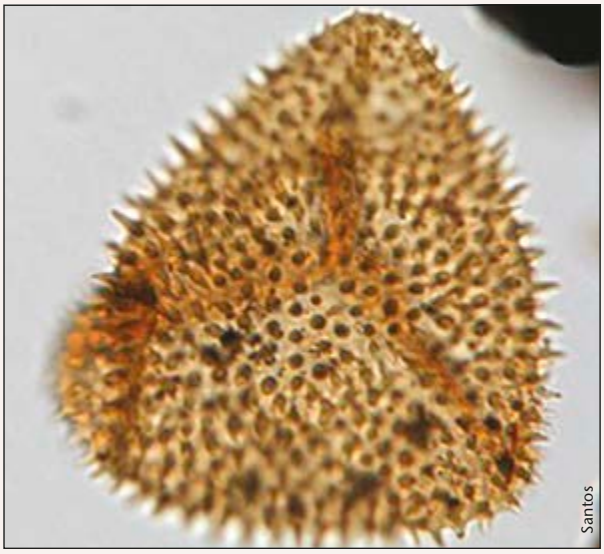
Microfossils are key to understanding the evolution of life on earth, as well as the organic matter on which the world's petroleum industry relies. They reveal a vast amount of information because the intricate shapes of microfossils are restricted to different time periods, allowing a date to be attached to the rock sample. The most important tools of the trade are highly detailed taxonomies of organisms, compiled over more than a century of study. Studying the assemblage of different microfossils makes it possible to reconstruct the climatic and depositional environment.

The type of microfossils can also indicate the likely hydrocarbon products. For example, a rock packed with algal remains is much more likely to produce oil than gas.

Even the colour of microfossils contains vital information. Microfossils are initially clear, but will darken towards black with higher temperatures. This can immediately show whether a source rock has been taken past the oil window into gas generation.



Perisseiasphaeridium inusitatum
A key marker dinoflagellate species in the Late Jurassic.



Didecitriletes longispinosus
Late Permian marker species for eastern Australian sediments

geologists that palynology is much more than age dating. It's being recognised as a tool that can help them gain a much better understanding and de-risking of the geology, allowing them to go for the more difficult targets, and that's increasingly important now all the easy oil has been found." He added that palynology also provided solutions for modern exploration challenges, such as horizontal and directional drilling, especially for unconventional targets.

Goodall said MGP's rapid growth was due to its emphasis on applying palynology to solving exploration problems, and speaking in a language that geologists understood. "We convert the science of palynology and all the long Latin names into a language the geologist can understand so they can go and find oil. Most people are not interested in Latin names, but if you convert them into geological thought, then that's a powerful tool."

Re-writing Geology

He says the working life of the modern palynologist is far removed from the stereotype of a lab-bound technician who is obsessed with the taxonomy of tiny organisms.

"These days, most of us work on the drill site where we are under intense pressure to provide information within an hour or so of drill cuttings reaching the surface," Goodall explains. "The information we provide is vital to decisions about drilling that could cost or save our clients millions of dollars. Wellsite palynology routinely rewrites perceptions of where the oil or gas is going to be found. There is often a perception among clients that their oil or gas field is contained in a nice blanket of sand. When it comes to drilling, particularly with horizontal wells, the sand can disappear and may or may not re-appear. The palynologist can provide real-time information about whether it's the same sand, and that's something that can't be done by electric logs.

"It's not uncommon for the geologist

to need to rewrite his geological thoughts on the fly as we are drilling. He or she is basically on our backs all the time wanting our information."

Goodall said MGP was very active in Papua New Guinea – with about eight palynologists on well sites – because of the very complex geology. "In PNG, the rocks can actually become younger the deeper you drill because the whole system has been tipped upside down. You can imagine how that affects people's perceptions of where the reservoir might be found," he says.


MGP

Jeff Goodall believes that palynology can help explorationists to gain a better understanding of the geology of an area, thus helping to de-risk it.

Steep Learning Curve

Geoff Wood has been part of the palynology group at Santos since 1987 and today heads a team of three young palynologists and two lab technicians. It is the only palynology group inside an Australian-based oil company, although the largest Australian independent, Woodside Petroleum, has a passionate palynologist on staff, Neil Marshall. He has promoted the value of microfossils within Woodside for 20 years and has been a large supporter of the consultants.

Wood said Santos was committed to training and developing its own experts. "The global majors were battling us for the younger, talented individuals, so we thought we would take on the training of our own staff. Our aim has been to give them an understanding of the geology as well as the palynology – that's the magic mix.

"In order to survive today in the oil industry, you have to have a good understanding of all the aspects of the industry in terms of the geosciences. You have to understand the geological problems and understand the best way you can use the biostratigraphy to solve the problem."

He said the present team of palynologists all have five or less years experience on the microscope, but what they lack in breadth of experience they make up for in enthusiasm to learn the trade.

"All trained initially as geologists and were chosen for their interest at graduate entry level in tackling the steep learning curve to become a palynologist," Geoff says. "They also possess the general petroleum geology skills to become an active member of the exploration and development teams which they are assisting. Their goal is to become proficient in a very specialised skill but have the ability to understand the challenges and problems brought to them by their customers in the

Geoff Wood and his team of young palynologists in their lab in Santos' head office in Adelaide.


Santos

exploration and development teams."

Wood said the nature of palynological studies within Santos had changed markedly recently. "In the past decade, our studies have focused on creating insights at a reservoir scale, rather than a regional scale. The regional-level studies were important when we began exploration in areas such as the Cooper Basin and North West Shelf, but now we are focused at a much finer level.

"For example, palynology allows you to look at the connectivity of reservoir sequences. We can tell our geologists whether the intersections from well to well are co-eval, and therefore likely to be connected."

Future is Bright

Wood is also committed to teaching his craft at an industry level in Australia. He is Australia's only palynology lecturer, at the Adelaide-based Australian School of Petroleum.

"Courtesy of Santos, I have given a short course on Applied Biostratigraphy for the honours and post-grad geoscientists each year for the past 25 years. With the major extinction apparently of palaeontology and stratigraphy lecturers in universities worldwide, this course is becoming increasingly important. The students at ASP come from all over the world and I sometimes do a straw-poll of their previous studies in biostratigraphy. Some of the overseas students have exposure to it, but in general palynology seems to have dropped off the radar."

However, Wood believes the future of palynology is bright. "It only takes a few people within an organisation to work out how valuable it is and it can really snowball. The recent growth of Morgan Goodall and other consultancies is testament to that."

The revival of palynology is also being actively promoted by Clinton Foster, the chief scientist at Geoscience Australia, who began his career as a palynologist in 1976. In welcoming this renaissance, including the successful employment of new palynologists by Santos and MGP, Dr Foster said there remains a need for people who can teach the subject.

"I strongly supported the push by academia for a new teaching position, and am delighted that industry has recognised the need by generously establishing a professorial position at an Australian university (details are to be announced soon). The re-establishment of palynology as a university subject will ensure the essential taxonomic studies that underpin the science are carried out. We have to get some young bright minds focused on this and I believe we will see the whole science thriving again."

Foster said Australia had provided some of the world's greatest palynologists, who had laid important foundations for Australia's modern petroleum industry.

"Isabel Cookson's early work was outstanding, and so was Basil Balme's. He did most of the work for WAPET as they worked out what has happening in Western Australia back in the 1960s. Basil started his career in the 1950s describing spores and pollen from Permian coals in New South Wales, and that work still underpins correlation studies for coal bed methane. More recently, Robin Helby's detailed and carefully documented work on the North West Shelf, together with studies of Alan Partridge and Roger Morgan, formed the first comprehensive industry standard for the Australian Mesozoic, published in 1987." ■

Sea of Sand
Dunes of the Namib

ROGER SWART

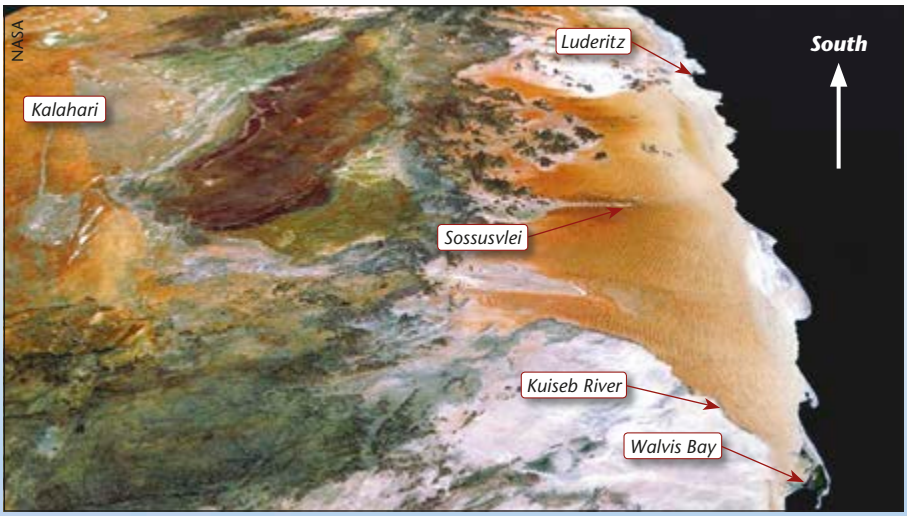
The Namib Desert stretches eastwards from the coast of south-west Africa as far as the escarpment of the central plateau, and extends more than 2,000 km from Angola in the north, through Namibia and southwards into South Africa. Within this arid zone there are many micro-environments, including dunes, rocky mountainous areas, gravel plains, perennial river mouth wetlands, coastal pans, lagoons, riparian forests and isolated springs. On over 100 days a year a cool coastal fog brings life-giving moisture and ameliorates diurnal temperatures, and as a consequence life abounds in this seemingly desolate environment. This wide range of environments also provides many different tourist opportunities, including eco-tourism, geo-tourism, adventure tourism and casual campers. Photographic opportunities abound and photos taken in the Namib often win awards in competitions. The high dunes of the

Roger Swart

Snuggled in against the south-western coast of Africa lies the Namib Desert, one of the driest and oldest deserts on Earth – but life abounds in this seemingly desolate environment.

Early morning or late afternoon is the best time for photographing the sinuous shapes of the dunes and capturing the rich colours.

Namib must also be the easiest dunes to access in the world. This central part of the Namib, dominated by the major sand sea, has recently been designated a World Heritage Site.



The Namib Desert is over 2,000 km long and about 150 km wide

Why Is the Namib Arid?

The aridity of the Namib is controlled by three factors, any one of which would make the Namib dry, but the combination of which make it hyper-arid. These three factors are its location on the south-western side of Africa, the fact that it underlies the South Atlantic anti-cyclonic high and that it lies adjacent to the cold Benguela upwelling system.

Firstly, moisture-bearing winds from the warm Indian Ocean in the east have generally lost much of their water content by the time they reach the Namib. Secondly, the location of the high pressure system means that the Namib has warm dry air settling over the land for much of the year. Thirdly, intensification of the aridity is caused by the cold waters of the Benguela upwelling system locking up moisture in regular, low, thick cloud banks. This, although minuscule, is the main source of moisture for the plants, invertebrates and mammals living on the Namib coast, which have devised creative ways of collecting and utilising the limited amount of moisture available.

The Dunes

Viewed from any scale the Namib Sand Sea is a fascinating place. One of the first images returned to Earth by astronauts was of the sand sea terminating abruptly against the Kuiseb River, an ephemeral river that flows just often enough to keep the major part of the dunes south of it. However, near the coast where the winds are stronger and more persistent, the dunes are winning the battle. A stream of dunes advances northwards from here, but only as far as the next major river

30 km to the north, the Swakop, where they are finally stopped.

On satellite images all the major dune types can be recognised, as well as numerous intermediate forms. The difference in dune types generally reflects changing winds and sand supply. Strong, unimodal winds in an area of limited sand produce barchan dunes. These are common near the coast where the sand is emerging from the sea and can move at over 60m per annum, as along the coastal road in the Skeleton Coast Park north of Walvis Bay. When the sand supply is higher and the winds are still from one direction then transverse dunes develop; again these are common along the coast, best seen on the southern side of the road from the Rooikop airport going into Walvis Bay. When two wind directions become important linear dunes begin to form and in the Namib Sand Sea these often have a complex, reticulate form. The massive size of these dunes means that they are best appreciated from a light plane. The final major dune form, star dunes, which are the highest, result when three or more wind directions interact. Again, a plane is the best way to appreciate these dune forms, but the physically willing can climb the dunes near Walvis Bay and also around Sossusvlei. Here one can drive parallel to an ephemeral river course that penetrates deep into the dunes and provides access to dunes over 300m high.


Roger Swart

Heavy minerals are surprisingly common in the dunes and are particularly noticeable when the dunes are slightly damp after rains, such as in this photograph. Recent animal tracks can be seen near the base of the dune.

In the Namib the dominant wind is from the south-west, a direction that seems to have been in place since the breakup of south-west Gondwana some 132 Ma. It can be extremely strong, reaching speeds of over 75 km/hr, and is capable of transporting small pebbles up to 12mm in size, forming large granule ripples with heights of up to 75cm. Although these south-westerly winds are strong, the less persistent, adiabatic winds that blow in winter are even stronger, reaching speeds of over 100 km/hr and raising coastal temperatures to over 40°C. Impressive plumes of dust can result from these wind storms, transporting sediment at least 150 km into the Atlantic; it has been calculated that a group of plumes in the south annually transport over 4,000 tonnes of aeolian dust offshore. Counter-intuitively, these strong winds can be a tourist attraction – there is an annual speed windsurfing event in Namibia. The current world record was set in Namibia in 2012.

The sand noticeably changes colour across the sand sea. In the west, close to the sea, the sands are whiter, becoming progressively pinker as one moves inland. The red colouration is caused by grain coatings of oxidised iron which comes from the weathering of lithic fragments. This process is facilitated further

Wildlife is common in the Namib despite its aridity. Large numbers of gemsbok (oryx), springbok, mountain zebra and ostrich are commonly found.


Roger Swart

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Roger Swart

inland by the slightly higher rainfall and organic processes related to roots and microbial activity. The lower strength and less persistent winds in the east are also not able to abrade and clean the sand grains as effectively as the coastal winds. The red colour of the eastern dunes along with the clear Namib skies helps to make this area a photographer's paradise.

Why So Much Sand?

But where does all this sand come from? The Namib Sand Sea is a temporary storage point on a conveyor system that is more than a 1,000 km long and encompasses fluvial, marine and aeolian processes. This conveyor system was a major consideration when the sand sea was declared a World Heritage Site.

While some of the sand is derived locally from either basement rocks or an older sand sea of Miocene age, the bulk of the sand comes from offshore of the Orange River, the mouth of which lies nearly 250 km away to the south. The river has a catchment area of nearly 1,000,000 km^2, draining a hinterland dominated by the ancient Kaapvaal Craton and thin sedimentary sequences. The Orange begins its life in the highlands of Lesotho and also in the Vaal River, a major tributary that rises in the high veld east of Johannesburg. The history of this system is well studied, as the Orange River has transported diamonds from the interior of southern Africa to the coast where they have been reworked into marine placer deposits. Seismic data and exploration boreholes offshore the Orange River mouth indicate that the river was locked into its present course by around 104 Ma, in the Cretaceous. During this time thermal subsidence resulted in the accumulation of a thick (and petroleum prospective) pile of deltaic to deep marine sediments offshore the Orange. However,

At night and early morning a coastal fog moves over the land from the cold Benguela current. This brings life-giving moisture to plants, insects and animals that have evolved ways of utilising it.


Roger Swart

The nocturnal palmetto gecko is endemic to the Namib Desert. It obtains moisture by licking condensation off its eyeball, one of the many remarkable examples of adaptation to the desert environment.

Roger Swart

When and Where to Go

The best time for visiting is in the dry winter months (May–September), but be warned that it can get very cold even though this is a tropical desert. Hot, dry winds do however occur during the winter and can make life unpleasant, especially if camping. It is possible to visit in the summer as afternoon sea breezes off the cool Benguela current can lower the temperature, but beware the summer rain storms which can cause flash floods, washing away roads and causing delays.

The number one destination for anyone wanting to appreciate the Namib dunes is **Sossusvlei**, situated at the end of the ephemeral **Tsauchab River** in the heart of the sand sea. This is located in the **Namib-Naukluft Park** and one can stay in lodges and campsites that are within and outside the Park.

The Namibian road network is excellent with a mixture of surfaced and gravel roads – in fact, it could be said that the roads are too good as many accidents occur as a result of tourists speeding on roads that look deceptively easy. One can visit the dunes in an ordinary sedan car but a 4x4 vehicle with extra clearance and better suspension is more comfortable, and also allows for some more adventurous off-road driving.

The coastal areas are a must as well. **Swakopmund** and **Walvis Bay** are the main tourist destinations, with old German architecture and a multitude of hotels, guest houses and B&Bs. From here there are also many different activities for tourists. Sandwich Harbour on the Atlantic coast is worth a visit but a 4x4 and experience in sand driving is required, otherwise take a guided tour. **Lüderitz**, now known as **!NamiNüs**, is less popular but one can visit ghost diamond mining towns from here.

Old diamond villages from the early 20th century are now ghost towns and the Namib sands are busy reclaiming their own.

from the beginning of the Cenozoic only a thin sedimentary succession has been preserved and the youngest sediments at the offshore Kudu well locations are of Miocene age. This suggests that the shelf has remained neutrally buoyant since the end of the Cretaceous and has largely been a sedimentary bypass system.

However, as the shelf is very wide, sediment has not been transported offshore into the deep marine realm, but rather has been moved back onshore, facilitated by the strong south-westerly winds mentioned above. Cyclonic systems moving across the south Atlantic are unimpeded for 6,000 km and the winds and resulting swells which reach the southern Namib coast have an extremely long fetch, producing swells with a period of 12 seconds and heights of 5m. Direct observation from semi-submersibles has recorded sediment moving at depths of 125m, around where sea level was during the last glacial maximum. As the shelf here is wide (c.150 km) sediment has no chance of being transported offshore and is instead driven along the coast in a northerly direction by the winds. At critical points the sediment may move back onshore where the strong winds can move it further inland. These winds along the coast can polish crystalline rock and are capable of transporting grains up to 5mm across; vehicles caught in a sandstorm commonly have the paint stripped off their bodywork within minutes.

The Age of the Namib

The Namib is reputed to be one of the oldest deserts in the world, but how old is it actually? A precursor of the modern sand sea, the Tsondab Sandstone, underlies the active dunes. Surprisingly many fossils have been found in this ancient sand sea, including a range of egg shells of different early ostrich-like birds. These fossil eggs have been used to develop a biostratigraphy, an unusual feature for a dry aeolian system, and they and many others can be seen in the excellent Earth Science Museum which is hosted by the Geological Survey of Namibia in Windhoek. The Tsondab Sandstone is at least 18–19 million years old and fossilised dunes from this time period can be seen at the Namib Desert Lodge. The minimum age of the modern dunes is disputed but is probably around 5–6 million years. A slightly wetter period with erosion and calcrete formation separates the two desert phases.

This article has focused on the Namib Sand Sea but Namibia has plenty more to offer, including the Etosha Game Park, the Fish River Canyon, the mountains of the north-west and game parks in the north-east. For star gazers the uncluttered Namibian night sky provides wonderful viewing.

Acknowledgement:

We acknowledge the use of imagery from the Land Atmosphere Near-real time Capability for EOS (LANCE) system operated by the NASA/GSFC Earth Science Data and Information System (ESDIS) with funding provided by NASA/HQ. ■

The Petrophysicist

*This **new column** takes a look at the different geoscience careers available in the oil industry and shows exactly what each one entails. In this inaugural article **Jackie Mullinor** describes her work as a petrophysicist with AGR in Aberdeen, and explains how the science of petrophysics fits into the exploration cycle.*

The petrophysicist plans, interprets and analyses data from wells and ensures the output is in the most useful format for the recipient. This might mean planning a logging suite, requesting core to be cut over particular zones, requesting tests to be carried out at certain points, or over certain intervals, to get data on the pressure regime or fluid type and flow and perhaps requesting a sample of the formation fluid be obtained.

Once the data is gathered and available, I take any general information I already know from nearby wells, where available, and use the measured logs to produce an interpretation which is meaningful for the other disciplines. For example, rather than have a log which indicates the background gamma ray count in the well, I would output a Clay Volume 'log' using the gamma ray, neutron and density logs. Similarly, a porosity value and a fluid indicator is more useful to the other disciplines than the measured logs used to calculate the results.

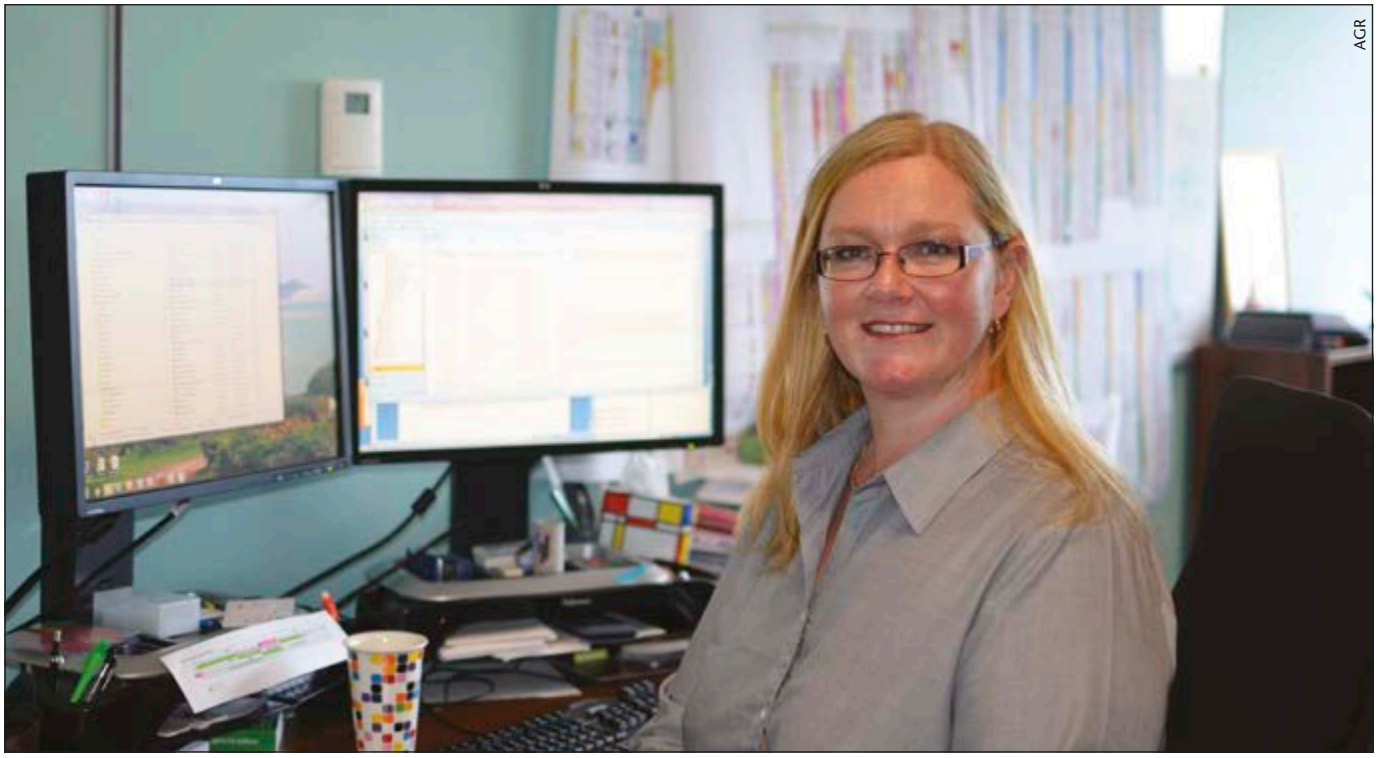
In addition to the log analysis, other types of data can be crucial for understanding what the logs are showing us. Although core analysis usually takes a while, cores are the best indicator of what is actually present in the well. Core results from the core, both routine and special analysis, would then be integrated with the log analysis. It might be an excellent match, or alternatively it might indicate differences; for example, something too small for the log resolution may be present, possibly a particularly high or low permeability feature which is an important piece of information for the reservoir engineer. The slabbed core itself shows us the lithology at that particular location and might also give indicators of deposition type, erosive surfaces, fracturing or diagenesis, which might not have been obvious from logs alone.

Test data is also incorporated into the interpretation. Pressure data is used to identify fluid type and perhaps fluid contacts, and can also indicate vertical barriers at the well location where different pressure regimes can be seen, or compartmentalisation within a field where the pressure regime varies between wells. Well test data can also indicate changes in permeability and fluid.

Integrated Teams

I generally work in an integrated team with a geophysicist, geologist and reservoir engineer. The log interpretation provides a depth reference for the geophysicist, to reduce uncertainty around depth conversion at the well location. The acoustic and density properties from the logs will also be used by the geophysicist for identifying properties which might be evident in seismic data, helping to map the property. Well data provides the

After completing her BSc Hons degree in Geography in 1991, Jackie's early career path in the oil industry started with an 'apprentice' type introduction in 1992, digitising well logs at Robertson's Research in North Wales. This progressed to training in log analysis, which was continually developed and added to in her five years at Robertson's. She then moved to Agip UK, in Aberdeen, as a log analyst. Following an eight-year career break when her family was younger, she returned to work, initially as a technical assistant and then as a petrophysicist with AGR in Aberdeen.



geologist with reference points in a field which might be correlated and which might indicate features which were not visible on seismic data, such as a sub-seismic fault which could dramatically change the overall picture of the area around the well. The reservoir engineer wants to know where fluids are and how they will flow and the petrophysical data gives some of the properties which need to be applied to the structural data.

Working as a petrophysicist means that I have varying amounts of data to work with – from only two logs and nothing else to a full suite of logs plus core and test data. This can be quite challenging since the other disciplines require my input. Occasionally I have to provide interpretations and updates as the well is being drilled since some decisions have to be made as the well progresses – that gets the adrenaline flowing!

Other disciplines might say the same, but the petrophysical data links everything together. This is measured data that tells us what is really present in the well and how it is behaving at that point in time, giving the best reference point for the other disciplines. ■

Returning from a Career Break

From a personal and professional point of view, coming back into the workplace after a long career break can be a daunting prospect, particularly in an industry where things change so rapidly. Having built my career up I had intended to take only a few months out after having my first child but, when the time came, I knew I wanted to be at home for longer. However, once both my children were a little older and in school, I started to think about returning to work and joined AGR as a technical assistant/petrophysicist in 2008.

It was perfect timing, as AGR's Reservoir Management team was working on a project with 300+ wells and needed someone with a petrophysical background to make final additions to the data and output plots for the client. I was well within my comfort zone in this first project, but I could see the types of projects going on around the office and this convinced me that I had returned to the best environment for someone in my position.


AGR

The project managers at AGR were fantastic, helping me find my feet again and encouraging me to get involved in a wide range of projects from the start. Within a year I was working as a petrophysicist in the integrated project teams with client contact and within two years I was officially promoted to petrophysicist. Since then, I have continued to gain experience in many different types of fields.

Mountains and the Sea
Muscat

"Muscat is a port the like of which cannot be found in the whole world."

– Arab navigator Ahmed bin Majid al-Najdi, 1490

JANE WHALEY

Sea and rocks are ever present

Muscat is indeed a unique city, surrounded by high barren mountains and for centuries almost inaccessible except by sea. Even the modern air traveller cannot fail to be impressed, as the ragged crags of the Al Hajar Mountains, seen in the distance at the airport, edge nearer the coast as you drive towards the city, which is revealed nestling in deep valleys separated by steep rocky promontories jutting into the sea. With few high rise buildings and Arabic architectural features like domes used throughout, it is still the 'very elegant town with very fine houses' that the Portuguese admiral Alfonso de Albuquerque described in the 16th century.

Strategic Position

There has probably been a settlement on the north-east coast of Oman in the region of Muscat for at least 2,000 years, with the Greek geographer Ptolemy mentioning a 'concealed harbour' in the area in the 2nd century AD. It certainly possesses a matchless and vital strategic position, overlooking as it does the Gulf of Oman, which leads eastwards towards the Indian Ocean, and westwards to the Straits of Hormuz, the narrow entrance to the Persian Gulf. The sea is ever-present and of great importance to the city – in fact some scholars claim that the name Muscat comes from an Arabic word for an anchorage, while 'Oman' and the country's old Sumerian name Magan both mean sea-people in Arabic.

The first settlers were probably Yemenis, who approached the inviting sheltered harbour from the sea, and the town was one of the first places in the Arabian Peninsula to convert to Islam, in the 7th century. It became a thriving trade centre, with Omani sailors travelling particularly to India, which attracted the attention of the Portuguese, who conquered the town in the early 16th century in a bid to protect their own trade routes

The Muscat cornice is backed by stark mountains composed of Cretaceous ophiolites

east. They fortified the harbour and were not overthrown until 1650, but the city then fell to the Ottoman Turks, until the Omanis, led by Sultan Ahmad ibn Sa'id, a direct ancestor of the present Sultan, regained control in 1741.

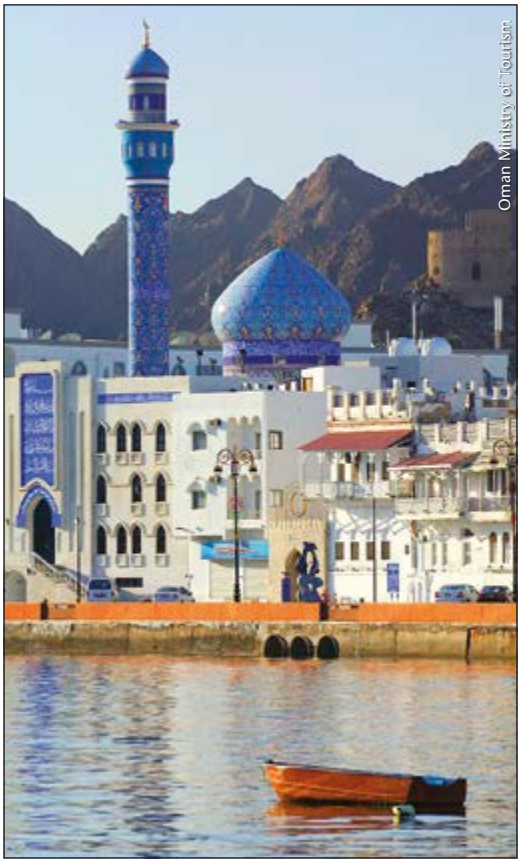
This was the start of a golden age for Muscat, which became the capital of Oman in 1793, as the country grew into the dominant economic and naval force in the western Indian Ocean and the Gulf, with influence extending from India all the way to Zanzibar in East Africa. A huge range of commodities were traded, from silk worms, pearls, spices and sandalwood to horses, sheep and even ivory.

However, over the years continuous infighting between members of the ruling family, religious leaders and local chiefs led to gradual neglect and economic stagnation, until by the outbreak of the First World War, Muscat needed a contingent of troops from the Indian Army to protect it from attack by local tribesmen. This situation was finally resolved in 1959, when the last Ibadi imam was evicted from the country by Sultan Said bin Taimur. Under his rule the country remained steadfastly guarded from the modern world, with very few roads or cars and the gates into Muscat locked every evening at sunset, until 1970, when his son, the present ruler Sultan Qaboos, took over after a palace coup.

Unique Heritage

His bid for power pledging 'a new dawn on Muscat' was given impetus by the promise of oil wealth for Oman. Despite the previous Sultan's reluctance to move into the 20th century, the doors had not been completely closed. There had been a few tentative exploratory expeditions as early as 1925, although their attempts were somewhat hindered by the 'independent spirit of the inhabitants'! The first well was drilled in the 1950s, and commercial quantities of oil were finally found in 1964 (see *GEO ExPro* Vol. 9, No.1). The Government of Oman acquired a 60% stake in Petroleum Directorate Oman (PDO), which is still the primary exploration company in Oman, in 1974, with Shell as the main partner.

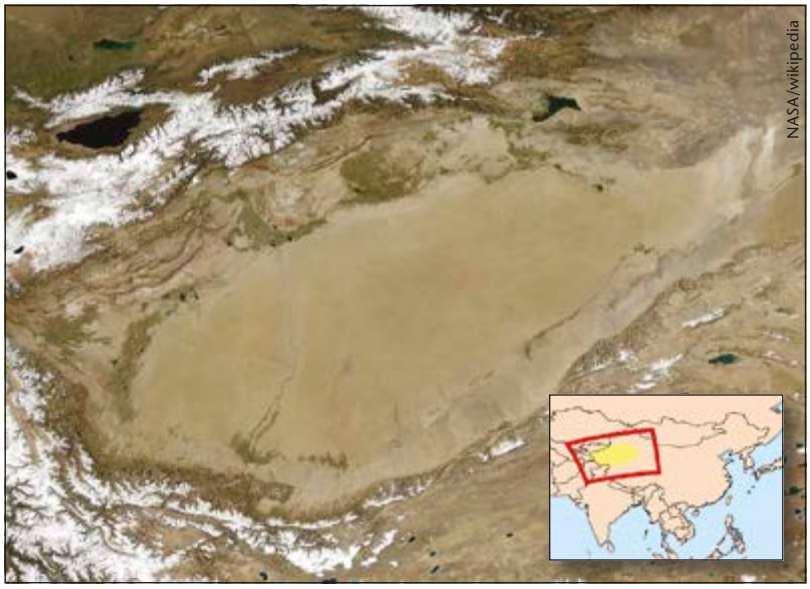
Although relatively modest in comparison with much of the Arabian Gulf, the resulting oil revenues have allowed Muscat and Oman to gradually catch up with the modern world, albeit gradually and in a distinctively Omani manner. Although now equipped with the trappings of the 21st century, such as a major port and an international airport, as well as designer outlets, five star hotels and fast water sports, Muscat still retains a delightfully old-fashioned atmosphere, where one feels that the inhabitants have time to sit and watch the world go by. The sights, sounds and smells of the Old Town souks, lying within the 500-year-old city walls, seem not to have changed for decades. Although Muscat is now a tourist destination, the traditional dhows in the harbours, dwarfed by oil tankers and cruise liners, are a reminder of the seagoing people who created this proud nation and unique culture and heritage. ■



China: Extending Deep Objective Campaign

PetroChina claimed an important gas discovery with a wildcat drilled on the **Keshen 9** prospect in the Kelasu structure belt in the Kuche depression. Drilled to a total depth of 7,580m, some 200m short of target depth, Keshen 9 flowed 39.89 MMcfpd from the interval 7,552 – 7,580m in the Bashijiqike Cretaceous Formation. The bottom hole temperature was recorded as high as 179°C and pressure was 127.68 Mpa at 7,552m. The company has yet to comment on the resource potential of this structure.

Since 2008 when the company made the significant Keshen 2 gas discovery, the area has become established as a key gas exploration area in the **Tarim Basin**, which in 2010 had accumulative proven in-place reserves of about 5 Bb and 42 Tcfg, having confirmed the huge potential in the Kuche depression, now ranked as one of the most petroliferous provinces in China. A number of giant gas fields have been discovered in recent years in the deep reservoirs (6,000–8,000m) in the surrounding region, including the Dabei 1, Dabei 3, Keshen 1, Keshen 2 and Keshen 5 gas fields. These new discoveries are typical tight reservoirs with extremely low porosity and permeability. Compared with other similar tight reservoirs elsewhere, however, the gas saturation levels in the newly discovered reservoirs are exceedingly high (around 60–90%), comparable to that of conventional reservoirs. Keshen 9 follows this trend.



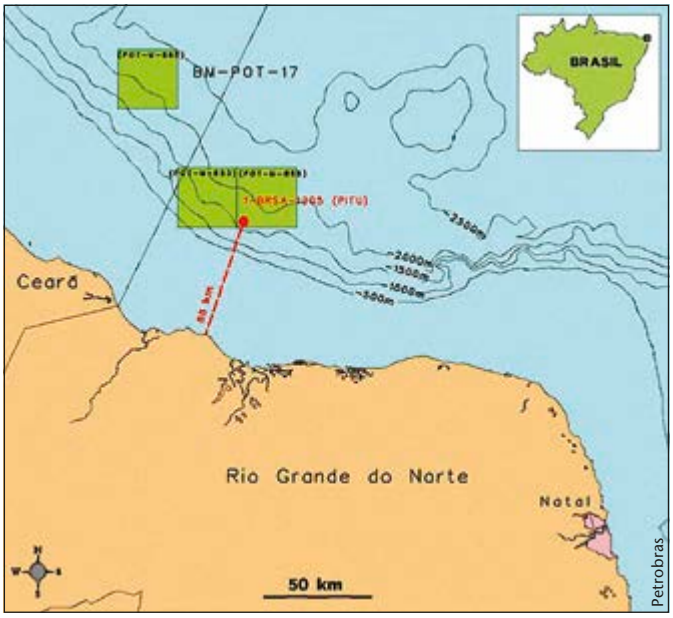
The Tarim Basin, situated in north-west China, is considered one of the most petroliferous provinces in the country

According to PetroChina, the company will produce 600 MMcfgpd by 2015 from the Keshen 1 and 2 area and 1.2 Bcfgpd from the wider Keshen area by 2020. ■

Brazil: First Potiguar Basin Deepwater Find

While a resource estimate is yet to be established, **Petrobras** is claiming that its 1-BRSA-1205-RNS (1-RNS-158) wildcat in the POT-M-855 block, which is testing the **Pitu** prospect, has established an oil column and is thus the first oil discovery in the deep waters of the **Potiguar Basin**. Located in 1,731m of water, the well continues to drill towards a planned total depth of 5,028m. The oil column was confirmed through log data and fluid samples at a depth of around 4,150m. At the moment Petrobras is the operator of the concession with 80% stake and Petrogal Brasil S.A. holds the remaining 20%. However, due to the farm-out agreement in progress at the moment, and after obtaining the approval of the National Agency of Petroleum, Natural Gas and Biofuels (ANP), BP Energy do Brazil Ltda will join the consortium and interests of the partners in the block will be: Petrobras – 40%, BP – 40% and Petrogal – 20%.

The Potiguar Basin is situated on the north-east coast of Brazil. Located in an undrilled area of the basin, in the south-western corner of the block, this is the third wildcat Petrobras has drilled in its exploratory programme in the deepwater area of the Potiguar Basin and is described as a play-opener. This basin currently produces approximately 125,000 boepd, making it the third most important producing area in Brazil after the Campos and Santos Basins. The offshore fields are all in the nearshore area, and there is little exploration data and no production from the deepwater portion, which has water depths down to 3,000m. ■

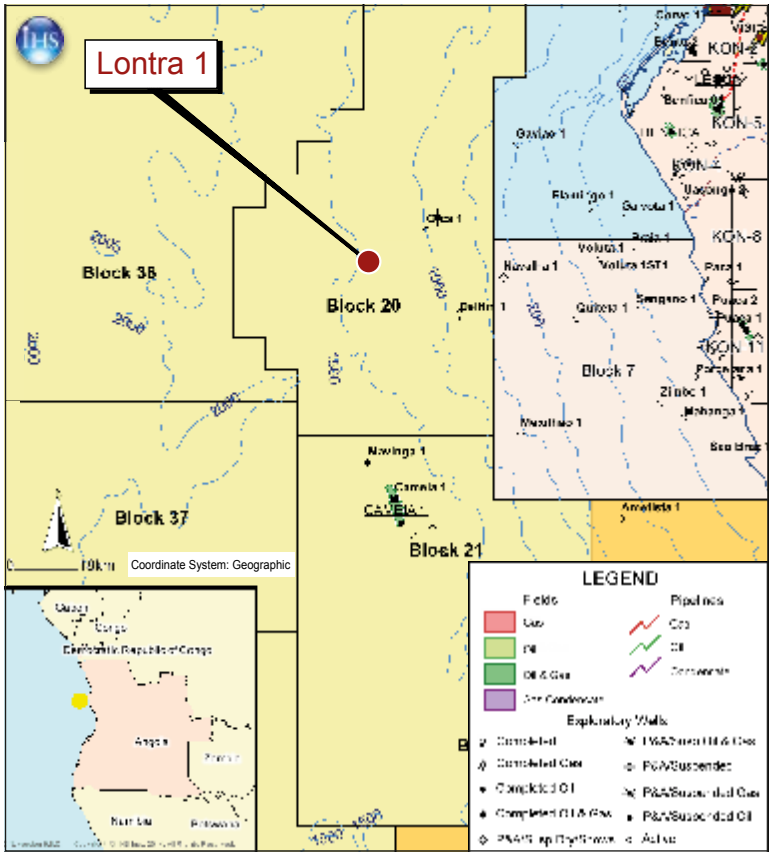


Angola: Is Pre-salt Gas Prone?

Described by **Cobalt International Energy** chief executive officer Joseph Bryant as a "discovery on a global scale", the **Lontra 1** discovery in **Angola's** Block 20 makes it four out of four for the company, a remarkable start for its campaign in the **Northern Kwanza Pre-Salt Basin**. Drilled to a total depth of 4,195m, the well encountered 75m of net pay in a high quality reservoir and was announced as a discovery in October 2013. Recently re-entered for testing, the well encountered both a high liquids content gas interval and an oil interval, and flowed 2,500 bcpd and 39 MMcfgpd, rates significantly restricted by surface test facilities. The drill stem test was conducted in the high liquids content gas interval in order to acquire data on the flow capacity and fluid composition of this interval. The estimated cost for the well has reportedly increased from an initial estimate of US$160 million to US$233 million, making Lontra 1 one of Angola's most expensive wildcats to date. The rig has been retained within **Block 20** and is now drilling the Orca 1 wildcat, also a pre-salt test.

Although the field contains more gas than pre-drill estimates, with the resource estimated at between 700 MMboe and 1.1 Bboe, the company believes that as Lontra lies offshore near Luanda, there exists a potentially large emerging market for gas. However, the production sharing contract for this and the majority of deepwater blocks do not include rights for gas. With reserves of 5 Tcf assigned to the four discoveries, Cobalt and its partners – Sonangol P&P (30%), BP Exploration (Angola) Ltd (20%) and China Sonangol International Holding Ltd (10%) – are now in discussions with the government on marketing options.

Results have put a dampener on the theory that Angola's offshore geology mirrors that off Brazil, where multibillion-barrel oil finds have been made. ConocoPhillips plans to drill four pre-salt wells in Angolan Blocks 36 and 37 starting in March 2014. In total around 15 pre-salt wells are scheduled to be drilled off the country in 2014 in a campaign estimated at US$3 billion. ■

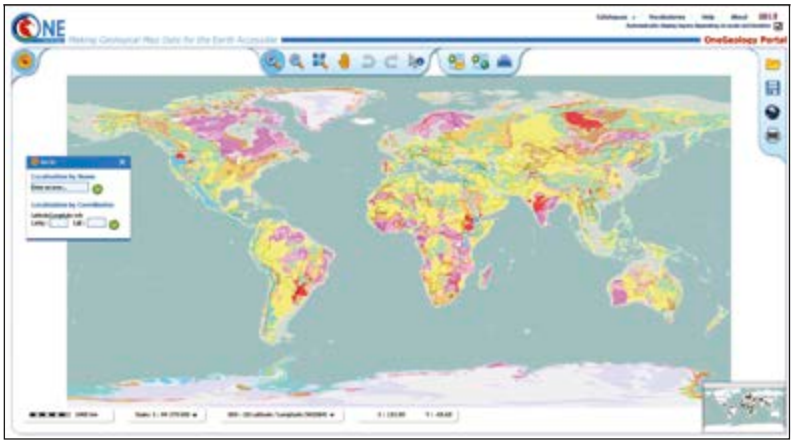


Novel Digital Platforms: OneGeology and OpenGeosci

Digital information technology has taken the world, including geoscience and the petroleum industry, to new horizons of research and data sharing. OneGeology and OpenGeosci are two online sources of immense help to the geoscience community.

OneGeology

In March 2007, over 80 scientists from 43 countries gathered in Brighton, UK, to discuss the proposition of creating an online geological map of the world for the benefit of students, teachers, researchers, professionals and other users anywhere in the world. The discussion was continued in another meeting held in Utrecht, Netherlands, in May 2007. The result was 'OneGeology', with the following mission statement: 'Making web-accessible the best available geologic map data worldwide at a scale of 1:1 million, as a geological survey contribution to the International Year of Planet Earth (2008)'. The initiative is supported by a dozen international organisations including UNESCO and the International Union of Geological Sciences, as well as the geological surveys of 117 countries. The web portal was launched in August 2008 during the 33rd International Geological Congress in Oslo, Norway.



OneGeology portal. For more information visit http://onegeology.com

OneGeology covers more than 100 million square kilometres or about 70% of the Earth's land surface. The website is hosted by the British Geological Survey and uses the GeoScience Markup Language (GeoSCiML) as schema for data exchange over the internet. OneGeology is planning to provide a more sophisticated query system as well as making applied geological data on 3D visual features.

OpenGeosci

OpenGeosci is a new initiative from GeoScience World (GSW), a collaborative internet resource for research in geoscience. GSW, a nonprofit organisation registered in Alexandria, Virginia, was established in 2000 with the vision to 'make earth science research information easily and economically available via internet.' GSW's founding organisations are the American Association of Petroleum Geoscientists, American Geoscience Institute, Geological Society of America, Geological Society of London, Mineralogical Society of America, Society for Sedimentary Geology and Society for Exploration Geophysicists. Tapping into its resource of 45 journals published by various geoscience societies, in 2013 GSW launched a new service: a cyber-infrastructure and map-based discovery platform called OpenGeosci which provides users with maps, graphs and data tables. The portal includes 'Search' (for keywords), 'Journal' (from *AAPG Bulletin* to *Vadose Zone Journal*), 'Category' (from applied geophysics to vertebrate palaeontology), 'Area' (scales from <1,000 to >100,000,000 hectares) and 'Data Range' (from 2000 to present). OpenGeosci currently includes more than 300,000 maps, cross-sections, figures, charts and tables, and is expected to grow at a rapidly increasing rate. There is also a link option for subscribers to read the original articles.

GeoScience World's OpenGeosci. For more information visit http://www.opengeosci.org/

GSW to Offer eBooks

Starting this year, Geoscience World will be providing an eBook platform in geoscience to its subscribers. The articles will come from GSW's journal archives (in hundreds of thousands) and the platform will include 'map-based and faceted searching, mobile access, related-content recommendations, and social sharing tools.' GSW is offering this service in collaboration with HighWire. ■

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Achieving Staff Integration Through Training

The training of non-technical staff can be key to improving communication and efficiency in oil-related companies. **Anastasis Kokkinos**, Director of Esanda, tells us how demand has grown for introductory, as well as specialised, training.

How did Esanda get involved in training?
The training arm of Esanda has developed organically as our client companies have identified a need to improve integration among their staff and, in particular, to demystify the industry for employees with a non-technical background. Because our core work involves helping companies with field planning, specifically lifecycle cost estimation and economics, we have found ourselves well placed to deliver training on all aspects of the industry. I personally got involved in training about 15 years ago and it now occupies about a quarter of my working time. We currently deliver training and mentoring to organisations throughout the world and companies find that by improving understanding between different disciplines, they achieve smoother workflows and, in general, a better end product.

What kind of courses are most in demand?
Although courses on field development and costing remain the most in-demand subjects, we now provide more general themes such as a basic introduction to oil and gas exploration and production, the technicalities of oil and gas facilities, LNG, FPSOs and subsea engineering. Providing training for non-technical staff has become increasingly important and we are often asked to design courses for professionals in related industries, such as banking, the legal profession and in government departments.

Which areas do you find participants are most interested in?
People are most interested in the offshore and subsea engineering as there seems to be a lot of mystique about them, probably because they are inaccessible to most people who don't get the opportunity to get offshore (or subsea!).

Are there particular areas that are difficult to explain to those with a non-technical background?
I'm always surprised by the extent of knowledge participants have, but we all have gaps. One area which can be difficult to grasp is the level of uncertainty that we deal with in the early stages and how reserves and costs can be +/- 50% – or more – depending on the level of information available. Other difficult areas can be chemistry and economics, which are kept to a very basic level in the non-technical courses. Generally speaking we try to keep things as simple as possible, depending on the audience, but in any case we try to use anecdotes and build analogies with everyday life. For non-technical course participants, the main aim is to offer bite-sized information and make the courses as interactive as possible, bearing in mind that the main aim is simply to bridge some of the gaps between disciplines to achieve more 'integrated teamwork'. This seems to be the buzz phrase at the moment!

Where do you see the industry heading in 2014?
This is a very interesting question because until recently I expected that the oil price would continue to be very strong. However, this has been thrown up in the air with the recent softening toward Iran. Also it will be interesting to see how the gas markets play out since there is the possibility that many new LNG projects will be sanctioned in the near future following recent big finds in East Africa. These will only add to the complex picture caused by the ever growing supply of shale gas in North America.

Are course participants particularly interested in the technicalities of shale production?
Yes, there is great interest in this as well as coal bed methane, coal seam gas and carbon capture and storage. They are quite topical at the moment and, as with other courses, we try to demystify these areas and give people a better understanding of what is involved.

Are there new areas where you would like to develop training?
Definitely. There's a demand for more understanding of offshore, FPSOs and subsea markets – demand is from technical as well as non-technical staff. It's because these areas tend to be at arms' length to most people in the industry and they need to feel more comfortable with their understanding of them. ■

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A present to the oil industry? Legislative reforms open Mexico's energy industry

With huge potential in both deepwater conventional and onshore shale resources, the Mexican Legislature voted on 11 December 2013 to allow investment in their oil and gas sector outside the state-run oil company, Pemex. Whether this might have been an early Christmas present to energy investors is yet to be seen, as many details are still to be determined.

Long History Yet Underexplored

Mexico is endowed with widespread and huge petroleum resources. Figures from their National Hydrocarbon Commission have the discovered oil-in-place at 306.44 Bb and gas at 288.44 Tcf. Just over 12% of the oil has been produced and 23% of the gas, leaving a lot out there yet to be produced and well below industry standards. Since nationalising in 1938, Mexico's oil industry has had just one oil company exploring and developing its vast resources. While Pemex's performance is comparable with that of most majors, it is nearly an impossible task for one company to find and produce all of Mexico's potential. For example, about 5,000 exploration wells (some counties in Texas exceed that number) have been drilled there in the last 110 years, leaving some petroleum provinces and plays totally untested.

Mexico's first commercial oil was discovered in 1904 in the heavy oil Ebano and Pànuco fields in the Tampico-Misantla Basin, located onshore and along the shelf of the western Gulf of Mexico (GOM). To the south-east, the North Golden Lane discoveries followed in 1908. This area remained Mexico's primary producing region until the early 1970s when deep wells in the states of Chiapas and Campeche along the southern GOM found huge oil reservoirs. These discoveries would open up Mexico's two other oil-producing basins, the Sureste and the offshore GOM, where the reserves were believed to extend over 200 km into the Bay of Campeche. This led to the discovery of the world's largest offshore oil field, the heavy oil Cantarell complex in 1976, located 100 km off the coast of the Yucatan Peninsula. Mexico's production had been gradually increasing from the late 1930s into the early 1970s but still failed to meet domestic demand, but after these discoveries, exploratory drilling increased and by the early 1980s, proven hydrocarbon reserves rose to 72.5 Bbo. Mexico has been a net oil exporter since the mid-1970s, with production peaking in 2004 at 3.4 MMbopd.

Because of the large discoveries, Pemex concentrated its resources in the Chiapas-Tabasco and Campeche oil provinces. Little was dedicated to exploration after the 1980s until the Cantarell field went into a steep decline after peaking at 2.2 MMbopd in 2004, with production being about 400,000 bopd today. The void in exploration over this period left nearly no large fields, with the exception of the very heavy oil Ku-Maloob-Zaap structures located 105 km offshore Campeche. While these fields were discovered between 1980 and 1991, it was not until 2007 and 2008 that investments were made in them to help offset Cantarell's decline. However, production from these fields peaked in 2013 and they are now in slow decline.

The Future and New Reforms

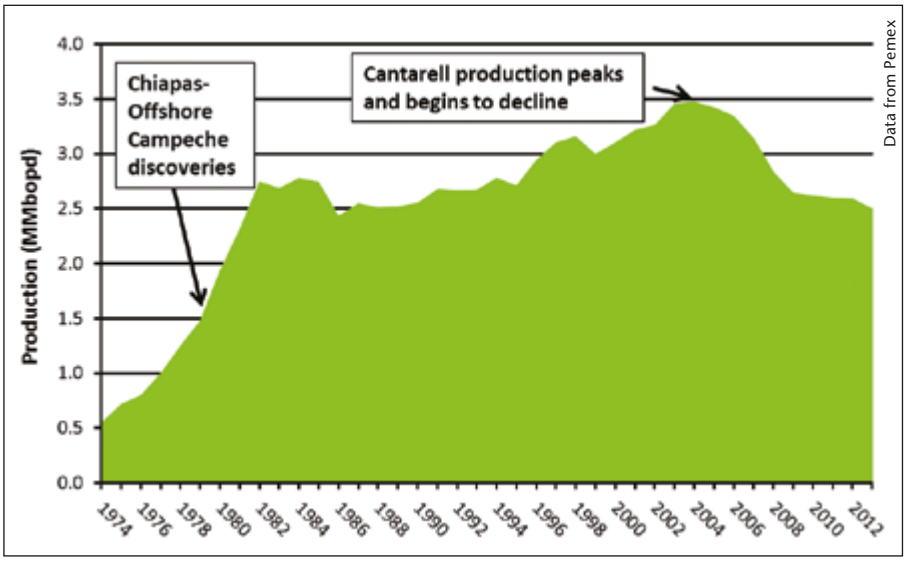
In efforts to reverse declining production, Pemex is now exploring the deep waters of the GOM and developing tight oil reserves in an unconventional play to the west of the Golden Lane oil province. As a result of their 'Energy Reform of 2008' that allowed very limited participation from the private sector, Pemex is offering blocks in mature fields in an attempt to optimise production. They have had several rounds now with offshore blocks being awarded last year, mostly to service rather than oil companies, and positive results have been slow in coming.

With the dismal results from the 2008 reforms, a new President, and a late 2013 vote to allow outside investment in their oil and gas sector, 2014 and beyond could yield significant development of Mexico's huge oil and gas potential. According to Nestor Martinez Romero, Commissioner, National Hydrocarbons Commission of Mexico, "600 Tcf of shale reserves, about 10% of the world's shale resources, could see significant development with current reforms. And Mexico's offshore drilling – already expanding in recent years – is predicted to see significant development post-reform."

Oil and gas companies are already 'lining up' to what could prove to be a radically different oil and investment environment in Mexico: one where opportunities abound. ■

THOMAS SMITH

Hoping to reverse a downward production trend since 2004, the government has opened up Mexico's vast and underexplored oil and gas resources to outside investment.



UK 28th Licensing Round

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For further information contact:

Tony Pedley
tony.pedley@polarcus.com
+44 788 44 81747

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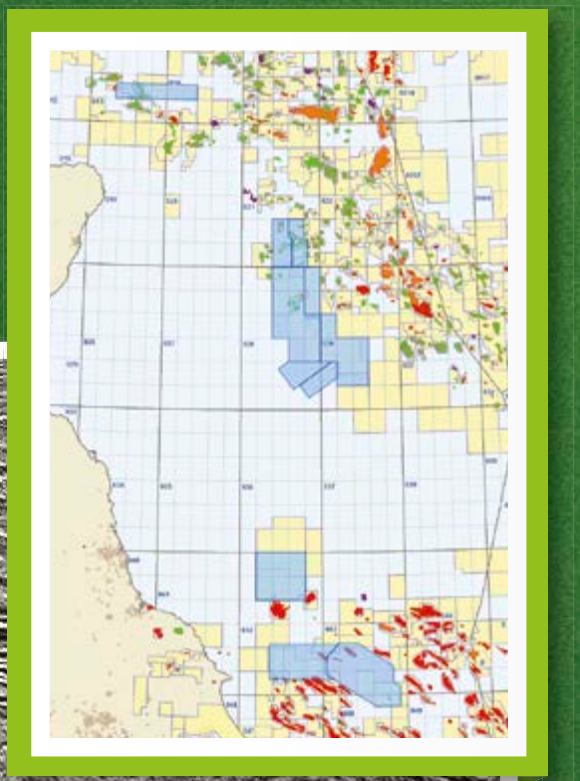

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Hubbert's Peak: Not Yet Reached

It is difficult to make predictions about the future. This is also true when it comes to oil production.

In 1956, Shell geophysicist M. King Hubbert predicted that US oil production would reach its highest level in the 1970s. Hubbert's prediction came true in 1971. The geoscientist got his fame and Hubbert's Peak was, of course, named after him.

Several doomsayers have later been inspired by Hubbert's prediction. In the 1990s, analysts said that the peak year for world oil production would occur during the first decade of the new millennium. The press grasped the bait, naturally, but the analyses were also reported in respected scientific journals like *Nature, Science* and *Scientific American*. Their editors are, obviously, also only human beings.

> "The 100 year period when most of the world's oil is being discovered became known as 'Hubbert's Peak'. The peak stands in contrast to the hundreds of millions of years the oil deposits took to form."
>
> *Kenneth S. Deffeyes*

We are writing in 2014. What happened? Did world oil production peak some years ago? And what about US production? Is it still declining from its peak 44 years ago? Luckily we are in a position to answer these questions by looking at some numbers. For this purpose I am using the BP Statistical Review of World Energy.

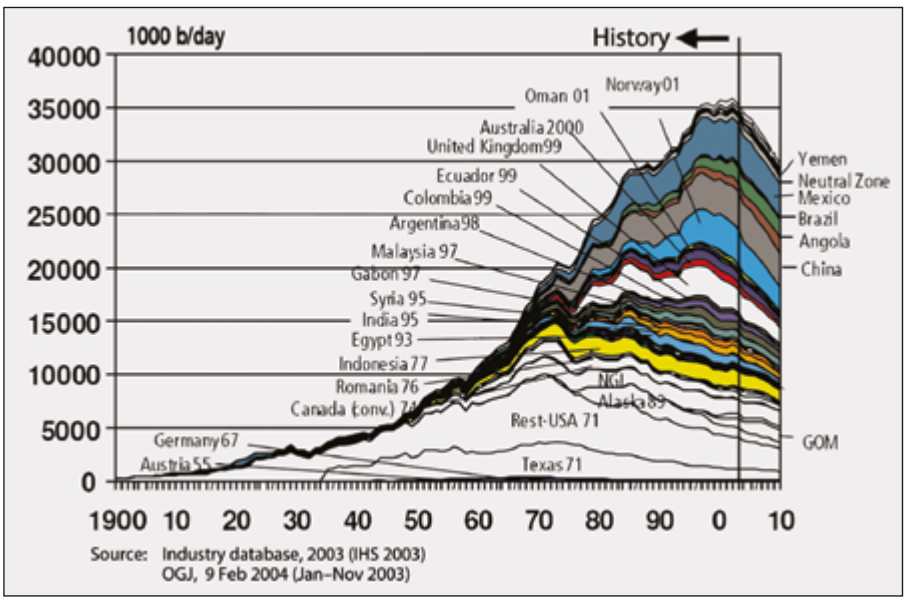
The hard facts are that the world's oil production increased from 75 MMbopd in 2002 to 86 MMbopd in 2012. And it will continue to increase, according to experts. IEA estimates that the world's oil output will be 115 MMbopd in 2035 – that is 20 years from now.

Is there any lesson to learn? Yes, I believe there is.

Do not always believe in the gloomy chorus. ■

HALFDAN CARSTENS

A previous prediction of world oil production showed it as peaking around the year 2000.



CONVERSION FACTORS

Crude oil
1 m^3 = 6.29 barrels
1 barrel = 0.159 m^3
1 tonne = 7.49 barrels

Natural gas
1 m^3 = 35.3 ft^3
1 ft^3 = 0.028 m^3

Energy
1000 m^3 gas = 1 m^3 o.e
1 tonne NGL = 1.9 m^3 o.e.

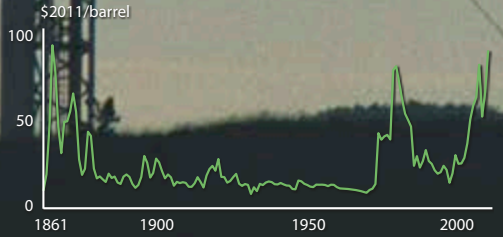
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

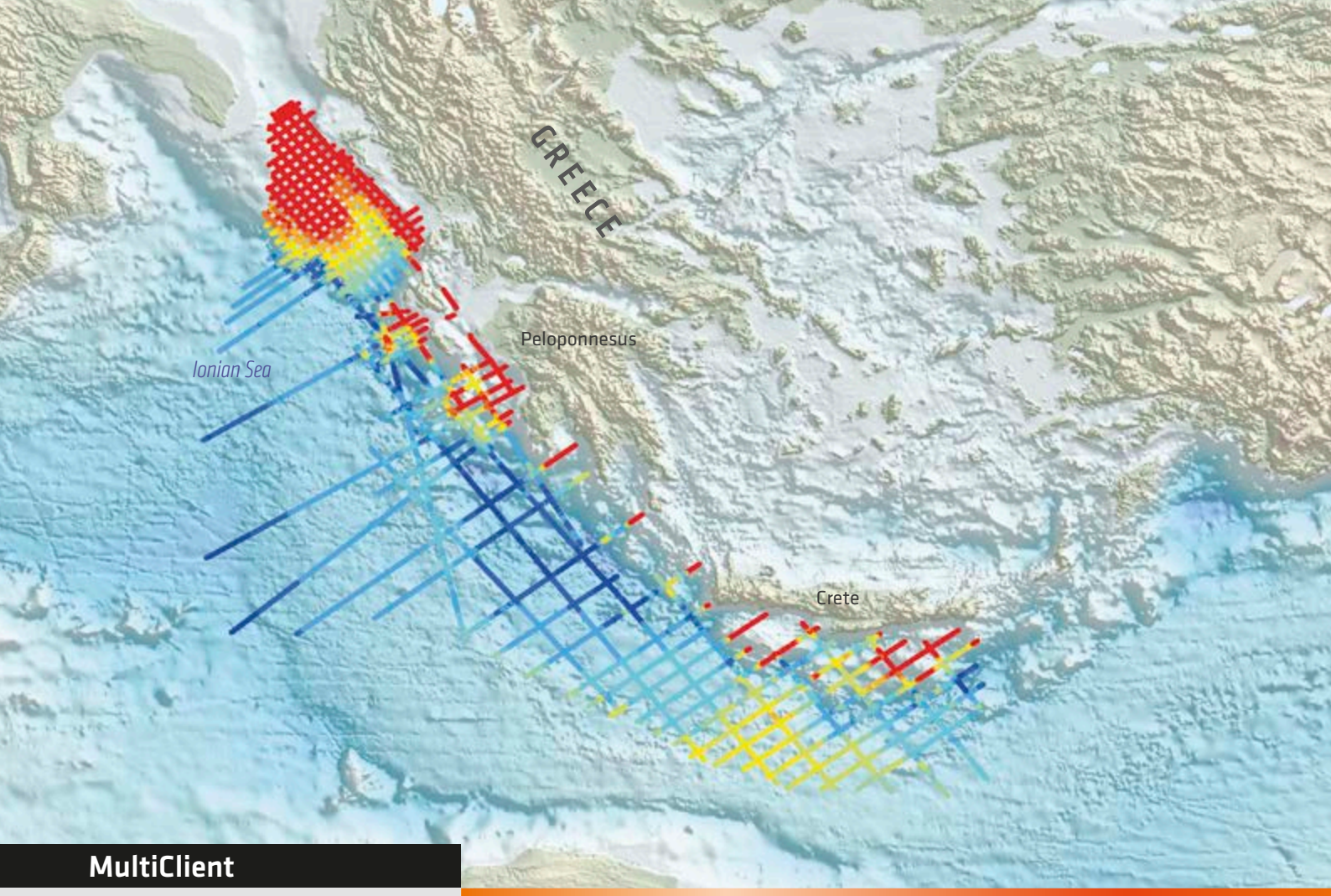
Supergiant field
Recoverable reserves > 5 billion barrels (800 million Sm^3) of oil equivalents

Giant field
Recoverable reserves > 500 million barrels (80 million Sm^3) of oil equivalents

Major field
Recoverable reserves > 100 million barrels (16 million Sm^3) of oil equivalents

Historic oil price





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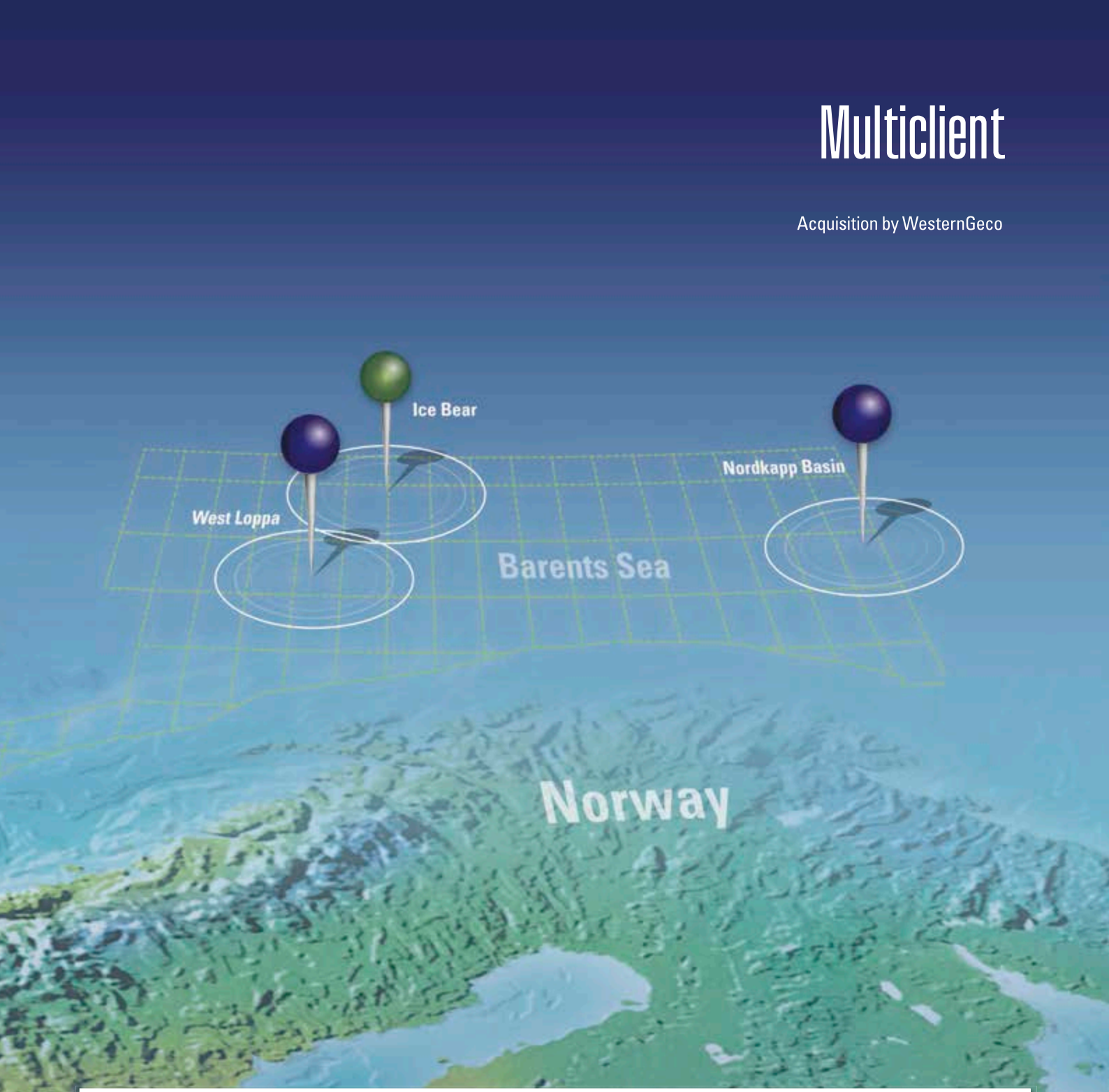

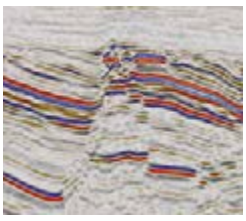

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