VOL. 13, NO. 5 – 2016

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

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EXPLORATION

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EXPLORATION:
Islands in the Mozambique Channel?

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A World of Drifting Ice

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OBS: Taking the Plunge

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GEOExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED

30 *A group of US roughnecks and drillers made a significant contribution to the UK war effort.*

34 *Both the Irish and UK governments have made the Rockall Basin available in the recent licence rounds.*

54 *Ilulissat Icefjord in western Greenland – a world of drifting ice.*

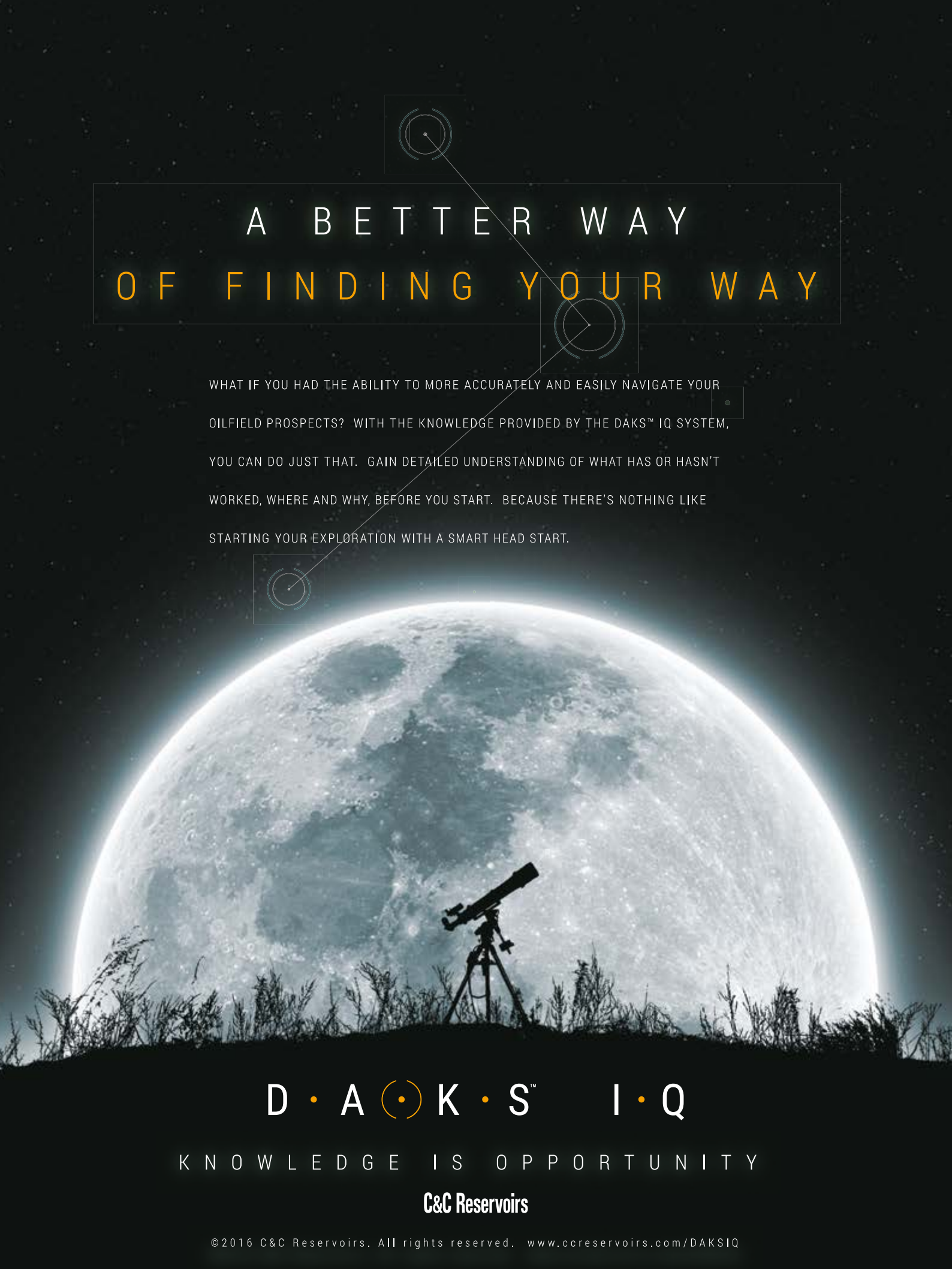
70 *Can nodes navigate ocean bottom seismic into the mainstream?*

78 *Doha has risen from the desert sands to become a major, glamorous regional power.*

Contents

Vol. 13 No. 5

This edition of *GEO ExPro* magazine focuses on Africa, North West Europe and the North Atlantic, and EOR.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Bucking the Trend

Drilling Kosmos Energy's Guembeul discovery off Senegal in April this year.

It will not be news to any reader that substantial oil or gas discoveries have been a rarity in the past year. In fact, according to Wood Mackenzie, new finds are at their lowest ebb for 70 years and explorers in 2015 discovered only about a tenth as much oil as they have found annually on average since 1960. Rystad Energy are reported as saying that we are replacing just 6% of resources we produce, with 2015 being the fifth year in a row in which the amount of new reserves discovered was smaller than in the previous year – and 2016 looks unlikely to reverse that trend. Since Wood Mackenzie also report that global spending on exploration has been drastically reduced, from around $100 billion in 2014 to about $40 billion this year, this result is hardly surprising.

One continent, however, is looking a bit more positive: Africa.

Since the beginning of 2015, nine of the biggest global discoveries have been in Africa: three in Senegal and Mauritania, two in Egypt, three in the waters off Angola and Congo and one on the eastern side of the continent in Tanzania. All of these are gas or condensate and all are offshore, the majority in deepwater. How easy it will be to monetise them in the present climate is uncertain, although Eni is making good progress with the development of the largest discovery of the last two years, the 30 Tcf Zohr field, anticipating first gas by the end of 2017. There is also a vibrant African LNG scene and significant potential in shale and other unconventional hydrocarbons. Africa desperately needs these resources: according to the OECD, in 2015 two-thirds of the population of sub-Saharan Africa still lived without electricity.

One company leading the way in West Africa is Kosmos Energy, and in this edition of *GEO ExPro* we have an interview with Vice President of Exploration and Chief Scientist, Paul Dailly. He believes one of the secrets of their success is being open-minded and refusing to 'go with the flow' – not 'betting with the pack', as he puts it. Looking at the company's recent successes, maybe there is a lesson for us all in that. ■

Jane Whaley
Editor in Chief

THE 'GATWICK GUSHER'

The Horse Hill discovery lies in a designated Area of Outstanding Natural Beauty, part of the protected 'Green Belt' of countryside which surrounds London. It has sparked wild claims and much controversy, but what is the geoscience behind the hype? We look at the geology, the exploration history, the newly identified plays and the prospectivity of this previously overlooked area.

Inset: Was the Mozambique Channel once scattered with islands? A look at the rocks of the Davie Ridge suggests this could be so.

GEOExPro

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

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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Optimists and Pessimists

Experts are divided when predicting the oil market

As Jarand Rystad of Rystad Energy recently pointed out, several important questions face the industry: when will the oil market rebalance? What will this mean for the oil price? Will shale oil alone be able to close the potential supply gap in 2017 and 2018? What other sources of short and medium supply exist? And at what cost?

Rystad believes that the market will rebalance soon and oil prices will improve in the last quarter of this year so that by 2018 large expensive offshore projects such as the development of recent discoveries in the Barents Sea will be in a competitive position.

However, another Norwegian consultancy, Nordea, lowered its Q3 oil price forecast in August, citing the pressure prices have been under from long term high petrol stocks, a more downbeat outlook for the world economy and the return of locked-in barrels after the wildfires in Canada. In September it further cut the oil price forecast for 2016 and 2017, believing that "the global oil balance is gradually tightening as OPEC's low-price regime is finally taking its toll on high-cost oil suppliers. Factors such as record-high commercial inventories, the weaker outlook for global oil demand growth and fierce competition among major oil producers to gain market share are expected to weigh on oil prices in the coming months."

The US EIA's Annual Energy Outlook, published mid-September, also suggested a slower recovery, with an average price for Brent crude in 2017 of about $48 per barrel, and remaining below $80 until 2020.

Libyan and Nigerian Barrels

American analyst Bloomberg also sounds a cautious note, pointing out that the global oil glut is likely to be added to in the next few weeks as two previously major OPEC oil contributors add hundreds of thousands more barrels to the market.

Torn by civil strife, Libya recently announced that it would very soon begin exporting from three key ports and plans to start shipping 600,000 bopd in October, hoping to increase to 950,000 bopd by the end of the year – a big jump up from its present 250,000 bopd. Reopening these ports, which had been closed for 18 months, would be a huge step for the North African country, although the ongoing political turmoil throws the plan into some doubt.

In Nigeria, also beset by civil unrest, ExxonMobil are set to reopen the Qua Iboe terminal, closed for several months after a suspected terrorist attack on a pipeline shut down production. In addition, *force majeure* on Shell's Bonny exports was lifted in September, and these two developments together will allow over 500,000 bopd of light sweet crude back into the market.

What About Shale?

The biggest unknown is probably the growth and impact of shale developments. Consultants Wood Mackenzie say that companies with US shale assets are likely to be at a competitive advantage for several more years. Rystad Energy, however, believes that while shale will have the largest growth in investment over the next few years and will continue to deliver large volumes in 2017, marginal costs for shale production will soon start to increase rapidly. By 2018 Rystad believes this will have had an effect on production, the surplus and the price of oil. ■

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.

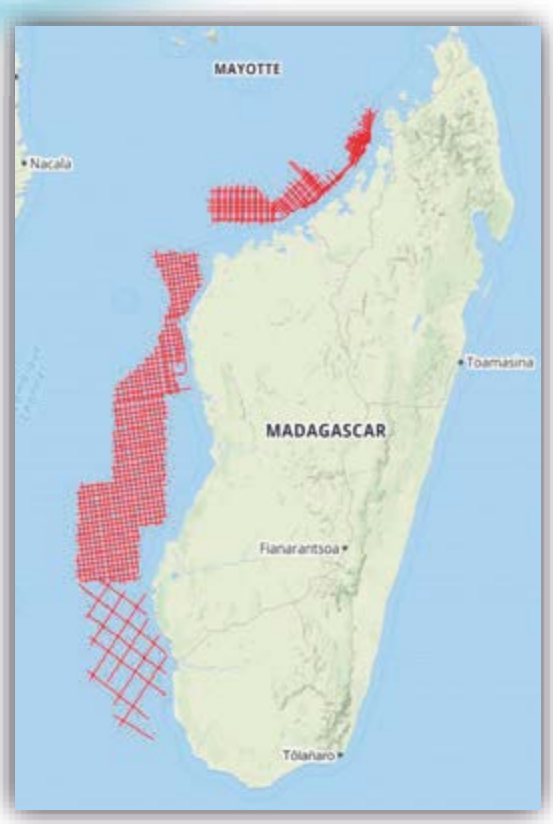
Reserves and resources
P1 reserves:
Quantity of hydrocarbons believed recoverable with a 90% probability

P2 reserves:
Quantity of hydrocarbons believed recoverable with a 50% probability

P3 reserves:
Quantity of hydrocarbons believed recoverable with a 10% probability

Oilfield glossary:
www.glossary.oilfield.slb.com

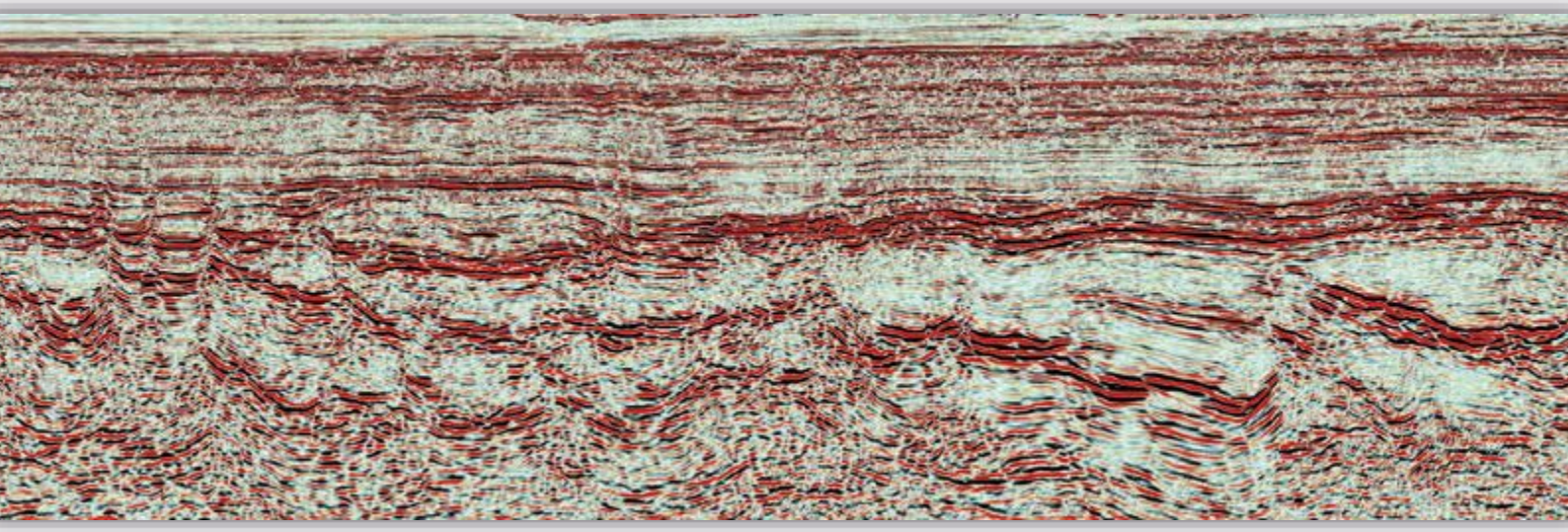
BGP Multi-Client



In 2013, BGP and TGS acquired 19,791 kilometers of long offset 2D Multi-Client data which included gravity and magnetic information in the Morondava and Majunga Basins offshore Madagascar. The project was jointly managed under the jurisdictional government authority of OMNIS.

The motivation behind the project was to deliver high quality seismic data to OMNIS and international oil companies that would allow for the exploration of the highly prospective area adjacent to the recent giant gas discoveries in Mozambique and Tanzania. The objective is meant to aid the government in promoting concessions in Madagascar's offshore blocks in the upcoming bidding rounds.

Final PSTM data is now available for IOCs to license.



Representative PSTM Section, Offshore Madagascar, In Association With TGS

Contact us for more information:
Tel : +86 22 66225097 **Email: multiclient@bgp.com.cn**
Fax: +86 22 66225058 **Web : www.bgp.com.cn**

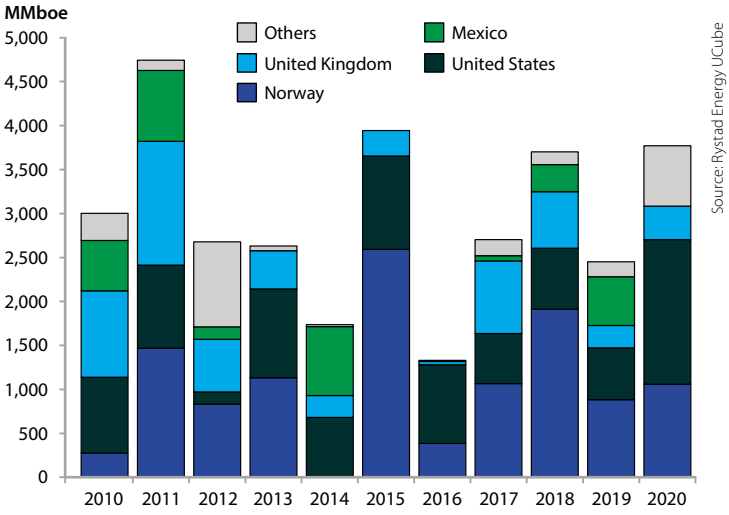
Activity Picking Up in 2017

The sanctioning of new projects is expected to pick up in the North Atlantic

Between 2010 and 2014 activity on the North Atlantic region was at an all-time high, reaching a peak spend of US$130 billion in 2014. Since then, however, the low oil price has reduced activity and spending levels. In 2016, total investments for the region are expected to fall to US$75 billion.

One of the main reasons for lower activity is the decline in new projects being sanctioned. At the beginning of this decade, around 3.5 Bboe of new hydrocarbon resources, both oil and gas, was sanctioned yearly, but by 2014, this number had dropped to 1.7 Bboe. Sanctioning activity increased in 2015 but this was driven by the development of the Johan Sverdrup field. For the current year sanctioned resources are expected to be 1.3 Bboe – the lowest activity level in 30 years.

Rystad Energy does not believe this trend will continue and expects to see a pick-up in activity in 2017. The low global activity level observed in 2015 and 2016 has contributed to the re-balance of the oil market, and the expectations of higher future oil prices will make it easier for E&P companies to make positive sanction decisions.

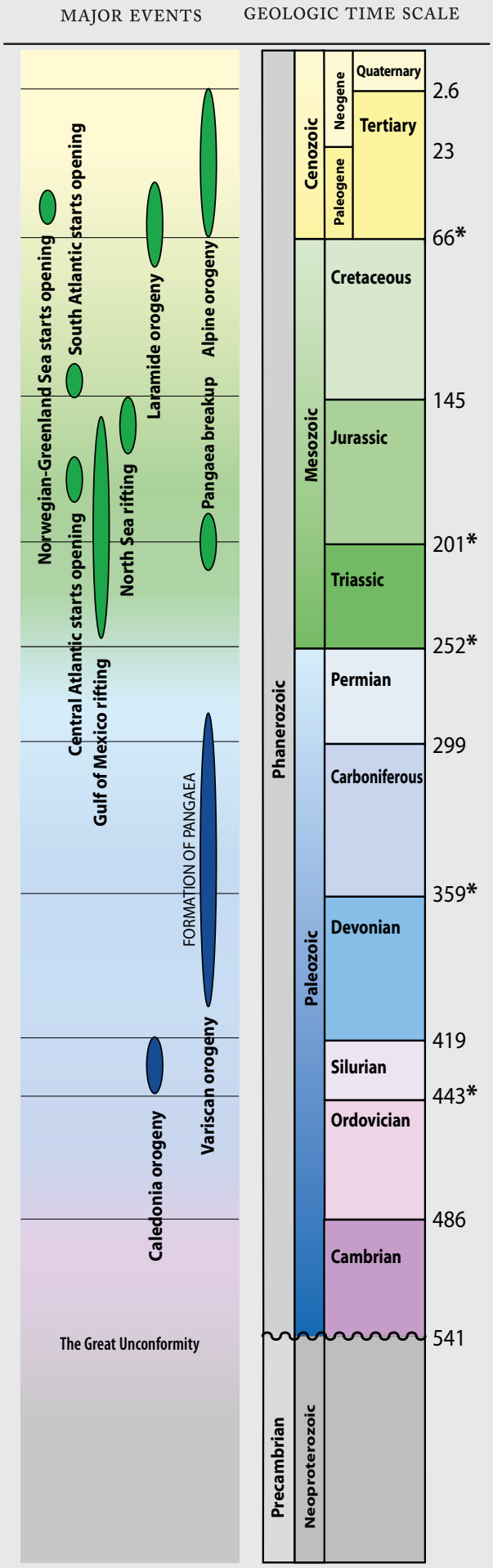


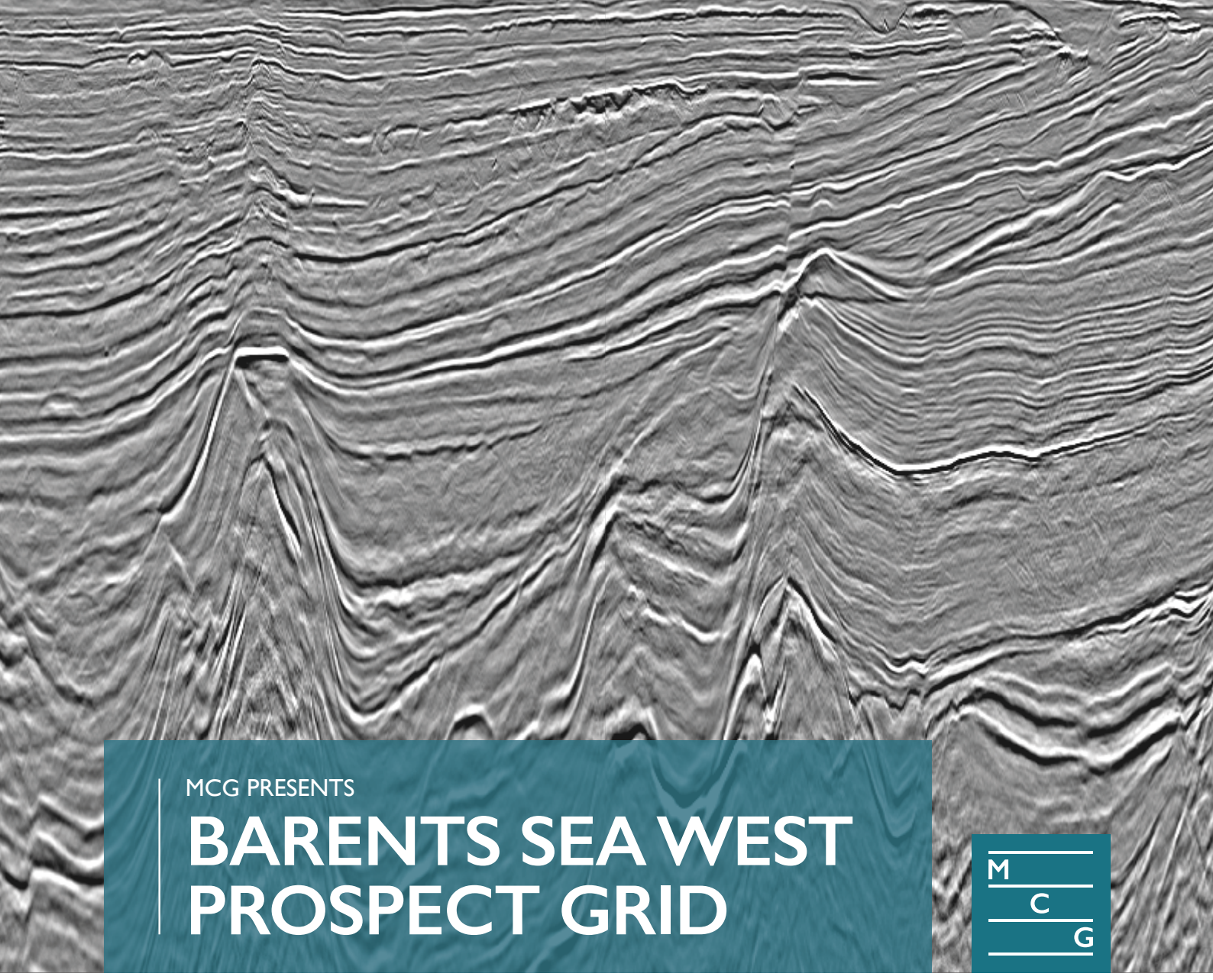
Total offshore resources sanctioned per year for the North Atlantic region.

In 2017 the value of sanctioned resources is expected to reach 2.7 Bboe, twice as much as compared to 2016. Norway, the United States and the UK will contribute to this growth, with the main projects being Johan Castberg (Norway), Lochnagar/Rosebank (UK) and Vito (US). The sanctioning activity is expected to continue to grow in 2018, and to reach 3.7 Bboe.

The conversion of discoveries into sanctioned development projects is important as it creates activity, increases the value for the E&P companies and shows the need for exploration. The Atlantic region has been through a tough period, and this is visible in the sanctioning activity. However, as oil prices are expected to gradually increase, new projects will be sanctioned again. ■

Espen Erlingsen, VP Analysis, Rystad Energy





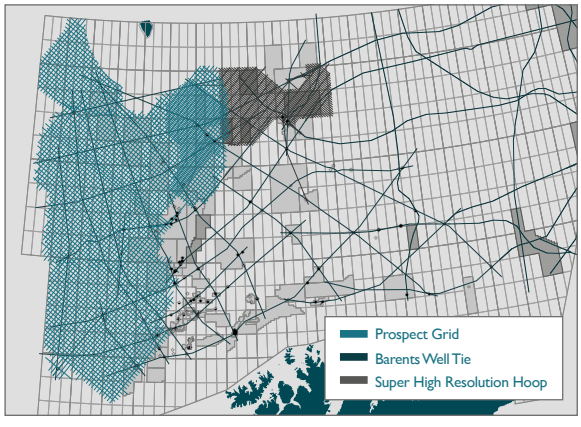
MCG PRESENTS

BARENTS SEA WEST PROSPECT GRID

Exploring the Western Barents Sea for the 24th Licensing Round

The brand new broadband deghosted version of the MCG Barents Sea West 4 x 4 km Prospect Grid, allows you to evaluate the potential of the highly prospective and under-explored western Barents Sea for the 24th Licensing Round.

Visit www.mcg.no/prospectgrid for more information on the reprocessed MCG Prospect Grid.



Please contact us for more information

Lars Ivar Leivestad
lars.ivar.leivestad@mcg.no

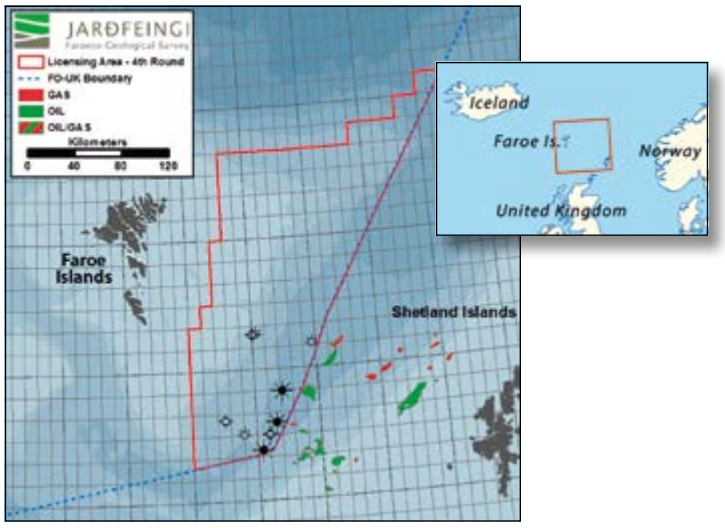
Tor Åkermoen
tor.akermoen@mcg.no

Faroes: New Round for 2017

During the 5th Faroe Islands Exploration Conference, which will be held on 17 May 2017, the Faroese Minister of Industry and Trade will announce the opening of the 4th Faroese licensing round. The round will last for nine months, with a closing date of 17 February 2018. The licensing area is concentrated on the eastern side of the Faroese Continental Shelf and comprises more than 160 blocks.

With the help of 15 years of exploration and the drilling of nine wells with proven discoveries, although not in commercial quantities, Jarðfeingi, the Faroese Geological Survey, have gathered substantially more knowledge and facts and a more mature understanding of the Faroese active hydrocarbon systems. As a result, Faroese geologists at Jarðfeingi believe they have increased the possibility of striking the first commercial field. At the conference they will be demonstrating how new and improved data has enabled them to make significant progress in their understanding of the geology of the Faroese Continental Shelf.

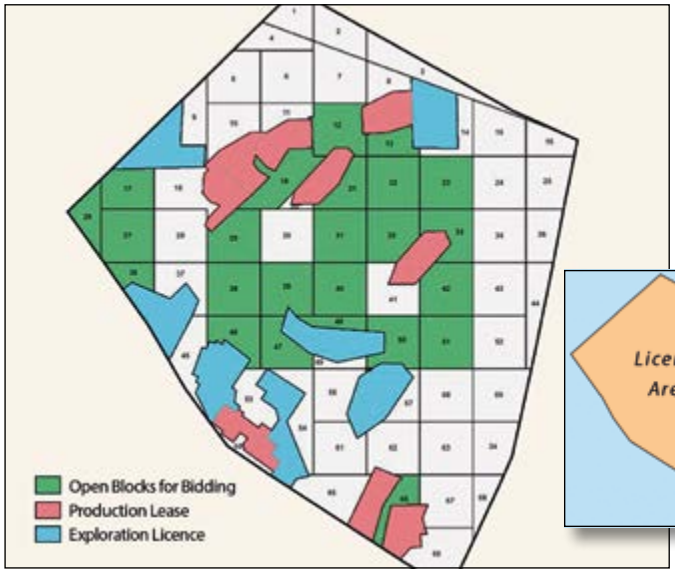
During the round a data room will be open and there will also be access to the core store at the Jarðfeingi offices in the Faroese capital, Torshavn. ■



Israel: First Round Announced

A string of recent giant gas discoveries in Israeli, Egyptian and Cypriot waters in the Eastern Mediterranean have heightened interest in this previously relatively overlooked area. Encouraged by these, the Israeli Ministry of Infrastructures, Energy and Water Resources (MIEWR), the government agency responsible for overseeing all petroleum-related activities in Israel, is planning a roadshow to introduce interested companies to the areas which will be offered in its first ever licence round. The roadshow commenced in September and the round is expected to be formally opened in November 2016 and to close in March 2017.

Holding a licensing round represents a new approach for Israel, which until 2012 accepted applications for exploration and development of areas from IOCs without using specific formal offerings. The round will reopen exploration in Israel's waters after four years of inactivity while the country prepared to offer the new licences.



High Potential

The Israeli blocks lie in the Levant Basin, where an independent report by Beicip-Franlab has estimated that the yet-to-find potential in Mesozoic and Tertiary reservoirs could amount to 6.6 Bbo and 75 Tcfg. To date six fields have been discovered in Israeli waters, all gas, with a seventh one under review straddling the border with Cyprus. These fields include the 17 Tcfg (2C) Leviathan field, discovered in 2010, and the Tamar field, with about 10 Tcfg. Over the past 15 years Israel has moved from being a net importer of fossil fuels to becoming self-sufficient, and now provides more than 50% of its own electricity generation.

A total of 24 offshore blocks will be on offer in this first bid round, each being up to 400 km^2, in water depths which range from 800 to 1,800m. Good data packages with spec seismic and historical well data and basin analyses are available, highlighting the potential of the blocks, where four potential plays have been identified, extending from the shallow margins in the east to the deeper part of the basin in the west. The Upper Miocene/Pliocene and Oligo-Miocene plays are considered to be only gas-prone, but there is potential for oil as well as gas in the Cretaceous and Jurassic plays.

IHS Markit is organising the Israeli offshore exploration licensing round roadshows, which are being held in London, Singapore and Houston. Interested E&P companies can meet the Israeli Minister of Energy and MIEWR staff, who will present the bid-round schedules and guidelines, the legal and fiscal terms, as well as a technical overview of the hydrocarbon potential of the nominated blocks and discuss the possible for monetising any discoveries. ■

Time for a re-think?

*Results from Dan Field Ocean Bottom Node (OBN) Survey – A Shallow Water Case Study. Zaske *et al.*, EAGE Conference (2014)

Seabed Delivers a Paradigm Shift

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EOR, Local Skills Development and Sustainability

Multidisciplinary interaction and local skills development proved critical when analysing scenarios for advanced chemical EOR in a Sudanese field, thus enabling future sustainability for the vital Sudanese petroleum industry.

MARTHE ÅSNES BIRKELAND and GUDMUND OLSEN, AGR

Following secession in 2011, Sudan's hydrocarbon production reduced dramatically from approximately 450,000 bpd to 100,000 bpd, changing the country's production status from that of a substantial oil exporter to being a nation just self-sufficient in petroleum. Sudan is currently producing about 250,000 bpd.

As part of Norway's commitment to the implementation of the Comprehensive Peace Agreement of 2005, the Oil for Development (OfD) programme provides foreign assistance focusing on petroleum policy, including the legal and institutional framework, and resource and HSE management.

Enhancing Heglig

Enhanced Oil Recovery (EOR) activity in Sudan was administrated by the Norwegian Petroleum Directorate (NPD) on behalf of OfD. International Petroleum Associates Norway (IPAN) were contracted as technical advisors to OfD and NPD, and global oil and gas energy and software company AGR were sub-contracted to IPAN to perform the technical studies and training. AGR's remit was to concentrate on finding the best methodology for EOR at the Heglig oilfield, which boasts much of Sudan's proven oil reserves.

Heglig is situated within the north-west to south-east trending Muglad Basin in south-west Sudan, part of the Central African Rift System. Three phases of rifting occurred between the Cretaceous and the Tertiary, resulting in deposition of a thick sequence of sediments over a long time span in the basin. Commercial hydrocarbons are sourced from the Aradeiba Main, Bentiu 1, Bentiu 2 and Bentiu 3 Formations. Heglig was first developed in 1996 by Arakis Energy (now part of Talisman Energy), and today is operated by the Greater Nile Petroleum Operating Company. Production reportedly peaked in 2006. The field is connected to Khartoum and Port Sudan via the Greater Nile Oil Pipeline.

Scenarios of EOR Strategies

Based on sector model screening, it was decided that there were two EOR actions to be incorporated to the full field model: horizontal producers in the Aradeiba F/Bentiu 1 Formation; and polymer injection in Aradeiba Main and Aradeiba F/Bentiu 1. The reference case used pertains to a full field model with existing drilling and production plans for the oilfield without any EOR actions.

An analysis of the results of inputting these strategies into the model follows:

Horizontal Producer Wells: It was found that new infill wells within the Aradeiba F/Bentiu 1 reservoirs require a specific length to obtain adequate initial productivity and sufficient reservoir contact. Simulations including inflow control device completion gave a small increase to the overall recovery. Horizontal wells will also reduce the water coning from the underlying aquifer. The main risks pertaining to horizontal drilling were a combination of more directional well placement and associated expenses when compared to vertical wells, which will require more thorough planning.

Polymer Injection: This method is expected to enhance oil recovery by improving the unfavourable mobility ratio for water displacement. The EOR potential is dependent on the polymer viscosity; 12 cp based on lab data is considered a highly optimistic case, whilst 1 cp is considered the most realistic case due to polymer break down and degradation. Polymers are sensitive to high temperature and high salt concentration. The temperature and connate (fluid trapped in the pores of sedimentary rocks during deposition) water, which proved to be fresh, should not be problematic for the shallowest reservoirs of Heglig reservoirs.

Surfactants were also considered as a combination with polymer injection. The aim of surfactants is to reduce the residual oil saturation in water-swept zones, thus the premise for surfactant injection is high residual oil saturation. The residual oil saturation in the water-swept zones of Heglig is unknown, so a programme for in-situ measurement was recommended.

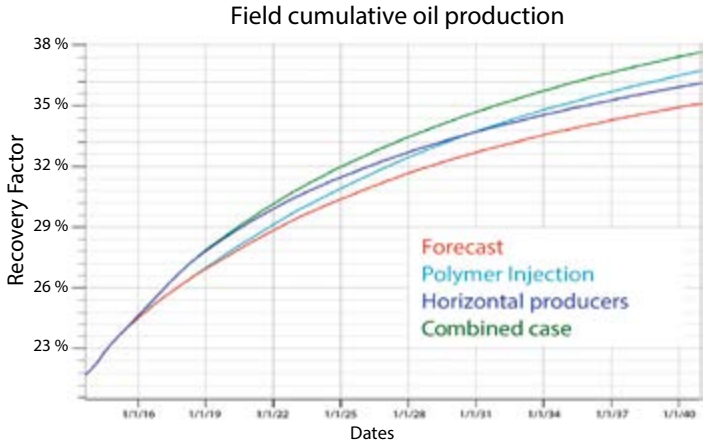
Risks with chemical injection include back production with regard to facilities, water handling, and polymer degradation during injection that may decrease the desired viscosity.

Combination of Producer Wells and Polymer Injection: All cases were constrained by a stepwise decline in total field liquid rate which was similar in all simulation cases and based on the reference case. In the plan for Heglig developed in 2014, two new water injectors in Aradeiba Main were planned for pressure maintenance.

As illustrated below, the applied EOR actions generate extra oil compared to the reference case. Evidently, horizontal wells increase the cumulative production instantly after

Overview and results from EOR measures applied to the full field model of Heglig. (Combined case: both horizontal producers and polymer injection.

Case	Injectors, Aradeiba Main	Injectors, Bentiu 1	Horizontal producers, Bentiu 1	RF (%)
Reference	2 New	None	None	35
Horizontal producers	2 New	None	11 wells	35.9
Polymer Injection	4 New	5 new, 7 converted	None	36.5
Combined case	4 New	5 new, 7 converted	11 wells	37.4



Simulation results – EOR potential and production curves. Recovery factor in Heglig 1/1 in 2014 was 22%.

application, whilst it is some time until the effect of the polymer injection is seen in the recovered volumes.

Technical Conclusions

These assignments resulted in a recommendation for further planning of the selected pilot(s). The recommended work prior to the Front-End Engineering Design phase evolved from the study covered a number of areas.

In the G&G disciplines, it was suggested that seismic should be re-processed to improve frequency content, and shallow events studied and interpreted to see if they could explain features at depth. In addition, G&G and petrophysical work should be implemented in the field static model so a detailed geological analysis of the pilot areas can be made, and geoscience input should also be included in history matching.

In the field of reservoir engineering, the recommendations included analysing fluid sample viscosity and asphaltene content, and the updating of the simulation model with an analysis of the final results from core experiments.

Well planning should be a multidisciplinary effort that involves a detailed geological evaluation of the selected area, a well design and borehole stability study, and risk and contingency planning. It was also recommended that there should be detailed planning at the pilot stage, including front-end engineering design; the infrastructure and logistics; and impact assessments covering the production facilities and environmental issues.

Training for Sustainability

The Heglig EOR study was challenging on many levels, particularly due to the lack of availability of a complete data set and field history. Multidisciplinary interaction proved critical to the overall study through the integration of knowledge and information so the three main scenarios could be investigated, from the reference case, to the action of drilling infill horizontal wells and to more advanced chemical EOR by polymer injection, and combination of the two.

The Heglig oilfield study also stressed the importance of providing knowledge transfer by training the Sudanese geoscientists and engineers to enable future sustainability of the much-needed Sudanese petroleum industry. ■

Training the local workforce was a vital part of the Heglig study.

PROSPEX 2016 – Come and Network!

PESGB and **DECC** bring you the 14th show in their highly successful series of **Prospect Fairs** – the UK's leading networking event for exploration and development. The show has gone from strength to strength and in 2015 we saw over 80 exhibitors and 900 attendees, in addition to a full two-day programme of 'prospects to go', overviews from government and presentations by explorers and consultants. Despite the downturn, this year we are expecting a similar number of visitors and exhibitors.

We are pleased to announce that this year we have frozen the 2014 rates. There are no increases to exhibition or registration costs. We have also listened to the feedback from previous years attendees and have introduced a new, One Day registration rate.

PROSPEX 2016 runs on 14–15 December 2016 at the Business Design Centre, Islington, London.

But don't just take our word for it, here are what some attendees and exhibitors said last year:

"PROSPEX is the industry benchmark conference, where you meet all the right people."

"This show always has a buoyant and optimistic mood."

"The exhibition was a constant hum of activity!"

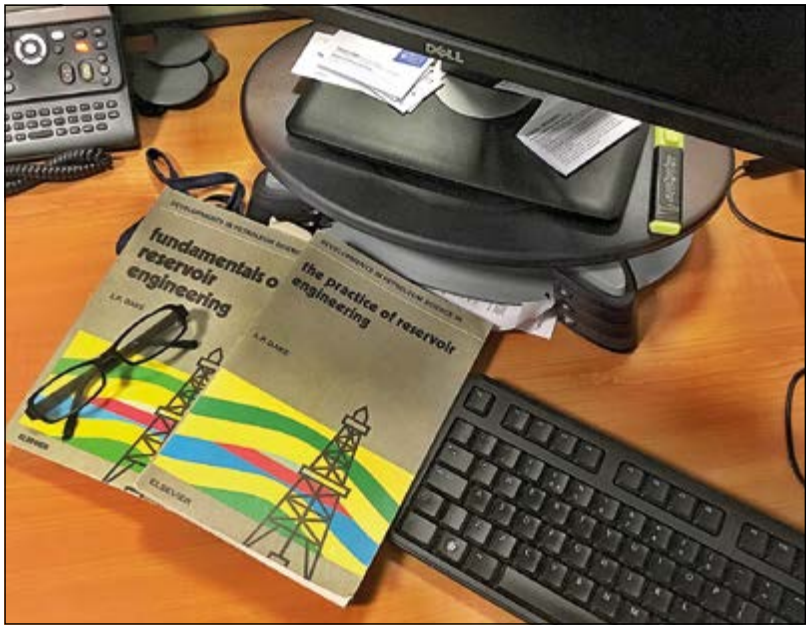
"A yardstick for activity within a region."

If you want to see what all the talk is about, registration is now open and includes admission to the exhibition and conference, all-day refreshments, luncheon and a networking wine reception – head to www.pesgb.org.uk for more details. ■

Fundamentals of Reservoir Understanding

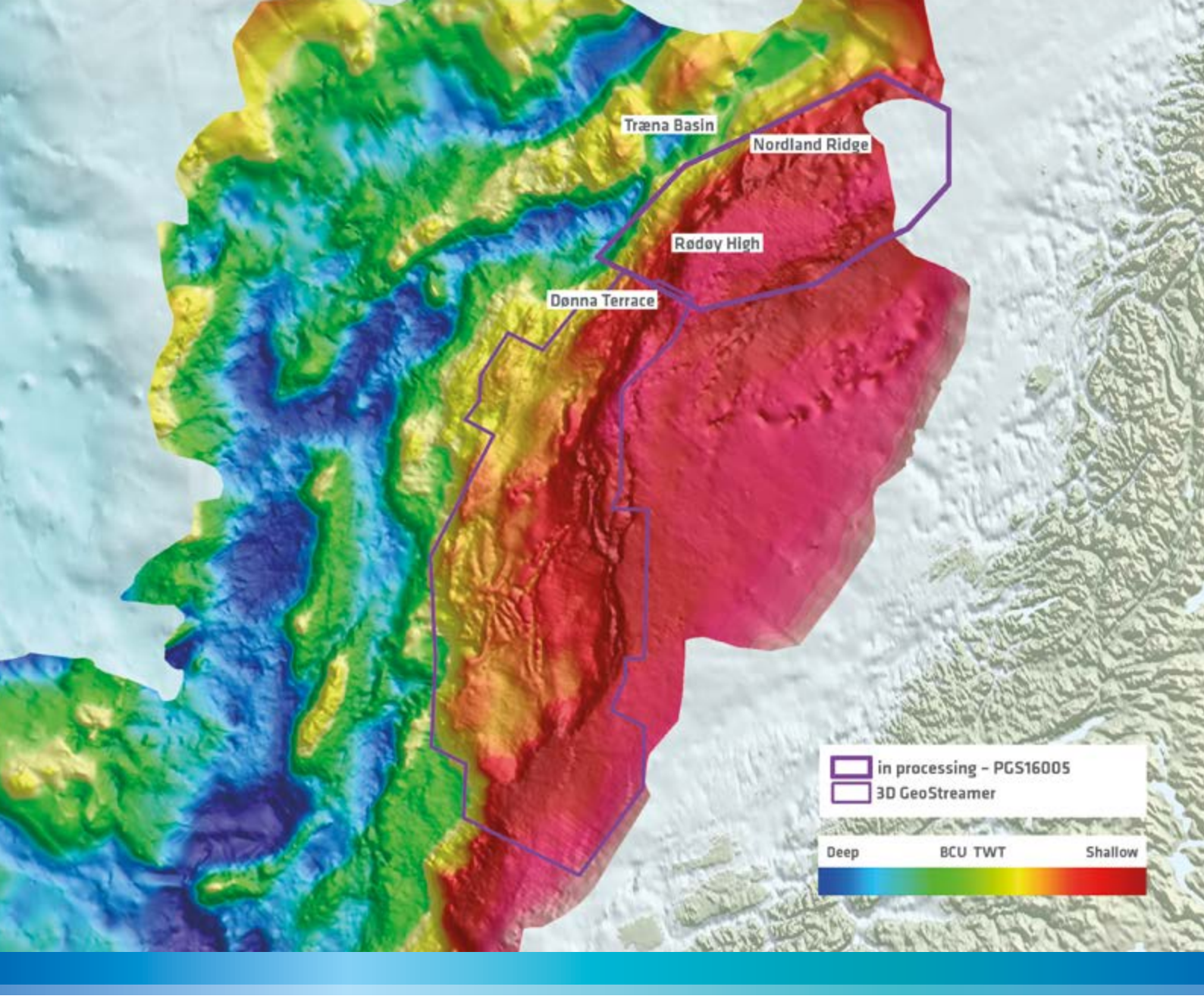
75 years ago – February 1941 to be precise – at the New York meeting of the American Institute of Mechanical Engineers, Messrs. S. F. Buckley and M. C. Leverett of Humble Oil & Refining Company, Houston, Texas, presented their thoughts and workings on the mechanism of fluid displacement in sands. The O&G industry refer to this as **Buckley-Leverett Fractional-Flow Theory** and it is a fundamental of how oil fields are flooded and produced.

Just a few weeks after Mr Buckley and Mr Leverett had made their presentation in March 1941, across the Atlantic on the Isle of Man in the British Isles, a boy was born – Laurence Patrick Dake. Known to the E&P industry as **Laurie Dake**, he provided us with the rules of reservoir engineering with his books, *The Fundamentals of Reservoir Engineering* and *The Practice of Reservoir Engineering* (Elsevier).



The oil industry has developed a tendency to resort too quickly to overly complicated, multi-million cell models in overly expensive modelling and simulation software. In the existing low oil-price environment, technically driven subsurface consultancies, such as the Isle of Man-based **MMbbls Ltd**., are utilising web-tech low-cost solutions to highlight the fundamentals of reservoir understanding and are returning to the proven mathematics and analytical modelling developed by Buckley, Leverett, Welge, Darcy and Archie and to the reservoir engineering rules taught so clearly by Dake.

A copy of Dake and a well-constructed spreadsheet or web-app should be a prerequisite for any decent reservoir engineer well before running any complex model in hundred-thousand-dollar simulation software. ■



PGS16005 – 3D – GeoStreamer – Norwegian Sea – 2016

Nordland Ridge GeoStreamer®

Processing has started on our 10 000 sq. km 3D survey for 2015 APA licenses and 2016 APA acreage.

We are extending the PGS library over the northern part of the Dønna Terrace and the southern part of the Nordland Ridge to provide over 30 000 sq. km of regional broadband coverage. The imaging products include state-of-the art broadband PSTM, full integrity PSDM and fast-track PSTM processing.

Fast track products will be ready early 2017.
Contact mceurope@pgs.com.

North Sea 4D Projects

ION in-field **Acquisition Optimization Services** were selected for all time-lapse, or 4D, towed streamer projects for the 2016 **North Sea** season. Experience and proprietary technology were key to the award of five 4D projects, which include real-time survey line planning and quality control for fields in the North Sea offshore the UK, Norway and Denmark.

ION acquisition specialists have in-field experience on over 100 4D programmes in a variety of environments around the world including the North Sea, West Africa, the Middle East, Asia, Australia and the Gulf of Mexico. Various proprietary tools are employed to optimally manage 4D surveys in real time, including **Marlin**, ION's new simultaneous operations management tool, allowing seismic plans to be represented alongside planned and actual activity for all operations in the area, enabling better real-time survey line planning while minimising operational disruption.

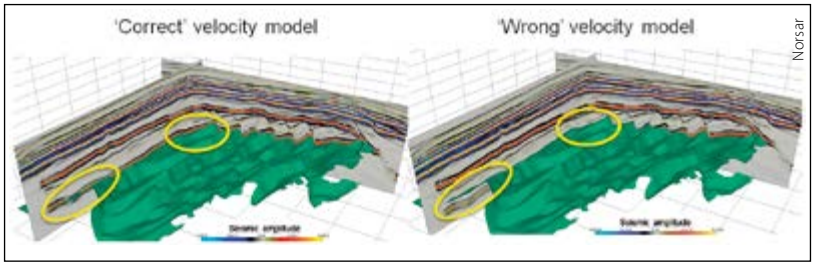
According to Stuart Darling, Vice President of ION's Optimization Software and Services, towed streamer 4D acquisition remains one of the most complex operations for the seismic industry, as the surveys require precise marine current predictions to accurately match past receiver positions and focused simultaneous operations management to ensure the vessel and equipment navigates around field infrastructure in a safe, efficient manner. ■

Modelling Complex Targets

This summer Norwegian independent research foundation **NORSAR** added two unique features to its best-in-class ray tracing package: **S-wave anisotropy** and **Kirchhoff modelling**. Exploration geophysicists have historically relied on seismic PP-reflection in isotropic models, but today's exploration targets are often more complex, deeper and smaller. Therefore, NORSAR extended the survey planning tool and the synthetic seismogram generation to include S-wave anisotropy modelling, enabling users to improve an anisotropic velocity model, as well as unlocking imaging through gas or similar matter, yielding more information about reflectivity on target.

NORSAR has also developed a method to combine the advantages of classical ray tracing, which is faster and more flexible than finite difference methods, with Kirchhoff modelling to include diffractions, caused by sharp discontinuities in a geological model. In addition NORSAR integrated the Kirchhoff migration concept in order to quickly generate different PSDM images of a reservoir considering varying velocity models, which can explain, for example, an erratic forecast on the depth of drilling targets.

These new advances in seismic modelling continue to contribute to the decision-making process of finding and selecting prospects to drill. ■



Welcome to NCS Prospects

So many issues in front of us: the Paris agreement; the green transition; the low oil price. And above all – miserable exploration results, worldwide as well as on the Norwegian Continental Shelf (NCS). Where do we go next?

NCS Prospects – The Exploration Strategy Conference – organised jointly by **GeoPublishing AS** and **Rystad Energy**, brings together the larger North Sea exploration community to exchange expert insight and to discuss how to go about exploration in a short and long term perspective.

Over two days we gather a multitude of NCS players, including governmental organisations, oil and service companies, the financial industry and consultants, in an attempt to investigate the future of exploration in mature and frontier basins.

Questions to be addressed include: do we need a new licence policy; is it necessary to increase the APA-areas; should we drill more wildcats; how do we go about new technology; and can the workflow be more efficient?

Help answer these and many more at NCS Prospects in Stavanger, 1–2 November 2016. ■

The Lynx Virtual Data Room

Lynx Information Systems has extended its comprehensive range of software and services and is pleased to announce the launch of a new **Virtual Data Room** (VDR) service for licensing authorities, farm-out, acquisition and collaboration opportunities.

Building on the success of the UK Onshore Geophysical Library and Belize Seismic Archive, the Lynx VDR is powered by **iSeisview** and **iLogview**, providing secure access via a web browser to interactively display 2D and 3D seismic, wireline log data, interpretations, core photos, maps and reports to the user. Each VDR can be configured to restrict access to authorised internal or external users or opened up to allow data to be presented to the widest possible audience, but still restricting unauthorised access to the source data itself within a secure hosted environment.

Backed by experienced staff in the London and Houston offices, a new Lynx Virtual Data Room can be online and operational within a few days, providing secure global access to potential stake holders.

The Lynx Virtual Data Room provides a cost-effective solution to securely showcase exploration data to a wider audience. ■

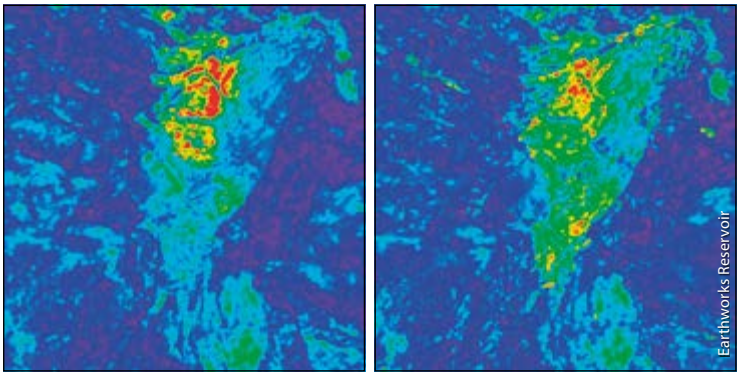
Direct Seismic Amplitude Detuning

A significant risk with seismic amplitude analysis is that **thickness related tuning** effects are the largest single factor affecting amplitudes in seismic data and mask the identification of genuine amplitude anomalies. **Tuning effects** are larger than any other effects due to geological changes, including lithology or hydrocarbon fluid effects (DHIs), responses we are often trying to interpret from amplitude information. It is very common for amplitude maps to be analysed and interpreted whilst completely ignoring tuning effects.

Until recently the only way to detune seismic amplitudes was to interpret a seismic event, extract the thickness and amplitudes in the form of maps and then detune the mapped response. This type of approach is slow, potentially inconsistent and may be subject to interpreter bias.

In response to this, **Earthworks Reservoir** has researched and developed a novel and unique detuning methodology called **DT-AMP**™. This is capable of directly detuning seismic traces in 2D or 3D surveys. By detuning the entire relative impedance seismic section, false amplitude indicators are suppressed and genuine anomalies highlighted. Amplitude analysis becomes robust and consistent and, because the analysis is performed in-situ and interactively on the seismic traces, the workflow is accelerated. ■

Amplitude map before detuning (left). Very bright amplitudes are tuning and the field outline is indistinct. After DT-AMP detuning (right), the amplitudes in the southern area now show the reservoir continuity observed in the wells and the field outline is sharply defined. Colour scaling is unaltered between the two images.



Ten Years of the Barrel Award

"… Best Student Petroleum Exploration Programme in the World"

The **AAPG Imperial Barrel Award (IBA)** competition is a programme for post-graduate, primarily MSc, geoscience students which gives them a taste of the role of a geoscientist in the exploration business. Universities throughout the world take part in what is probably the largest student competition organised by any geoscience society.

Teams that successfully apply to join the programme are provided with a dataset comprising seismic and well data from a sedimentary basin. The objective is to interpret and analyse the data to evaluate the petroleum prospectivity of the basin within an eight-week timeframe. Participants have access to a number of on-line training modules which are of particular importance to universities that do not have petroleum geoscience programmes. The teams present their findings and recommendations to panels of industry experts, initially in regional semi-finals and ultimately at the global final, held just before the AAPG annual convention. In 2016, 147 teams and more than 1,000 students, representing 42 countries, participated in, and learned from, the programme.

Originally created in 1976 as part the Petroleum Geoscience MSc course at Imperial College, London, the AAPG organised an international competition in 2007, the first one having teams from the US, the UK and Russia, with the University of Aberdeen taking the honours. Since then the AAPG IBA programme has gone from strength to strength. The number of universities taking part has risen from 7 to 142 in 2016, the tenth year of the competition, and the number of students directly involved in teams reaching the semi-finals and finals is now over 700.

The value of the competition lies not only in the educational opportunities it provides but also in the opportunities for students to network with experienced industry professionals to gain insight into what a career in petroleum exploration might offer.

See www.geoexpro.com for more about the IBA. ■

London Pavement Geology

A wealth of high quality rock samples of all types can be seen in **London**, mostly visible to the public from the pavement – but how do you know what it is and where it comes from? **Dave Wallis**, a geologist with 45 years' experience in the oil industry, first dreamed of creating a database of rocks as a student in the 1960s, and has finally been able to bring the project to fruition through an interactive website, with the assistance of **Dr. Ruth Siddall** of University College London. The rock and fossil sites which make up the structures and pavements of London are mapped in a searchable database, and buildings as varied as Tower Bridge and Hampton Court Palace Fountain are included in the database, with details of the rock's age and provenance as well as photos.

The Houses of Parliament: Permian Anston Limestone from a quarry in South Yorkshire.

The site has now been enhanced by a free App for both Android and Apple platforms made possible through awards from the PESGB, Geologists' Association, British Geological Society and Geoscience Wales, among others.

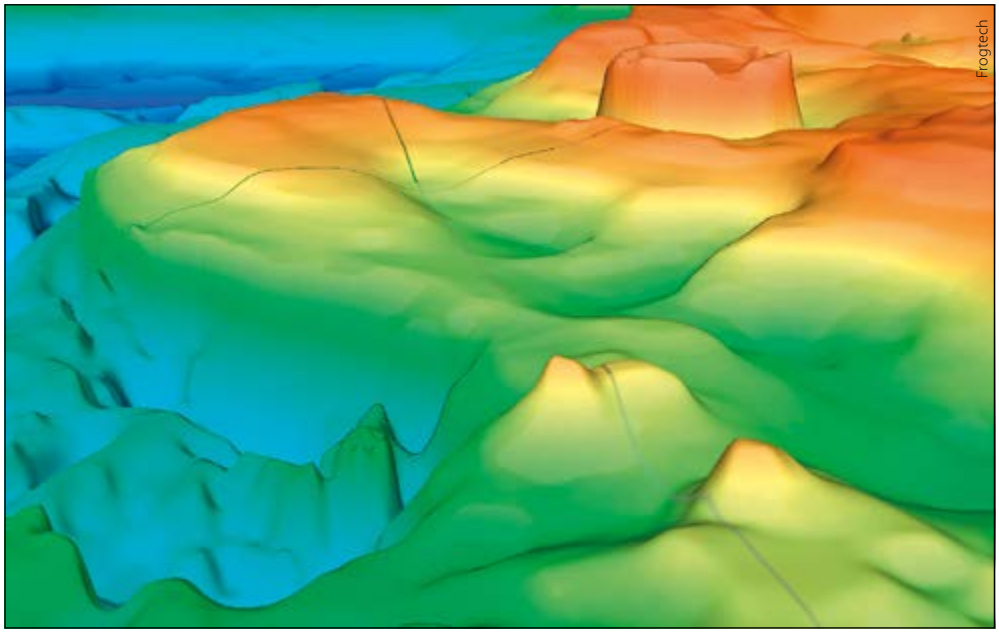
Students, amateurs and professionals alike are encouraged to search for locations and also to submit their own information to add to the database. The website is ***londonpavementgeology.co.uk*** and the app can be downloaded by searching for '**London Pavement Geology**'. ■

Early Rift Architecture of GoM

Frogtech Geoscience has launched the first commercially available **regional interpretation of basement** architecture covering US and Mexico permit areas for the **Gulf of Mexico**, revealing pre-salt Triassic–Jurassic rifts and paving the way for a new and improved understanding of Gulf petroleum systems. This **SEEBASE** (Structurally Enhanced view of Economic BASEment) study incorporates a hand-contoured 3D model of the depth and geometry of the Gulf basement. It provides important insights on the level of structural control basement has on primary salt deposition in the Gulf, its subsequent mobilisation, and the distribution and thickness variations of Jurassic source rocks.

The new interpretation was made using Frogtech's proprietary potential field geophysics interpretation process, incorporating both gravity and magnetic profile modelling, which has overcome the known challenges of mapping detailed basement architecture below the significant salt bodies that exist across the Gulf.

Frogtech Geoscience provides industry-leading solutions in non-seismic geophysics, geodynamics, structural geology, seismic and well interpretation, stratigraphy and petroleum systems to reduce exploration risk. ■



3D image of the Gulf of Mexico depth-to-basement SEEBASE showing the Campeche Shelf (lower left) and Yucatan Platform with the Chicxulub crater (top right; shallow basement indicates the central melt zone).

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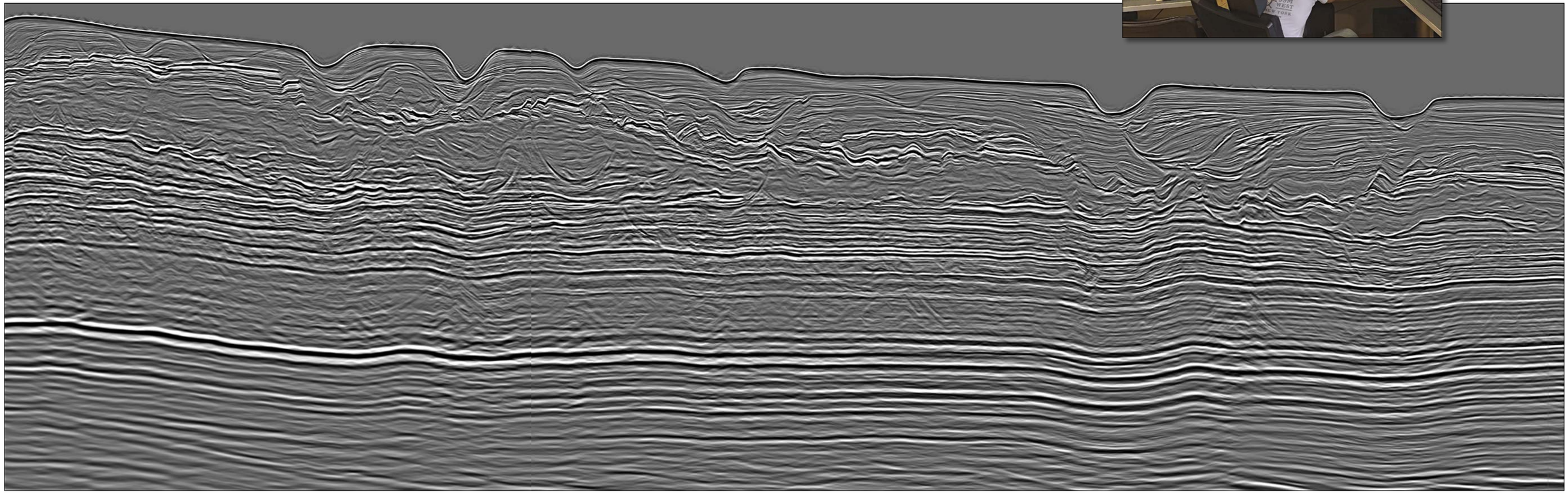
Priority Onboard

An advanced marine seismic service that creates an exciting new shortcut in the road from exploration to production

Below is an example line from priority processing the final broadband isotropic Pre-STM volume, delivered straight from the vessel after 1D conversion to depth. Taken from Polarcus' Deepwater West Africa project, the Mesozoic to Recent age strata are clearly shown and their TWT structure and a series of erosional unconformities provide clear evidence for prograding clinoforms over downlap surfaces, thereby helping to understand reservoir facies development and ultimately assisting optimal location prediction. This priority processed volume was responsible for direct interpretation and early identification of all the main intervals of interest and also potential problem areas, such as shallow velocity anomalies.

Polarcus®

Onboard processing: field geophysicist Andrey Seliverstov utilising the interactive map view.



How to Break the Stereotype

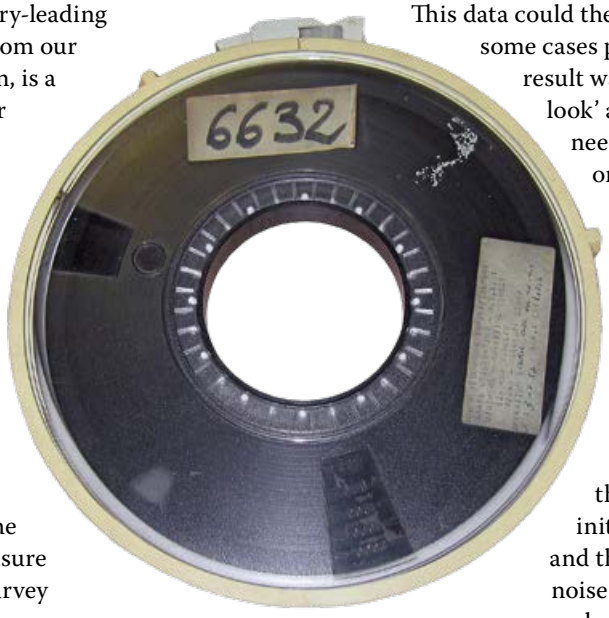
ED HAGAR, Polarcus

A priority service without compromise.

Sometimes in an industry, we have to ask ourselves: what's in a name? Our industry in particular has a history of renaming to reinvent, even when the 'reinvention' is little more than a refresh. Polarcus onboard processing, an industry-leading technique delivered straight from our vessels shortly after acquisition, is a priority service that means our clients receive the finished product ahead of the competition. So, is this true innovation, or nothing more than a step change? To answer that we need to go back to the beginning…

'Fast-Track Processing'

When I first started out in the seismic industry 25 years ago, the shared motive was to achieve processing of the navigation data on board to ensure that when the vessel left the survey area, we at least knew where it had been! The seismic data quality control was pretty much down to the occasional shot gather, some rather sketchy near-trace displays and the occasional brute stack. A PC with software called MicroMax and a 9-track tape drive attached, a hefty piece of equipment that was the size of a fridge, performed the stacking. However, any processing such as a simple Stolt migration would run for days, hence processing had to be done onshore. Gradually, computers became more powerful, the tape drives more compact and the processing software more capable. We had the capability to clean and sort data effectively on-site and thus, the start of 'fast-track' processing. Over the years, this term has had various interpretations and stigmas attached, but it can be generalised into two main types: the first is an enhanced QC product to verify the seismic data quality in a 3D sense, or alternatively, a product that is started on board but completed onshore to allow for initial interpretation to commence.



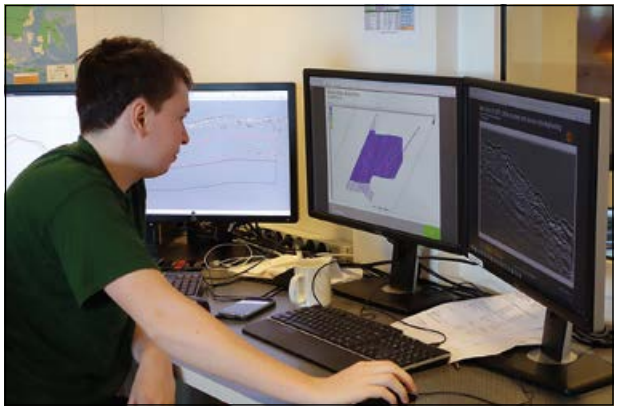
The first 9" track tapes were produced in 1964. Each one could hold 180 Mb, so my iPhone could hold 700 tapes worth of data.

The 3D QC fast-track was generally completed on board and featured a very limited processing sequence, with data volume decimation and trace-drop performed early on, sometimes output with limited offsets. This data could then be brute-stacked and in some cases post-stack migrated. The result was a useful but quick 'first-look' at the data to see if something needed further consideration or was note-worthy for the subsequent 'main-track' processing onshore. That was all that volume could be used for: a guide for the onshore geophysicists and interpreters.

In the second use of fast-track processing, the aim was to get a product off the vessel to be used as an initial interpretation volume and the focus was on the testing of noise removal, simple de-multiple, and velocity picking. This data could then be taken onshore for completion of the time-processing and 3D pre-stack migration. After some post-stack 'cosmetics', you end up with a pretty good dataset within a reasonable time-frame. The fast-track volume can be comparable to the main-track processing, at least in some ways, but nevertheless required the joint efforts, time and expense of onboard

The processing hardware in the vessel rack room: total compute power available 200 TFLOPS.

Field geophysicist Curtis Craiggs testing DUG Broad.



and onshore data processing, which was not ideal.

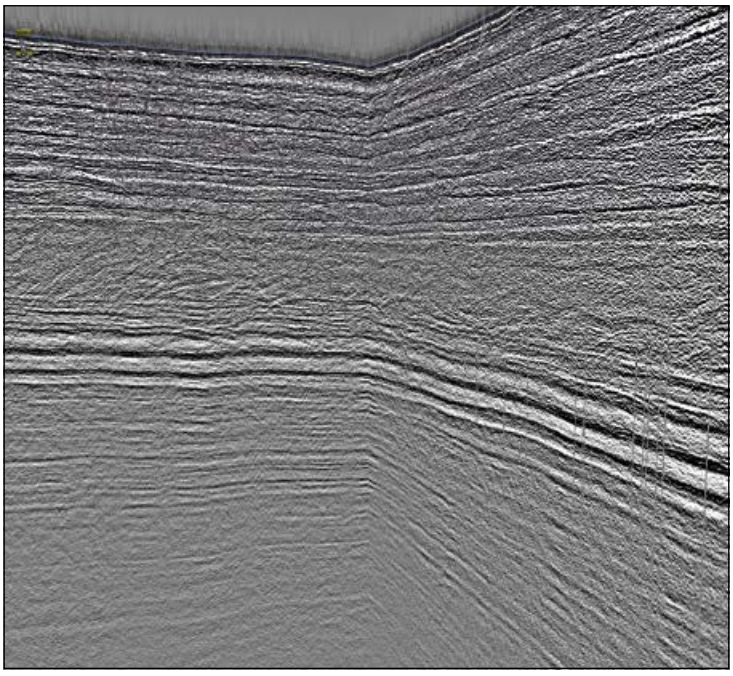
Over the years, we have witnessed the evolution of 'fast-track', with some companies even tackling the likes of pre-stack depth migration on board. However, until technology could catch up with aspiration, there was always some compromise made to processing and imaging that left the user wanting more, needing more, before committing to placing an expensive well. If nothing else, nobody wants to hear that the volumetric calculations for reserves have come from a fast-track derived geological model!

Technology and People

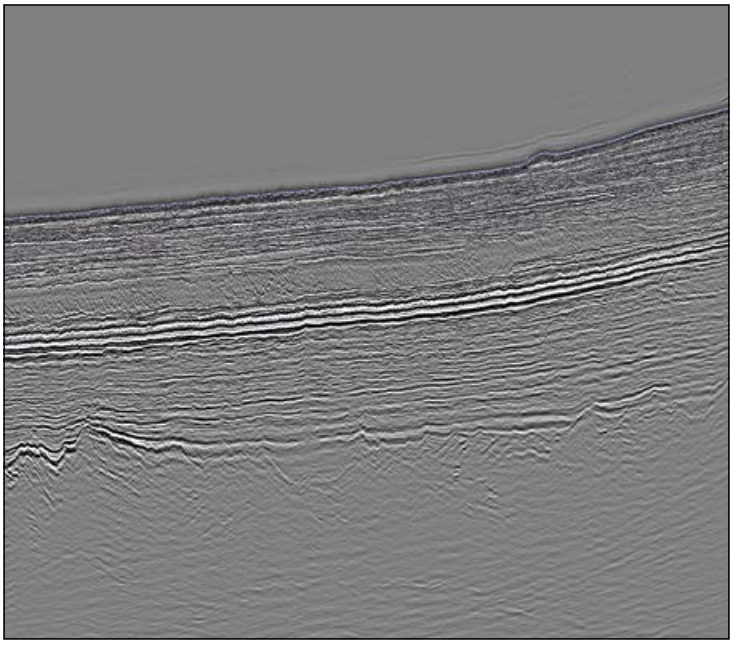
Has the technology finally arrived; do we now have the computers and the software required to achieve our goal of delivering a product straight from the vessel without a compromise in quality? Two years ago, Polarcus formed a partnership with DownUnder GeoSolutions (DUG), who provide the hardware and software that we use on board. The reasons for this alliance are multi-fold. Their software is fresh and optimised rather than a modification of an old platform. It is also coded to run on Xeon Ivy Bridge and Intel Phi Coprocessors, components found in supercomputers, unlike traditional 'GPU' based systems, allowing for more than just a few specific types of processes or algorithms to be run through these powerful sub-systems. These features combined offer a hugely powerful computer system that runs code very efficiently. So, for a given compute size, we get more speed and use less power for compute and cooling than other comparable systems.

However, we can't just throw technology at the problem. What is equally important is that other aspect: the people. At Polarcus we have innovators who innovate! This means that we have a very flexible acquisition team who can adapt and develop to suit the combined needs of the client, the industry and our environment. We start the onboard flow with well sampled, low-noise and high quality data that is then passed to our experienced processing geophysicists, who utilise the tools on board to turn around deliverables within the tight deadlines often required.

We now have the compute power, the software and the people. Lastly, we apply common sense. To achieve an advanced product, we need to work from the start with our clients and likewise, our clients need to work with us. Together, we create the right flow that is tailored specifically for each project, maximising on the potential rather than compromising; exceeding rather than matching expectations.



Onboard delivery 3D post radon stack.



Onboard delivery of lattice migrated stack.

Start of Something New

So, what does our priority processing flow look like? It includes high end linear and time-frequency variant de-noise, broadband source and receiver de-ghosting, 3D de-multiple, high-resolution radon and pre-stack time migration on a 25m grid with full offset range incorporating Voronoi weighting. Shortly after the last shot point, interpreters receive the final volumes delivered straight from the vessel. All this with the added benefit of a seamless input into any one of the global DUG processing centres which, of course, have the same systems and offer a wide range of FWI, QI and depth imaging services.

Two years ago, we had an ambition to change the status quo and the perceived attitude of what can be delivered from the vessel. Have we reinvented 'fast-track'? No, we believe we have actually started something new.

Oh, how I miss the days of my 9-track tape drive chugging along under my desk onboard the boat, dreaming that surely we will be able to do this faster and better one day... ■

The 'Gatwick Gusher' Fact or Fiction?

Horse Hill, one of the most talked about discoveries in the UK for decades – not just by the industry – lies in the Weald Basin in south-east England, an area considered potentially rich in hydrocarbons, but which has been ignored for decades. With the help of experienced UK geologist, Chris Pullan, we look at the geology, the newly identified plays and the prospectivity behind the hype.

JANE WHALEY

"More than 70% of the wells in the Weald Basin, most of which were drilled between the 1960s and early '80s, have encountered hydrocarbon shows," says Chris Pullan, a consultant with Magellan Petroleum. "There was evidence of hydrocarbons at several levels, so why were they not followed up properly until now? There could be several reasons, including the fact that drilling in the very populated and protected south-east of England, a mere 60 kilometres or so south of London, is practically quite difficult – but mostly, I think we just didn't look hard enough at the results."

Interest in the Weald's potential has been increasing in recent years, but the area really hit the headlines late in 2014 when preliminary results from Horse Hill-1, drilled on PEDL (Petroleum Exploration and Development Licence) 137 on the northern flank of the Weald Basin, suggested the total in-place resource for the area could be considerably larger than previously estimated. Further positive analysis and testing of the well led to news reports suggesting the discovery – nicknamed by the press the 'Gatwick Gusher' – may be 'a world-class resource with millions of barrels of oil', which could play a 'key role in transforming the UK's energy balance'.

Less positive press exposure to the hydrocarbon potential of the area had occurred in 2013 and 2014, when Cuadrilla Resources proposed a test well near the village of Balcombe in the centre of the Weald Basin. There was considerable public concern and active anti-fracking protests over the proposed well, although no application to use hydraulic fracturing had been made.

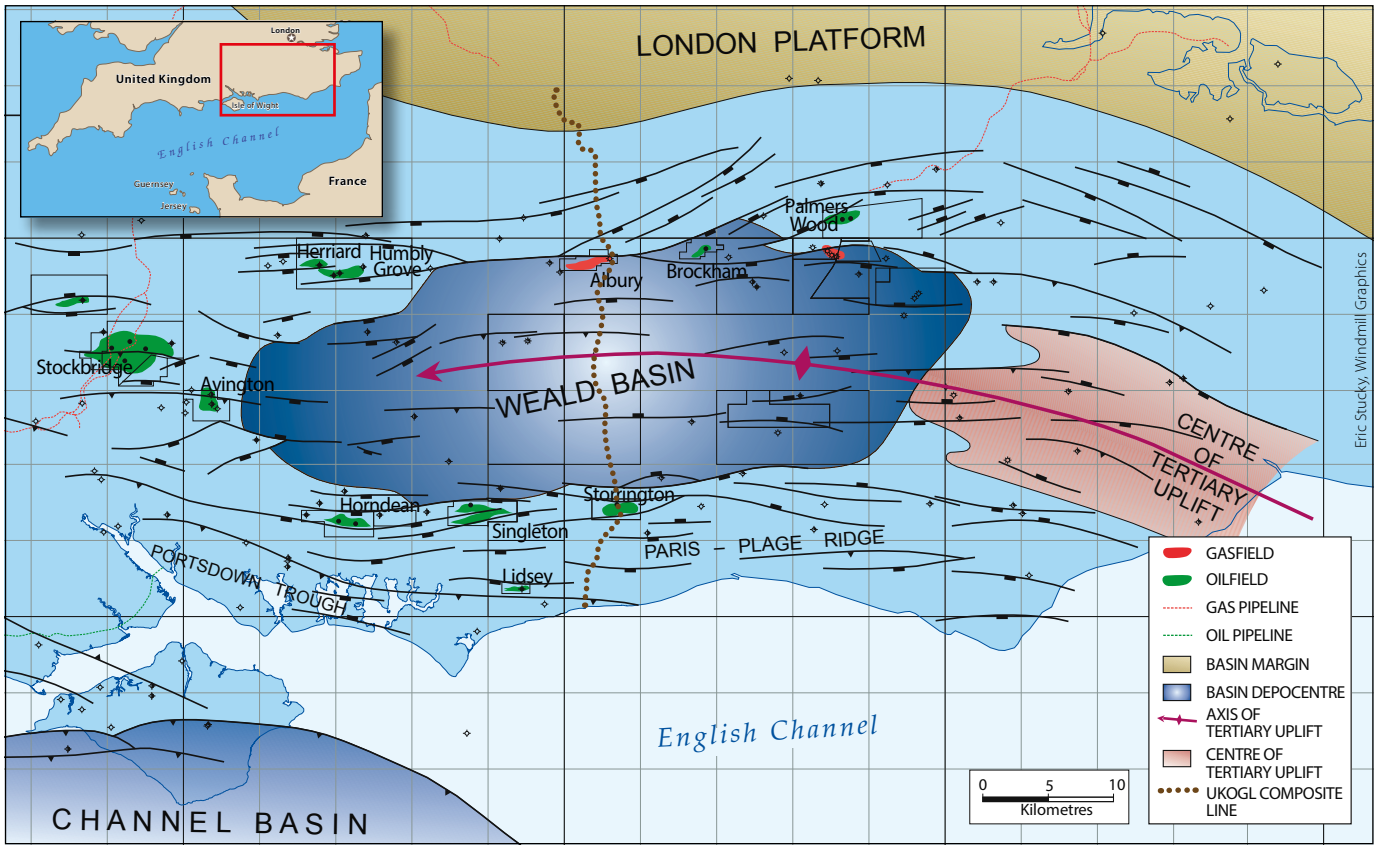
Early Gas Use

The occurrence of hydrocarbons has been recorded in southern England for over 150 years, with gas being reported in water wells as long ago as 1836, as well as natural oil seeps being noted. In fact, the first UK discovery and production of onshore gas was in the Weald Basin, when gas was found in water wells during the construction of Heathfield railway station, subsequently used to power the lights for the station.

The first exploration wells were drilled in the Weald Basin in the 1930s. A major phase of exploration from 1930 to the 1960s focused on drilling surface features, but with little success. The 1973 discovery of oil in Triassic sandstone at Wytch Farm – at the time the largest onshore oil field in Europe (see *GEO ExPro* Vol. 10, No. 6) – in the adjacent Wessex Basin to the east of the Weald Basin, led to a resurgence of interest in the region.

Also in the 1970s, improvements in seismic acquisition techniques enabled exploration of prospective plays which were previously hidden below unconformities. A number of

A peaceful rural scene near Dorking in Surrey, not far from the location of the Horse Hill well.



Structural elements of the Weald Basin.

new wells in the first half of the 1980s resulted in the first commercial discoveries in the Weald Basin. These included the Humbly Grove, Herriard, Horndean and Singleton oil fields in the western parts of the basin, reservoired in the Middle Jurassic Great Oolite Formation. Fields found in the Upper Jurassic sandstones and limestones in the northern and central part of the basin at this time included the Palmers Wood and Brockham oil fields and Albury and Godley Bridge gas fields.

After oil prices crashed in the late 1980s there was little interest in the region for nearly two decades. At the moment, there are 13 producing sites in the Weald Basin, but some are almost 30 years old and many reservoirs are declining. However, the last decade has seen a considerable resurgence of interest in the area, with some very interesting well results.

Time for a Fresh Look

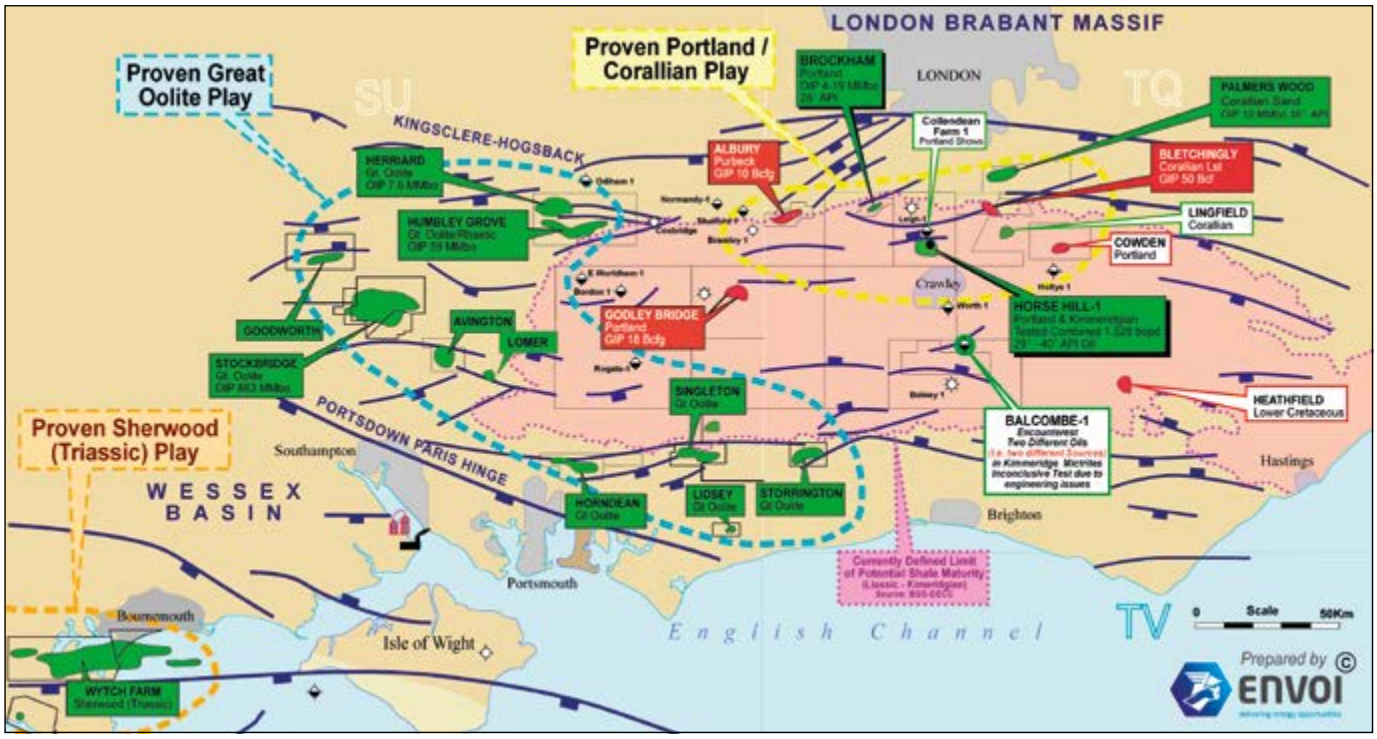
"In the 1980s, following the success at Humbly Grove, companies were primarily focused on the Middle Jurassic Great Oolite limestones in the south and west of the Weald Basin. The basin centre was written off due to rather poor reservoir development," Chris explains. "And because of the oil price drop people did not follow up the Upper Jurassic discoveries on the north flank. There was very little focus on other horizons, particularly on any deeper potential. No one had really tried to see the bigger picture of the overall basin, partly due to the fragmentation of the database.

"Magellan Petroleum first got into the Weald Basin during the 9th UK Onshore Round back in 2000. We knew there was potential, but had a lot of questions. For example, what was the source of the oil in the younger formations – could it be the same Lower Jurassic shales as at the Wytch Farm field, even though their quality in the Weald Basin was fair at best? Or was it sourced from a higher level, such as the Oxford or Kimmeridge Clays? What about the possibility of a deeper gas play? How deformed was the centre of the basin? We methodically set about preparing a regional study to find answers to these questions, benefitting from the release of the well data and the UK Onshore Geophysical Library which had recently been established, so we could obtain long composite lines across the whole area. Once we had the regional perspective, including reprocessed vintage seismic, the plays just jumped out at us!"

New Plays

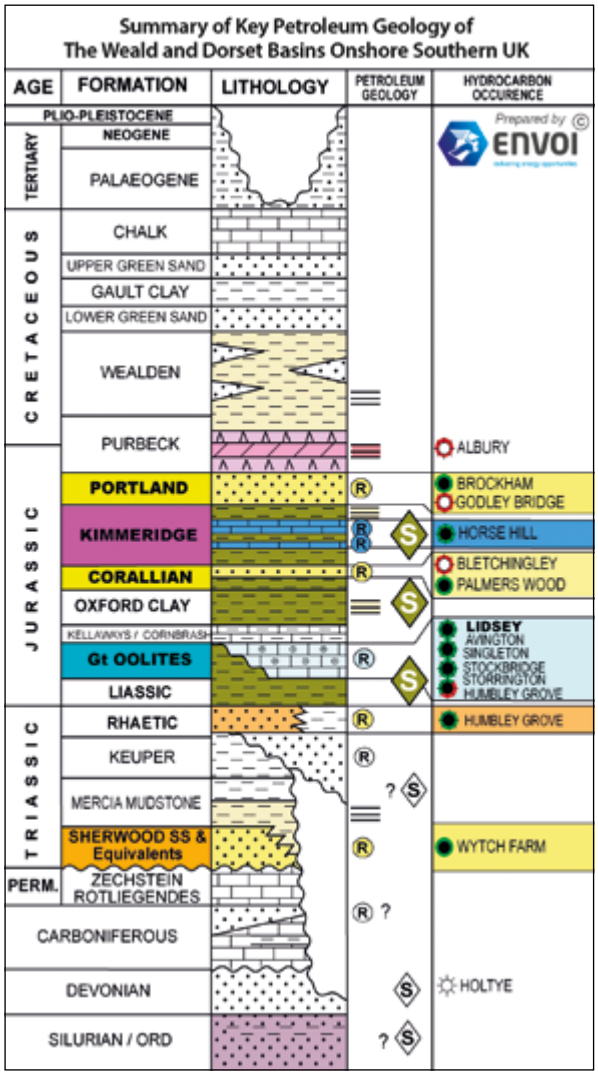
"As a result of this new comprehensive analysis, we have identified a number of potential petroleum systems in the Weald Basin," Chris says. The plays traditionally chased in the area are the Upper Jurassic Portland and Corallian Sandstones, although the latter shale out in the middle of the basin, and also the Middle Jurassic Great Oolite carbonates, all sealed by Upper Jurassic Kimmeridge Clay shales and Purbeck anhydrites. Magellan's regional re-evaluation included new petrophysical and geochemical analysis and maturity modelling, which suggested that the oil could be coming from the Upper Jurassic Oxford Clay and in some areas from the Kimmeridge Clay. Furthermore, the source of the gas in the area was unlikely to be Jurassic and probably came from a deeper level, possibly Palaeozoic.

"This was a very exciting realisation, as it suggests that in addition to sourcing gas in higher levels, deeper Triassic reservoirs could also be charged from this source," Chris explains. "The deeper gas play is virtually unexplored here since



Map showing discoveries and hydrocarbon prospectivity of the Weald Basin.

Stratigraphy of the Weald Basin.



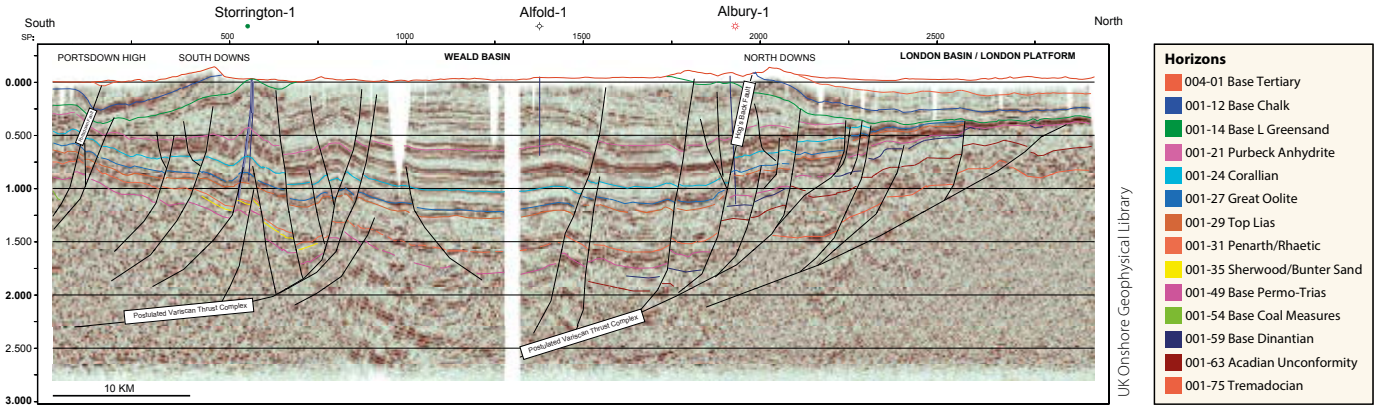
few wells have reached sufficient depth. This led us to look in more detail at the centre of the basin, where Jurassic reservoir development is poor, but where the Triassic sands are expected to be present."

Meanwhile, some of the questions as to whether Upper Jurassic Kimmeridgian Clays could be a source were answered by geochemical analysis of oil from a test of the Kimmeridgian Limestones in the Balcombe-1 well, originally drilled by Conoco, in the centre of the basin, which suggested the presence of a second, less mature, source. As Chris says, "The unconventional industry in the US had breathed new life into the UK onshore. We realised that the Kimmeridgian Clays might not just be sourcing the overlying Portland Sandstone, but also a new, unexplored play: the interbedded and stacked Kimmeridgian Limestones. We needed to map out the extent of the mature Kimmeridgian Clays as well as the interbedded limestones, known as the Micrites."

Horse Hill Rears Up

Magellan invested in more blocks in subsequent licensing rounds and by 2010 had a large acreage position in the Weald Basin. One prospect the company started looking at closely was Horse Hill, a tilted horst block prospect in PEDL137, which lies on the northern edge of the basin, close to Gatwick Airport. A previous well on the block, Collingdean Farm, drilled in 1967, encountered 'good oil shows' in the Jurassic reservoirs and was even tested but did not flow. However, seismic reprocessing suggested that the well was off-structure, on the downthrown side of the major bounding fault.

"By 2013, Magellan was ready to drill a new well on the upthrown side of the fault. The prospect was farmed-out to Angus Energy Ltd., who later created Horse Hill Developments Ltd with multiple consortium partners in order to fund the exploration drilling, and who became the operator," continues Chris. "The well was completed in November 2014 and encountered several hydrocarbon-bearing horizons, including the Portland Sandstone and the Kimmeridge Limestone. Earlier this year, very successful flow testing was carried out on these horizons and light



South–north composite interpreted seismic through the Weald Basin, modified from M. Butler and R. Jamieson, 2013. For line of section see map on p27.

sweet oil was produced from both reservoirs at high rates. This is particularly exciting, as it indicates that the Kimmeridge micrites are naturally fractured."

Along with the new vitrinite reflectance data, the test results have redefined the limit of the maturity of the Kimmeridge source, suggesting that it is mature over a greater area than previously expected, possibly up to the northern bounding fault, thus considerably expanding the overall potential of the Basin.

A Large Resource

Public interest in the Horse Hill well was high, partly spurred by an incorrect belief that the well would be fracked, although this was never planned and the tests all took place above the UK fracking ceiling of 1,000m. There was additional interest when the results of technical studies of the well carried out by Nutech and Schlumberger were released, which suggested large estimates of oil in place. This led to a media frenzy about the somewhat inaccurately named 'Gatwick Gusher' and the millions of barrels of oil underlying the protected 'Green Belt' areas of the Weald.

"There is a very large potential resource here, but it is far too soon to make any realistic estimate of its size and how much of it can be recovered," Chris says. "We need more data and a lot more fundamental analysis needs to be done, particularly so we can gain a much greater understanding of the hydrocarbon trapping; all wells so far have been drilled on structural highs, for example, so we need to prove that a stratigraphic trapping mechanism is effective. We also need to test long term and also look at several other horizons, before we can have a reliable idea of the size of recoverable reserves.

"The potential of the Kimmeridge is particularly exciting; we don't have any good core from the section, as previously we just drilled through it to look at the deeper horizons. More work needs to be done on the geochemistry of the clays to analyse their oil potential and maturity. The centre of the basin is underexplored and we have yet to fully understand the level of uplift it has undergone during the Tertiary and the amount of resulting deformation. Also, the conventional Triassic gas play could be very significant, but needs a lot more data, work and analysis."

Unlocking the Potential

The Weald Basin is home to millions of people and environmentally very sensitive, with large swathes being protected from development, which adds an extra layer to the issues surrounding the exploitation of this potential resource. Gaining permission to drill a conventional well requires considerable time and financial resources, and the negative response from much of the UK population to the idea of fracking, particularly in environmentally sensitive areas, makes developing the resource underlying the Weald Basin a challenging activity – but Chris is optimistic: "The main risks are at the surface – I don't think exploring in the Weald Basin carries a high subsurface risk. At the moment there is a lot of uncertainty, but with further work we will be able to understand much more about the geology, the resource and ultimately the potential," he explains. "Several wells could be drilled in the near future and we are learning more all the time.

"For me, the most thrilling thing was realising that there are really interesting plays literally in my backyard and, with recent technological developments, developing these opportunities is possible. There are lots of undrilled structures and plays out there and I cannot wait to help unlock the potential of this area." ■

Drilling Horse Hill in September 2016.

The Yanks Are Coming

As Britain fought for its survival during World War II, a team of American oil drillers found themselves on their way across the Atlantic to help the war effort. They became known as the roughnecks of Sherwood Forest.

BRUCE BLANCHE

During the dark days of WWII, when Britain stood alone against the Nazi regime, there was a dire need to increase oil production from indigenous hydrocarbon resources. By 1942, the strategic importance of discovering more oil in the UK was becoming critical. In fact, by August 1942, Britain's oil stocks had fallen below safety reserves and the requirement to discover and produce additional oil was of paramount importance to the survival of the United Kingdom and its ability to continue the war.

In July 1941, Geoffrey Lloyd, Britain's Secretary of Petroleum, wrote to the oil companies in the UK highlighting the need to discover and produce more oil, saying, "In the present emergency, every tonne of oil produced in this country is a direct contribution to the national war effort." He also commented: "It is felt that an output of at least 100,000 tonnes per year of British petroleum is a target at which our most vigorous endeavour should be aimed."

According to the official history of the US Petroleum Administration for War (PAW), during the first seven months of 1941 a total of 681 vessels, including a large proportion of US and British oil tankers, had been sunk, and by the autumn of 1942, German U-boats were sinking 700,000 tonnes of shipping per month. In 1943, 65% of the total tonnage of overseas shipping consisted of petroleum products; it was becoming increasingly important that some supply was found that the U-boats could not sink.

The deepest well to be drilled at Dukes Wood was No. 146 to a depth of 2,328m. Pictured are members of the drilling team involved in this achievement.

Dukes Wood Oil Museum via BP

A Secret Oil Field

In August 1942, Geoffrey Lloyd called an emergency meeting in London of the Oil Control Board with members of the oil industry's advisory committee. The subject was the impending oil supply crisis. The Admiralty had reported fuel stocks were two million barrels below safety reserves and were sufficient to meet only two months requirement. Reserves of approximately five million barrels were normally held in some 40 widely scattered storage facilities. Bombing raids in dockland areas had destroyed almost a million barrels.

Philip Southwell was at the Oil Control Board meeting. He was a representative of the D'Arcy Oil Company, and he had a secret – and that secret lay underneath Sherwood Forest, in Nottinghamshire in central England: potential oil fields, located inland, in a heavily wooded area safe from inquisitive eyes and which could be easily camouflaged from the attentions of the Luftwaffe. The challenge was to drill and produce from the oil reserves at these fields at Dukes Wood and Eakring as rapidly as possible.

But how was this to be achieved? Manpower and equipment were in short supply during the early war years. Vital supplies of fuel needed for the war effort had to be shipped through the dangerous U-boat infested waters surrounding the British Isles. What was clearly needed was new equipment and the necessary expertise to use this equipment efficiently.

The main problem with existing equipment was its age, weight and difficulty in being manoeuvred between locations. The need for lighter, easily transported drilling units, with experienced crews, was paramount if the number of wells to be drilled to meet target production levels was to be achieved. Southwell suggested going to America for equipment. This was agreed, particularly as he thought that an additional 100 wells could quadruple production (Roberts, 2009).

Experienced Drillers and Roughnecks

Under strictest secrecy, Southwell flew to the US In September 1942 to meet with Don Knowlton, the Deputy Administrator responsible for the US PAW. Lease-lend was considered but would take too long to set up and it was finally agreed that a drilling contractor, based in the US, could be employed by D'Arcy Exploration to operate in the UK and that the contractor could purchase the necessary equipment to bring to the UK. Contact was made with the Noble Drilling Corporation and the Fain-Porter Drilling Company, both of Oklahoma. These companies agreed to the contractual arrangements with D'Arcy and also agreed to the purchase and supply of drilling units and equipment. Both companies agreed to not receive any profit after re-imbursement of expenses.

In February 1943, 42 experienced drillers and roughnecks and their equipment and two toolpushers, Eugene Rosser and Don Walker, arrived in the UK from the US in two groups on the *RMS Stirling Castle* and *HMS Queen Elizabeth*. They had been told that they would be working under austere wartime conditions and subject to strict censorship and absolute secrecy. They were accommodated at Kelham Hall, a former monastery which was secret, secure and in the vicinity of Dukes Wood.

In March their four American jack-knife rigs and other drilling equipment started to arrive, the rigs having been shipped in separate vessels. Only three rigs made it – the ship carrying the fourth was attacked and sunk by a German submarine. Later, a replacement was sent over and arrived safely (Woodward and Woodward, 1973).

The more modern American methods led to great improvements in drilling efficiency and resultant costs. The American drilling equipment employed consisted of a 'state of the art' drilling unit and jack-knife 87 ft (26m) mast, the whole being designed for maximum mobility, often employing skids to avoid dismantling, and for a drilling depth of 5,000 ft (1,524m). With the old-type heavy exploration equipment, the time to transfer drilling equipment from site to site had been about two weeks, but by using this special mast, in combination with utilised draw-works, this was reduced in good weather to about 12 hours. At Eakring a record move of six and a half hours was made and on one occasion an outfit was transferred to a new site and drilled 650 ft (200m) in a mere 24 hours.

During their 365 drilling days in Sherwood Forest, the American volunteers managed to drill 106 wells in the Eakring and Dukes Wood fields, of which 94 were new producers (Johns, 1999).

With their contract up, the crews sailed from Glasgow on *HMS Mauretania II* on 3 March 1944. D'Arcy continued to produce oil from Eakring and Dukes Wood to a total of 300,000 tonnes of oil (2.25 MMbo) by the end of the war, via 170 'nodding donkeys' spaced every 10,000 m^2.

The 42 American drillers and roughnecks. (Part of the Guy Woodward Collection, American Heritage Center, University of Wyoming.)

Small but High Quality

Eakring must have been one of the best kept wartime secrets, for it was not until April 1944 that the veil was officially lifted by the government, having been prompted to act by an 'exclusive' report on the oil discovery in a national newspaper. Geoffrey Lloyd and the then BP Chairman Sir William Fraser, later to become Lord Strathalmond, hosted a visit by Fleet Street journalists to the operations centre at Eakring.

Kelham Hall, where the American oilmen were stationed, is a stately home built in the mid-1800s, which later became a monastery.

Commemorating the Drillers

In March 1991, a statue, called *The Oil Patch Warrior,* was unveiled in Dukes Wood by the Rt. Hon. John Wakeham, MP, Secretary of State for Energy, to commemorate the contribution of the American Volunteer drillers during WWII. At the commemoration ceremony, 16 Oklahoma-based survivors of the original drillers and roughnecks were in attendance. A duplicate of the statue was built in Ardmore, Oklahoma, ten years later, so two identical bronze statues separated by the Atlantic Ocean now commemorate the achievements of World War II American roughnecks.

After vandalism in 2012 by metal poachers, the bronze statue in Dukes Wood was moved to a safer, new home at Rufford Abbey Country Park, 10 miles away, and repaired – a new statue was commissioned for Dukes Wood, this time made out of stainless steel and resin, less attractive to thieves. Two of the 'roughnecks' were on hand for its unveiling in May 2014.

Surviving 'roughnecks' who made the trip to England for the commemoration ceremony in 1991.

***The Oil Patch Warrior:** The bronze statue originally in Dukes Wood, now at Rufford Abbey Country Park (above), its duplicate in Ardmore, Oklahoma (top right), and the new stainless steel and resin replacement statue in Dukes Wood today.*

Mr Lloyd commented: "This oilfield, like Britain, is small but of the highest quality; it yields a whole range of refinery petroleum products. This oilfield came into operation just when we needed every barrel of oil to carry this country through the crisis of the war. These were supplies that the U-boats could never sink."

These fields established a new oil province in the East Midlands Plateau Basin and the Gainsborough Trough.

Oil from Eakring and Dukes Wood was indeed of very high quality and superior to Middle Eastern oil. After it was refined it was found to be particularly suited to the Rolls Royce Merlin Engine, the engine extensively used by most of the Royal Air Force's high performance fighters and bombers.

Thus it was that Dukes Wood and Eakring, along with a contingent of US drillers, made a significant contribution to Britain's war effort.

Acknowledgements

The author would like to acknowledge the following organisations and individuals: Kevin Popham and the Dukes Wood Oil Museum; American Oil and Gas Historical Society, Washington DC, USA; Mrs Janet Roberts for permission to quote from Oil Under Sherwood Forest; Mrs Jean Blanche for her valuable support and patience.

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http://www.dukeswoodoilmuseum.co.uk/museum.htm.

http://aoghs.org/

One of the wellheads which has been preserved at Dukes Wood.

West of Shetland

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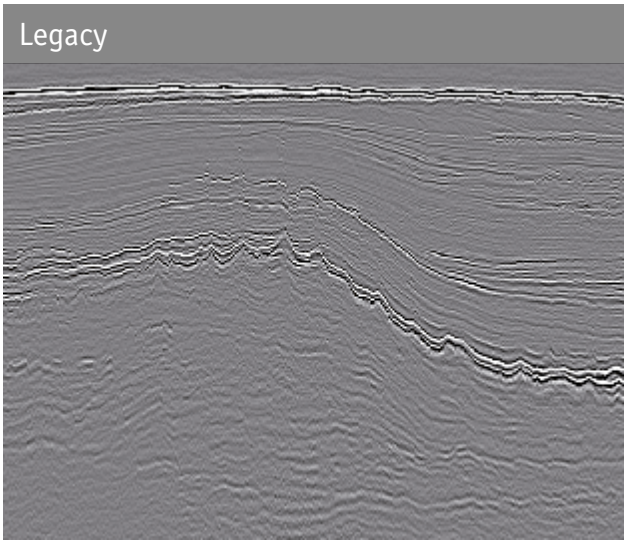

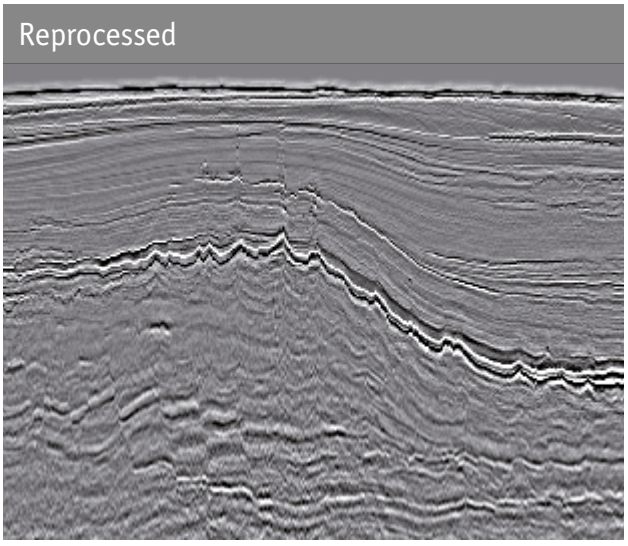

Comparison of the legacy and reprocessed data, showing improved clarity and resolution in the new data.

CGG has just reprocessed the Judd Basin 3D survey, West of Shetland, with the latest bandwidth extension and demultiple technology to deliver a state-of-the-art pre-stack time-migrated dataset to identify the remaining subtle Tertiary traps.

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Exploring Rockall
A Renaissance or a Dark Age?

The increasing maturity of the North Sea is forcing explorers west, towards the frontier Northern Atlantic Margin in search of the next oil province. In response, both the Irish and UK governments have made the Rockall Basin available for licensing in the recent 2015 Atlantic Ireland Licensing Round and the ongoing UK 29th Frontier Licensing Round. Does this herald a renaissance or will a dark age prevail?

CATHERINE CAULFIELD,
HANNON WESTWOOD

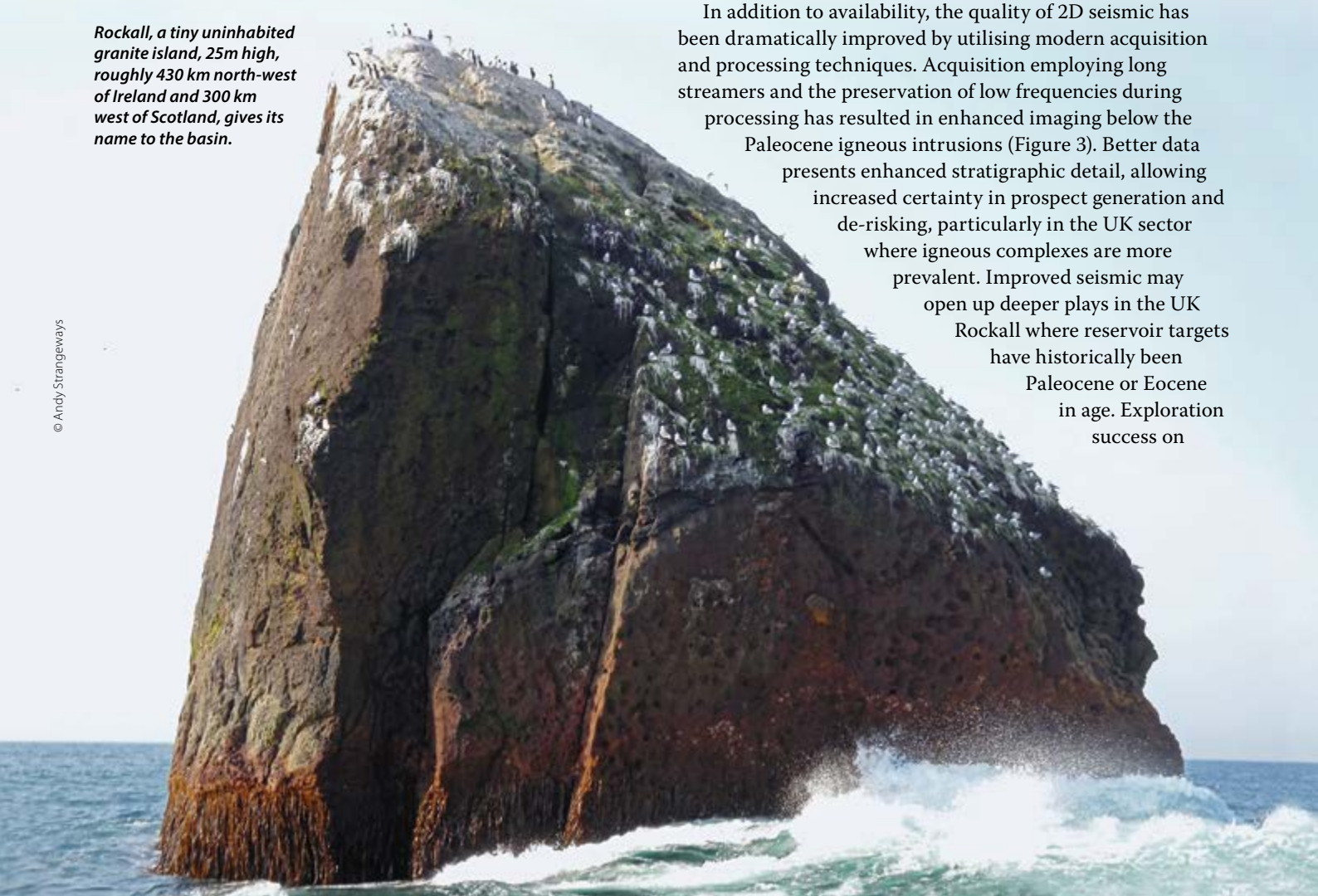
The Rockall Basin trends north-east to south-west, extending across the Irish and UK sectors of the North Atlantic Margin. Rockall is a failed rift of Mesozoic age approximately 1,200 km long by 300–400 km wide, located 100–500 km from landfall in water depths of 400–3,000m (Figure 1).

Difficulties arising from distance to landfall, deep water, harsh weather conditions, lack of infrastructure and intrusion-related seismic distortion have deterred exploration. The combination of historically poor seismic quality and coverage in addition to a lack of well control has resulted in a poor understanding of the structure and sedimentary fill of the basin. Such obstacles result in both high exploration and development costs and large uncertainty, resulting in high risk, all of which discourages explorers.

What has Changed in Recent Years?

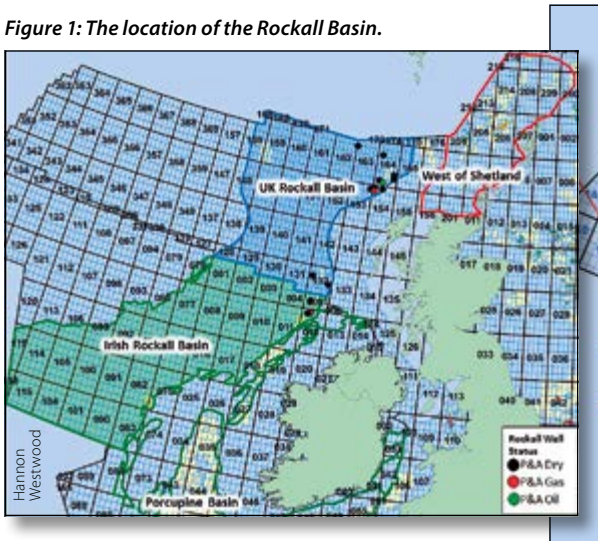
The increasing maturity of the North Sea is forcing explorers west, towards the frontier Northern Atlantic Margin, in search of the next oil province. In response, both the Irish and UK governments have made the Rockall Basin available for licensing in the recent 2015 Atlantic Ireland Licensing Round and the ongoing UK 29th Frontier Licensing Round. In an effort to encourage bids both governments provided subsidised 2D seismic prior to the application deadline, allowing interested parties a glimpse at what Rockall could offer (Figure 2).

In addition to availability, the quality of 2D seismic has been dramatically improved by utilising modern acquisition and processing techniques. Acquisition employing long streamers and the preservation of low frequencies during processing has resulted in enhanced imaging below the Paleocene igneous intrusions (Figure 3). Better data presents enhanced stratigraphic detail, allowing increased certainty in prospect generation and de-risking, particularly in the UK sector where igneous complexes are more prevalent. Improved seismic may open up deeper plays in the UK Rockall where reservoir targets have historically been Paleocene or Eocene in age. Exploration success on



Rockall, a tiny uninhabited granite island, 25m high, roughly 430 km north-west of Ireland and 300 km west of Scotland, gives its name to the basin.

Figure 1: The location of the Rockall Basin.



the Canadian Atlantic Margin has also piqued interest in the Irish conjugate.

Exploration Success on the Conjugate Margin

The Flemish Pass Basin on the Canadian Conjugate is a rift margin of similar age to the Rockall Basin where exploration has had commercial success. It is situated 500 km east of St. Johns in water depths of 1,100m.

Since 2003, a total of 13 wells, ten exploration and three appraisal, have spudded in the Flemish Pass (Figure 4). The wells targeted structural traps with Upper Jurassic and Lower Cretaceous reservoirs, charged by Kimmeridgian source rock and capped by Berriasian shales. Twelve of these – nine exploration and the three appraisal wells – have targeted the Upper Jurassic and four of the exploration wells are considered to have made commercial discoveries, equating to a commercial success rate of 44% for the basin: Baccalieu (Lower Cretaceous); Mizzen, Bay du Nord, Harpoon and Bay de Verde (Jurassic) (REP 2016). Post-appraisal estimates of 300–600 MMboe for Bay du Nord and tie-backs have reduced the initial discovery reserves shown in Figure 5. However, results remain encouraging and the Flemish Pass Basin is set to become an important producing area for Statoil post-2020.

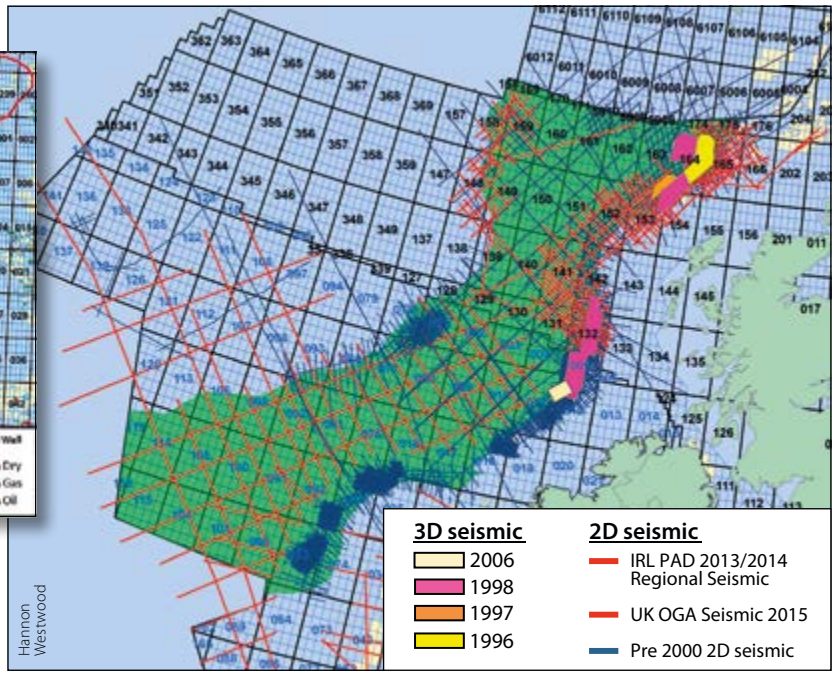


Figure 2: Location of modern and vintage seismic in Irish and UK Rockall Basin.

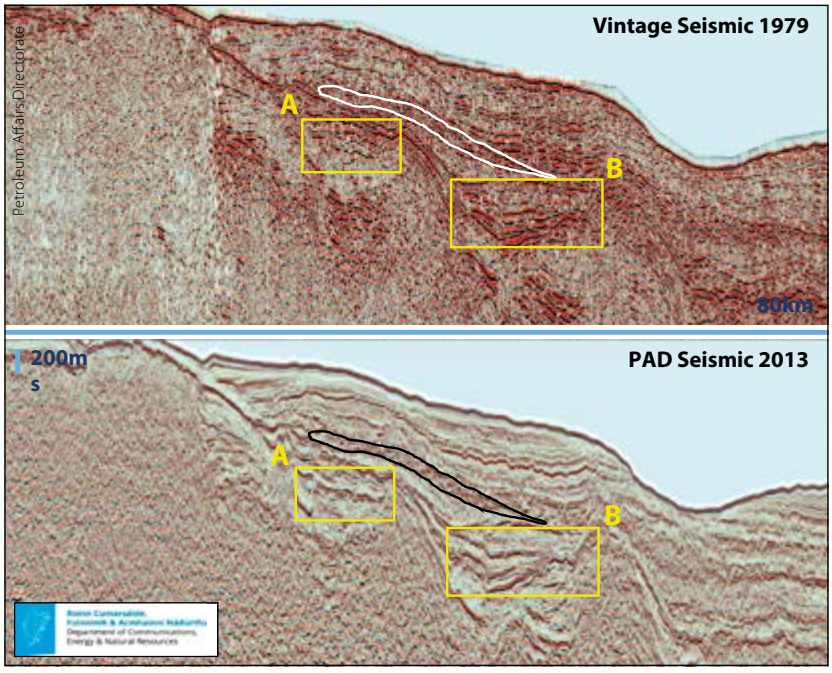


Figure 3: Modern vs. vintage seismic comparison in the Irish Rockall Basin. Improved sub-basalt imaging can be seen on modern seismic in both Basin A (20 km) and Basin B (30 km).

The question remains whether exploration targeting similar Jurassic and Cretaceous plays in the Rockall Basin could have greater or equal success. Seismic data over the Flemish Pass (Figure 6a) demonstrates a similar horst and graben structure to the section across the UK Rockall Basin (Figure 6b). Both basins contain thick Cretaceous sequences, but to date, only one commercial discovery has been made in the Cretaceous of the Flemish Pass. While five wells in the UK Rockall penetrated the Cretaceous, the only discovery made there was in the Paleocene with well 154/1-1, which discovered an estimated 487 Bcf (87 MMboe) at Benbecula. The majority of the oil discovered in the Flemish Pass is in the Jurassic succession (Figure 5). The Dooish discovery in the Irish sector found a 200m gas-condensate column in Jurassic and Permian sandstones with a resource estimate of 293 Bcf (52 MMboe) but the structure was not filled to spill.

Kimmeridge Clay is considered to have been deposited between Ireland and Canada during Mesozoic rifting and is the proven source rock in the Flemish Pass Basin. A Carboniferous source may also be viable in the Rockall; however, source rock distribution, quality and maturity is not fully understood. The UK Rockall section highlights widespread igneous intrusion into the Cretaceous stratigraphy which are commonly considered to act as barriers to migration and reservoir compartmentalisation. However, research by Schofield et al.

suggests that igneous intrusions may act as migration pathways and could form a key element of petroleum systems in this region. Conversely, the Flemish Pass has no intrusive features, potentially highlighting some differences in crustal thickness and both structural and thermal history.

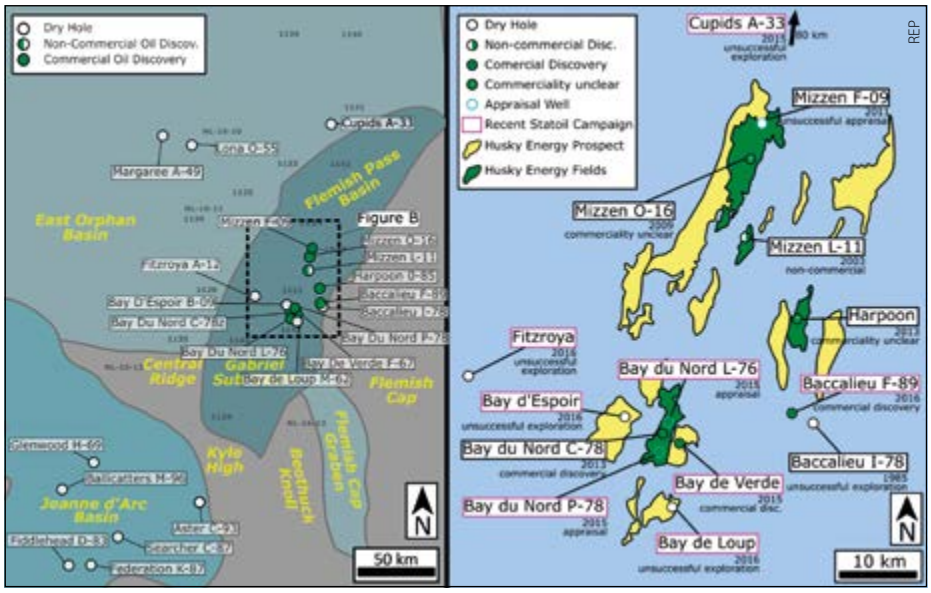


Figure 4: Location of the Flemish Pass Basin and commercial discoveries.

Benchmarking a Rockall Commercial Development

The development of discoveries in regions with adverse operational conditions requires a large resource base in order to warrant high CAPEX and OPEX. To develop a benchmark for the minimum economic reserve size required for development in the Rockall, Hannon Westwood used the Rosebank Discovery as an analogue development scenario. Rosebank is situated 140 km west of Shetland in water depths of 1,100m, making it comparable to Rockall. The Paleocene reservoir is estimated to contain 256 MMbbls oil and 347 Bcf gas (314 MMboe). Plans for its development include a new-build FPSO for oil separation, processing and export in conjunction with a ~250 km gas pipeline connection to the nearest export infrastructure. The development has not yet been approved but cost estimates are currently in the region of $8–10 billion but historically had reached $12.5 billion.

All fixed data were taken from the Rosebank development scenario, including UK fiscal system inputs (Figure 7). This should be taken into account when considering Irish Rockall prospectivity, which is subject to a different fiscal regime. Full field economics were run based on two variables of resource volume (300–1,000 MMboe) and CAPEX ($7/10/15 billion).

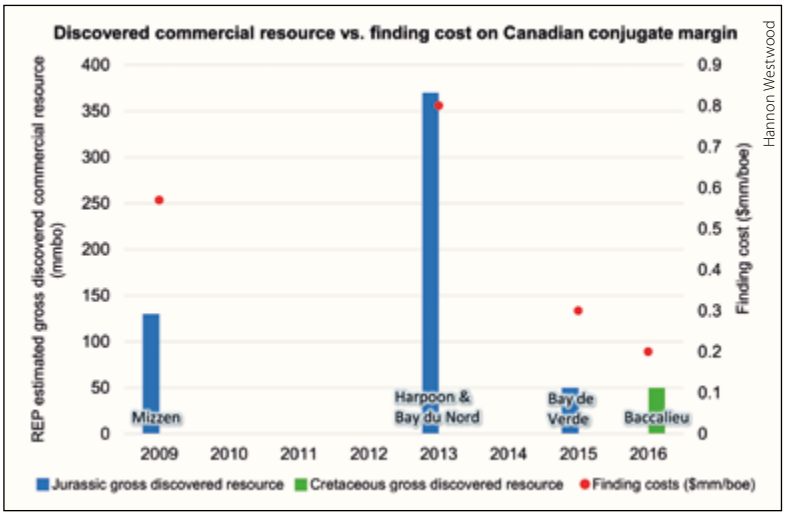


Figure 5: Discovered commercial resource per year and finding cost comparison.

Results show the reserve size that is required to bring a discovery to production utilising a low, mid and high case CAPEX under various commodity prices. Assuming an oil price of $60/barrel and a development cost of $15 billion, prospects of less than 1 Bboe unrisked resource barely break even, indicating that they cannot be commercially developed. At a mid-case development cost of $10 billion, about 650 MMboe resource breaks even, while at $7 billion CAPEX, reserves as low as 450 MMboe do. However at an oil price of $40/boe only the low CAPEX development can break even at reserves in excess of 800 MMboe. The analysis highlights the impact of high CAPEX on a project's breakeven oil price, a key factor in the decision to spud an exploration well.

Hannon Westwood holds an inventory of Rockall Basin prospects with unrisked resource estimates that lie within the graphed volume range. The UK Rockall has one 560 MMboe prospect and a further two that exceed 1 Bboe in the Paleocene. The Irish sector has 12 prospects that range between 300–1,000 MMboe, targeting primarily Jurassic and Triassic-aged reservoirs. If the lowest development cost of $7 billion is assumed and the 44% chance of commercial success from Flemish Pass is applied, prospects or potential clusters with an unrisked resource estimate less than 1 Bboe should not be targeted. This whittles the Rockall prospect pool down to three viable prospects, one in the Irish sector and two in the UK sector.

Europa Oil and Gas recently identified 300–600 MMboe of unrisked resources on LO 16/22 (2015 Round), which is situated in the perched Padraig Basin on the eastern flank of the Irish Rockall. According to this breakeven analysis at mid-case development costs the higher end of the unrisked resource breaks even at $62/barrel. To achieve the 20% rate of return (ROR) necessary for attracting investment, an oil price of $98/barrel is required under the modelled scenario. This does not include additional prospectivity that may be found on the licence or future tie-back options that may be available pending commercial discovery in the South Porcupine. The analysis includes a tax break in the form of the UK investment allowance, something that is not currently available under the Irish fiscal regime, meaning that the economics presented are more positive than perhaps they would be in reality.

Renaissance or Dark Age?

The uptake of acreage in the Rockall Basin in the 2015 Atlantic Ireland Round was disappointing. Despite this, the entrance of global deepwater players Statoil, ExxonMobil, Eni, Woodside and Nexen in the South Porcupine is considered to be encouraging and if commercial reserves are discovered exploration efforts may expand into the Rockall Basin. Results from the UK 29th Round have yet to be announced and may attract players from the Canadian conjugate margin.

For Rockall to succeed, acreage uptake by an operator with deepwater experience and sufficient capital for 3D seismic acquisition followed by exploration drilling is required. A high impact commercial discovery made by a company that can afford to put the necessary infrastructure in place is essential to open up the basin.

Multi-million barrel discoveries made in the Flemish Pass are encouraging and successful plays can be traced across the Atlantic to the Rockall. Both margins require a large reserve base for commercial development and Hannon Westwood analysis suggests that under mid case CAPEX, in order to generate a 20% ROR in the UK sector, a reserve of 900 MMboe and an oil price of $69/barrel is necessary. The Irish sector potentially requires an even larger critical volume as a consequence of differences in tax regimes.

Improved seismic imaging of the Rockall Basin will provide the key to understanding its structure and stratigraphy and may unlock prospectivity. It represents the first step in the progression from exploration in a frontier area to commercial discovery. Drilling costs have reduced by up to 50%, allowing for lower cost deepwater exploration drilling. Companies with free cash flow have the opportunity to firm up reserves in advance of a commodity price rise.

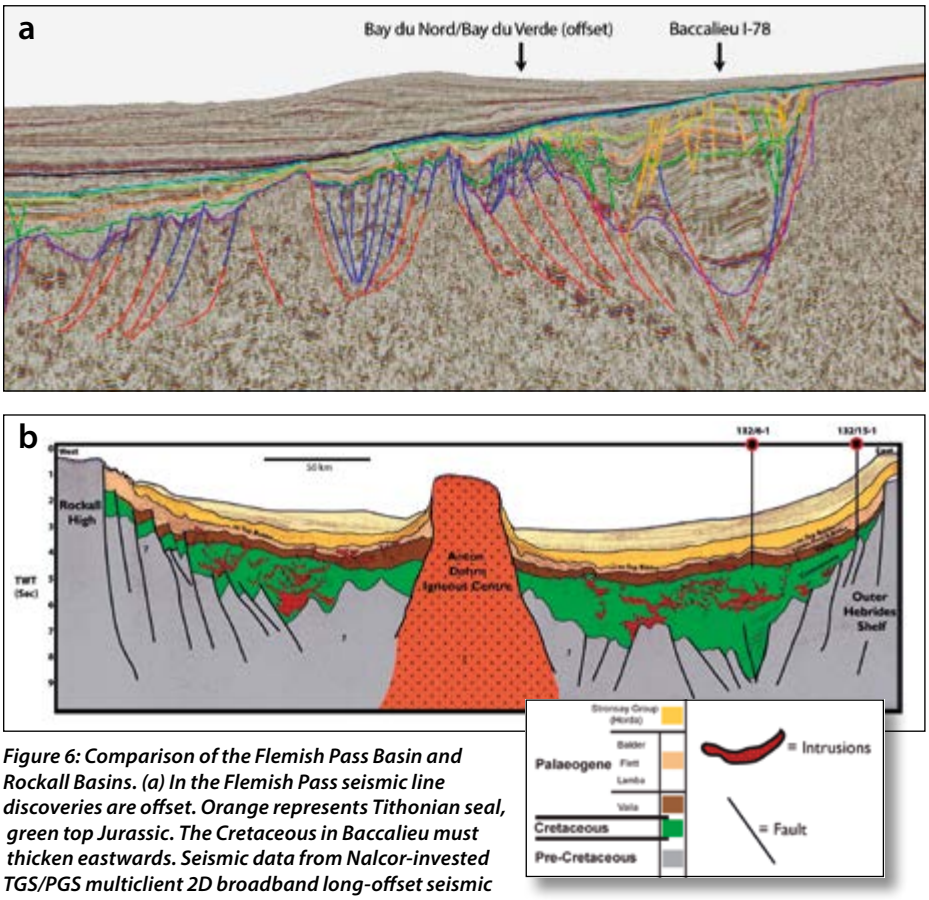
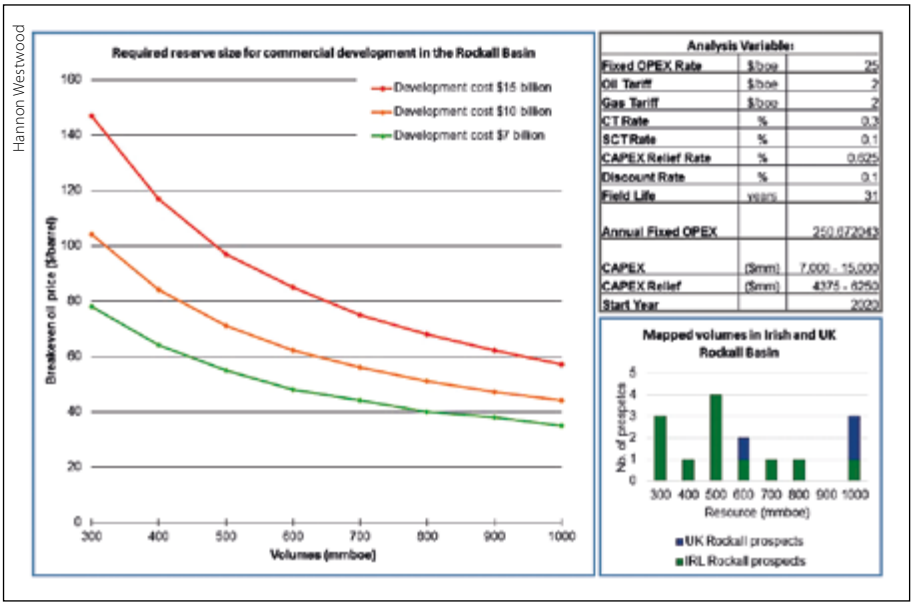


Figure 6: Comparison of the Flemish Pass Basin and Rockall Basins. (a) In the Flemish Pass seismic line discoveries are offset. Orange represents Tithonian seal, green top Jurassic. The Cretaceous in Baccalieu must thicken eastwards. Seismic data from Nalcor-invested TGS/PGS multiclient 2D broadband long-offset seismic programme offshore Newfoundland (2012-2014). (b) The Rockall Basin from Schofield et al. (submitted – Petroleum Geology Conference Series, Challenges of Future Exploration within the UK Rockall).

Figure 7: Experiment to determine reserve size required for commercial discovery in the Rockall Basin and resource volumes for identified prospects.



The future of the Rockall is dependent on the success of the South Porcupine and the results of the UK 29th Round. Commercial discoveries that may be made in the Rockall Basin on the back of the 2015/2016 licensing rounds will have a long lead time to both drill and develop and much could happen in the interim. However, exploration in frontier provinces is a long term game and we are unlikely to see any drilling in the Rockall before 2020 and the development of any reserves from the area in less than ten years after that. Oil price, costs and taxation cannot be accurately predicted and so frontier exploration on the North Atlantic Margin is currently the province of large integrated multi-nationals who can afford the cost and risk of such ventures in their portfolios. ■

Searching for Overlooked and Underexplored Frontiers

JANE WHALEY

As a founding partner of Kosmos Energy, Paul Dailly has been involved in some of the most exciting and significant discoveries of recent years. He tells us the story behind the building of this successful exploration company.

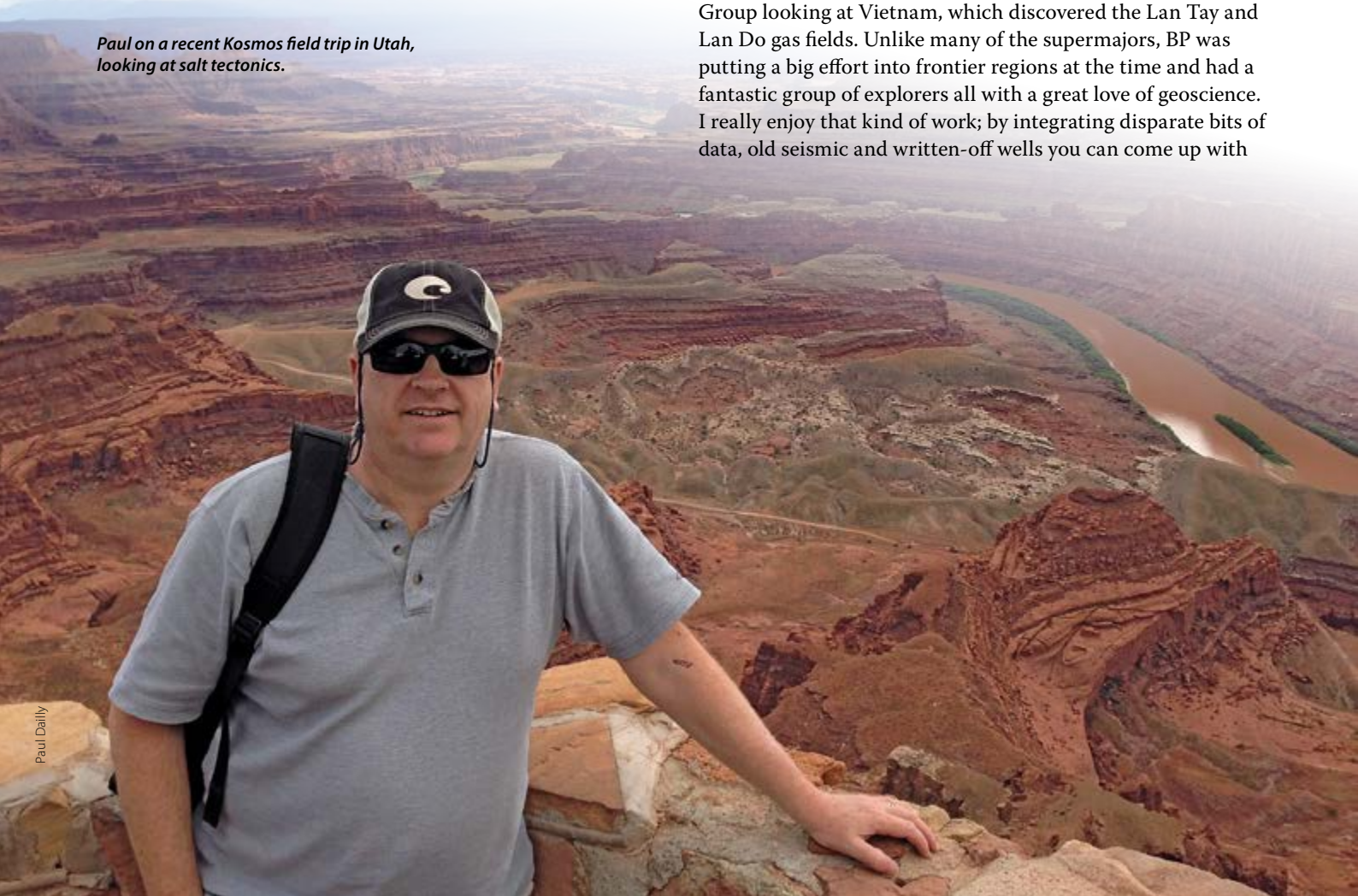
"The most exciting moment of my career thus far was when Kosmos drilled its very first well, Mahogany 1, in Ghana – and we discovered the Jubilee field!" says Paul. "It was a great feeling. What's more, we had initially planned for our first well to be in Benin, which came in dry when we eventually did drill it, so it turned out to be the right decision!"

Dr. Paul Dailly, Senior Vice President and Chief Geoscientist of Kosmos Energy, which he co-founded in 2004, is a veteran oil finder, with over 25 years in the business, much of it looking at frontier regions.

New Ideas and Concepts

Paul was first inspired by geology when growing up in his native Scotland. "I always loved being outdoors and enjoyed hiking and camping and going on expeditions with the Scouts," he says. "The only two things at school I was any good at were maths and geography, overall an odd combination of interests which eventually led me to geoscience being the thing I enjoyed most. I studied for my B.Sc. at Edinburgh; one of the main attractions of the degree course there was that we did so much fieldwork and saw a lot of rocks. I then embarked on a BP-sponsored Ph.D. based in Durham and Oxford, where John Dewey had started a basin evolution research school integrating tectonics and sedimentation, a very new and hot topic at the time. It was a great research environment with a lot of talented researchers. I studied Carboniferous and Permo-Triassic basin evolution in the Solway Basin in Scotland, combining oil industry data with a lot of fieldwork, which gave me early exposure to integrating apparently different datasets to make the whole greater than the sum of the parts.

"After that I joined BP as an exploration geologist and worked from the Glasgow office, spending my first few years offshore and then on the exploration and appraisal of the Mungo and Monan fields in the Central North Sea. I loved living there, mostly for the access to the fantastic countryside, but eventually moved to London to work on more frontier exploration regions. I did a lot of fieldwork in Russia and in the Andes and spent a number of years in the South East Asian Group looking at Vietnam, which discovered the Lan Tay and Lan Do gas fields. Unlike many of the supermajors, BP was putting a big effort into frontier regions at the time and had a fantastic group of explorers all with a great love of geoscience. I really enjoy that kind of work; by integrating disparate bits of data, old seismic and written-off wells you can come up with



Paul on a recent Kosmos field trip in Utah, looking at salt tectonics.

Paul Dailly

new ideas and concepts. It's very rewarding."

By the early 1990s Paul had itchy feet and was ready for a move. "I enjoyed working with BP, but there were not many foreign postings at that time and I wanted to go abroad, so I took a job as a geologist with Triton Energy and moved with my wife Chris to Dallas."

The NewYork Stock Exchange the day of the Kosmos IPO in 2011.

New Ventures

Triton, at the time one of the most successful independent E&P companies in the United States, had just discovered the huge Cusiana field in Colombia. "Triton were expanding fast," Paul explains. "The New Ventures team were picking up acreage in interesting areas in Indonesia, Madagascar, and China and also in Equatorial Guinea in West Africa, where we were looking at a new Cretaceous turbidite play which eventually resulted in the Ceiba and Okume discoveries in l999 and 2001."

These Equatorial Guinea discoveries spiked the interest of Amerada Hess (now Hess Corporation), who were looking to fast-track production from African fields. They bought Triton in 2001 and Paul moved with them to Houston to manage the Gulf of Mexico regional exploration team, but before long found himself back in Dallas with an exciting new venture: Kosmos Energy.

"Myself and a number of the ex-Triton management decided to form Kosmos and managed to get funding from two New York private equity houses: Warburg Pincus and Blackstone. It was a big leap for us to take: from solid careers with international companies to a small group of people starting from scratch. With me there were two other technical guys, Brian Maxted who is still the CXO, and Kenny Goh, and also Jim Musselman, who was CEO at the time, and Greg Dunlevy the CFO.

"Kosmos was one of the first private equity-backed 'boutique' international deepwater explorers; we were at the vanguard of this type of funding in the international E&P business," Paul continues. "The financiers had previously invested in US E&P companies but not in ones working internationally; however, our track record with Triton persuaded them to give us a chance, as it was essentially the same management and technical teams."

Looking for Opportunities

"Having got the team and the money in place, we went looking for opportunities – and saw plenty of exciting ones, particularly in Africa. Because of the sorts of prospects we were targeting there was not a great deal of competition from the oil majors, who were not doing much frontier exploring in the early 2000s but rather were focused on proven basins; it was good time for smaller companies like us to rapidly build a portfolio. Another important factor in establishing the company was the fact that many of the software applications we use, such as seismic interpretation systems, had fairly recently moved from mainframes and large operating systems to more manageable and affordable PC-based, off-the-shelf platforms. This helped level the playing field for a lot of small companies with more modest resources and allowed them to compete with much bigger organisations," Paul adds.

As he explains, through the 1990s most major E&P companies had focused on exploring the Tertiary deltas such as the Niger, Congo and Gulf of Mexico, and were concentrating on developing the resulting discoveries. A number of other play types, however, like the transform margins of Africa, had not seen much exploration in a number of years. Kosmos saw these big gaps in knowledge and activity as opportunities.

"We initially concentrated on the Gulf of Guinea and picked up acreage in Ghana, then Benin, Nigeria, Cameroon and Morocco," says Paul. "In 2007, three years after we signed the agreements with Ghana, our first well discovered the giant Jubilee field and opened a significant new hydrocarbon province, the Tano Basin."

Success at Jubilee was the result of the company's identification of the overlooked Upper Cretaceous structural-stratigraphic play concept along the transform margin of Africa. It turned out to be one of the largest finds of 2007 worldwide, and the biggest discovery of the entire decade offshore West Africa. Kosmos farmed out to Anadarko and Tullow to help fund the drilling of the discovery well and the partnership fast-tracked development of the field, with production starting up just three years later.

Good Acreage – and Good Ideas

"After Jubilee everyone wanted to move into Ghana and the transform margin and it became very expensive," Paul explains. "We decided to switch geography to North West Africa, which we considered to be just as overlooked and underexplored as the transform margin had been. In 2012 we took acreage in Mauritania, which a lot of companies had downgraded after the much-vaunted Chinguetti field proved to be more complicated than initially expected and many companies exited the country. We thought the

fundamentals of the geology still showed promise and in 2015 drilled the Tortue-1 well (later renamed Ahmeyim), which opened a new, giant hydrocarbon province in Cenomanian and Albian sands in combination traps. It was the industry's second largest discovery of the year and opened up the Greater Tortue gas area, which stretches south into Senegal.

"Tortue was typical of our strategy – we try to be counter-cyclical," he continues. "Firstly, it is always important that our investors are happy that we 'bet against the pack'. We maintain a small but very experienced technical group at the core of the company who can look in detail at all the prospects. Frontier opportunities can often initially have a 1 in 10 chance of success, but we have to see a pathway to reducing that risk down to a drillable 1 in 3 to 5. It's important that we continue to invest in new opportunities even at a low point in the cycle. Not many people are actively picking up acreage at the moment, which helps our longer term exploration strategy, but makes it tougher when we look for partners.


Paul Dailly

Paul, wife Chris and daughter Meagan in Iceland.

"At the moment we are continuing to grow our portfolio around the Atlantic margins. We have a position in Suriname, where we are exploring both structural and stratigraphic plays and will be shooting our second 3D survey soon and hope to drill over the next year or two. Another focus area is Portugal, where we acquired 3D last year. It's a country which has been off the exploration radar, and we believe that some ideas from West Africa can be applied to the North Atlantic, rather than North Sea analogies. We have also built up a big position in Sao Tome where no one has really explored for over a decade, and where again we plan to shoot a large 3D next year. In most of these areas we are focusing on Cretaceous structural/stratigraphic plays, many of which are conceptual and based on 2D with well-defined play elements but trap fairways that need new 3D for prospect definition."

Paul is justifiably proud of the Kosmos team, which has grown from about 20 people when Jubilee was discovered to over 180 now, most based in Dallas. The exploration group has about 30 people with a high percentage of geoscientists, bringing a broad range of experience but maintaining a small company, team-oriented culture.

"We typically operate through the exploration and appraisal phases and in the case of Jubilee were the development operator. However as a company we are less focused on operating at the production stage," Paul says. "This helps to keep the team relatively small, which we think is important in maintaining the company's strengths and culture. It means we can all focus on the most value-adding activities."

An Open Mind

I ask Paul what makes a good hydrocarbon explorer.

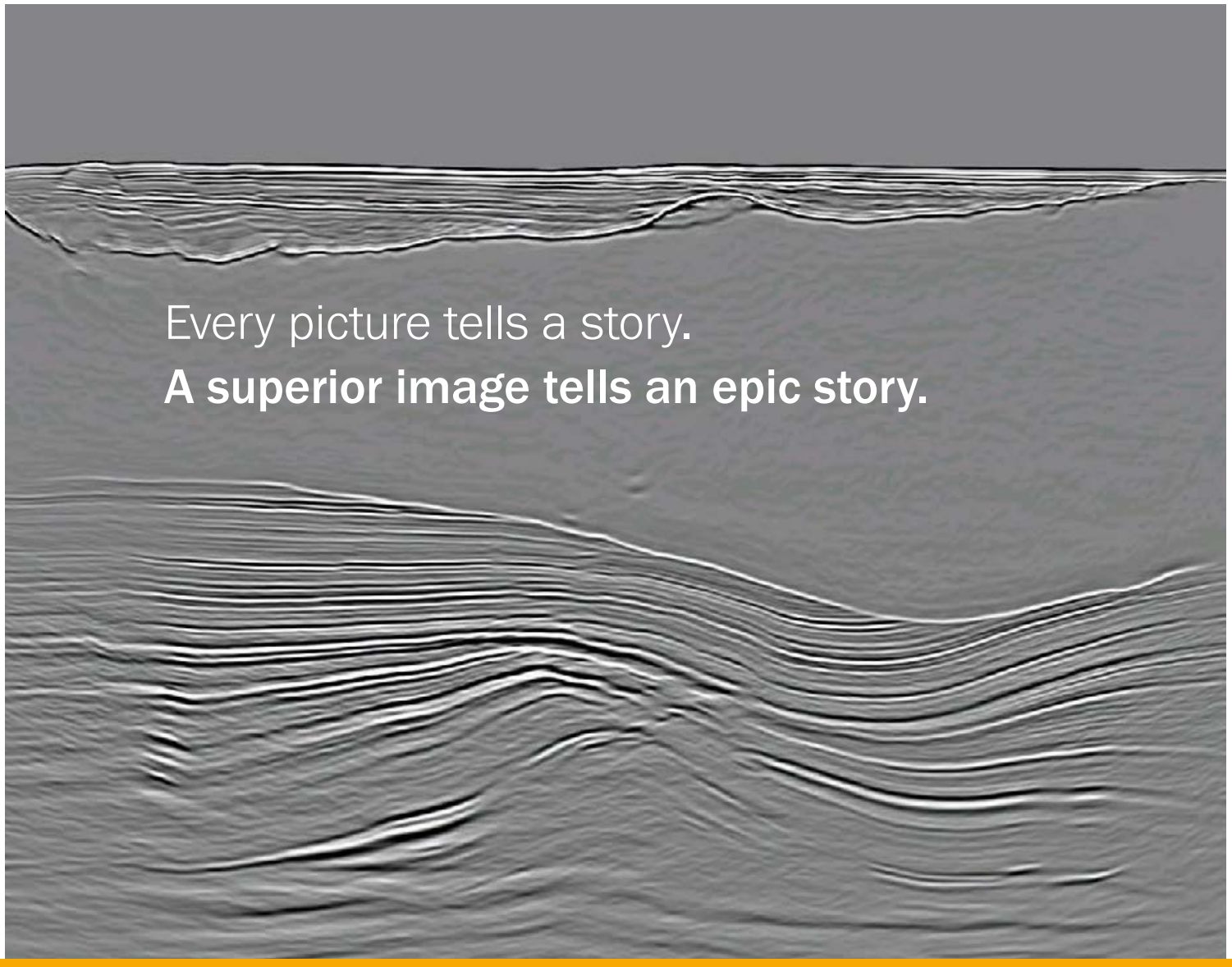
"An open mind is probably the most important thing, so you are not caught up in the conventional wisdom as to why some things have worked and others have failed. The ability to integrate technically is also vital. We see lots of high quality work done in isolation but which hasn't been sufficiently leveraged by integration to lower risk. This is partly an issue of company size – it's much easier to collaborate between disciplines in a smaller company, where everyone is co-located and where having cross-discipline conversations with smaller groups is a natural process. At the same time we believe you must be big enough to have the range of in-house technical expertise to compete.

"Focus and playing to your strengths is also very important; in Kosmos we are very geographically focused and try to avoid following the pack. We look for evidence of good petroleum system fundamentals but typically are not in basins with existing commercial fields. We find we have a three-year cycle from identifying a play to drilling it; frontier plays, especially obscure ones, frequently only have 2D seismic, so we arrange to shoot 3D as soon as possible after signing, to maximise the time available to enhance the data, define the play concept and lower the prospect risk. We frequently then bring in partners at the drilling stage. It's an approach which has worked well for us but it's important to constantly ensure the portfolio has sufficient petroleum system tests and the individual positions have large enough footprints to manage the play risk."

After 20 years in Texas, Paul recently moved back to Scotland, close to his home town of Dundee ("near the Highland Boundary Fault," as the geologist points out), partly to help his parents. However it is also easier for him to look after Kosmos' African new venture interests from Europe than from the US. He is enjoying being back, and particularly relishes the rural environment and the access to outdoor activities like hillwalking.

"The great thing about working with a small organisation is that despite getting so involved in the management and decision-making sides of the business, I continue to get a kick out of the geology. I still enjoy figuring out how a bunch of rocks comes together to make a play, and then doing whatever is needed to get the idea tested," Paul concludes.

Paul Dailly is clearly a man who enjoys what he does – and does it well. ■



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DATA ACQUISITION DATA PROCESSING DATA LICENSING

Finding More Gaveas in the Campos Basin and Beyond the Salt Domes…

The recent Gavea discovery is just the latest in a series of successful pre-salt discoveries in the Campos Basin, Brazil. Seismic imaging in the pre-salt section using careful depth migration is key to identifying undrilled analogous structures. Spectrum's 2D seismic dataset provides a tool to understand drilled structures in detail, as well as to extrapolate, locate and evaluate on-trend analogues. It offers a unique opportunity to visualise future potential play types beyond the salt dome province. A new acquisition programme currently being undertaken will help define the plays of the future, both under the salt domes and out into the clastics beyond the salt domes.

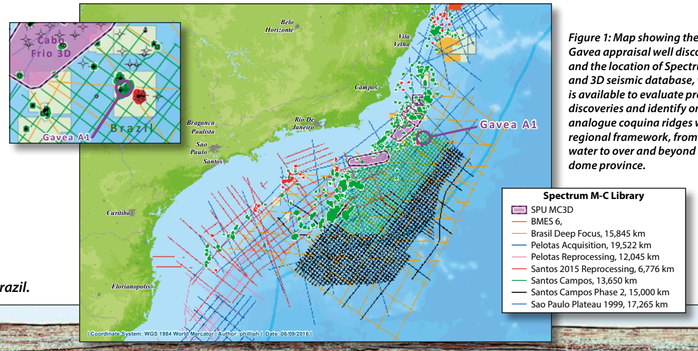
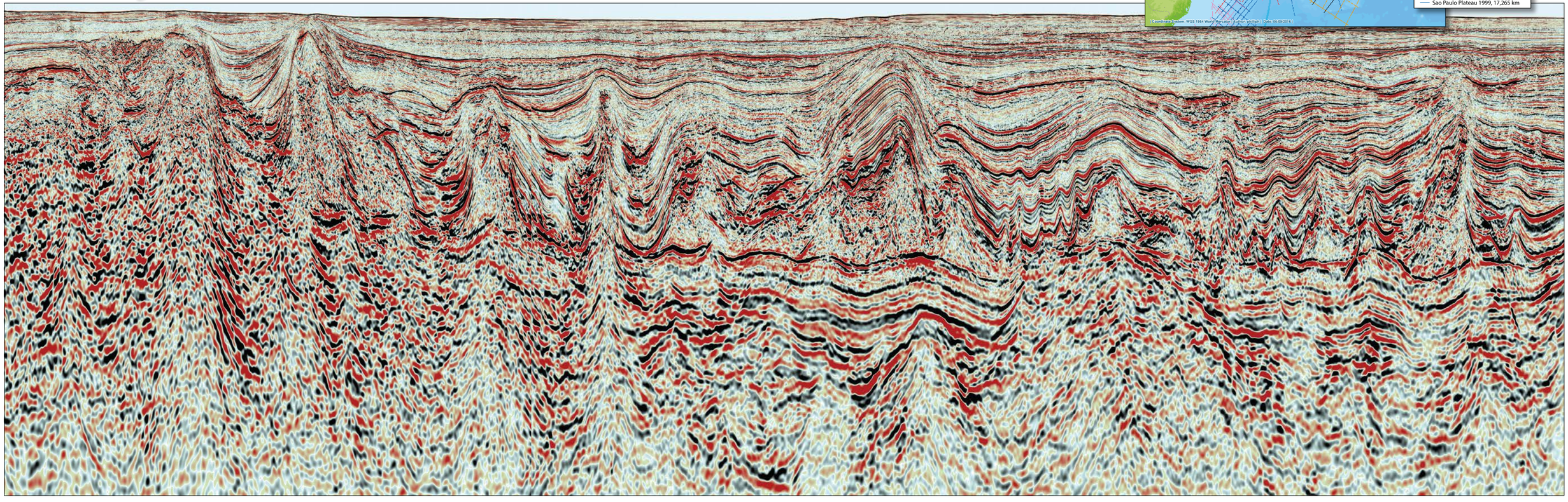


Figure 1: Map showing the latest Gavea appraisal well discovery and the location of Spectrum's 2D and 3D seismic database, which is available to evaluate pre-salt discoveries and identify on-trend analogue coquina ridges within a regional framework, from shallow water to over and beyond the salt dome province.

Below: PSDM (depth) seismic line through some recent pre-salt discoveries and analogous undrilled structures in the Campos Basin, Brazil.



A Complete Regional Picture

KARYNA RODRIGUEZ and NEIL HODGSON, Spectrum

First exploration efforts in the Campos Basin began in 1968. The giant Albacora and Marlim fields were found in the mid-1980s and by 2003, 41 oil and gas fields had been discovered in water depths between 80 and 2,400m. Today, this basin is one of the top producing basins in the world with over 1.7 MMboepd.

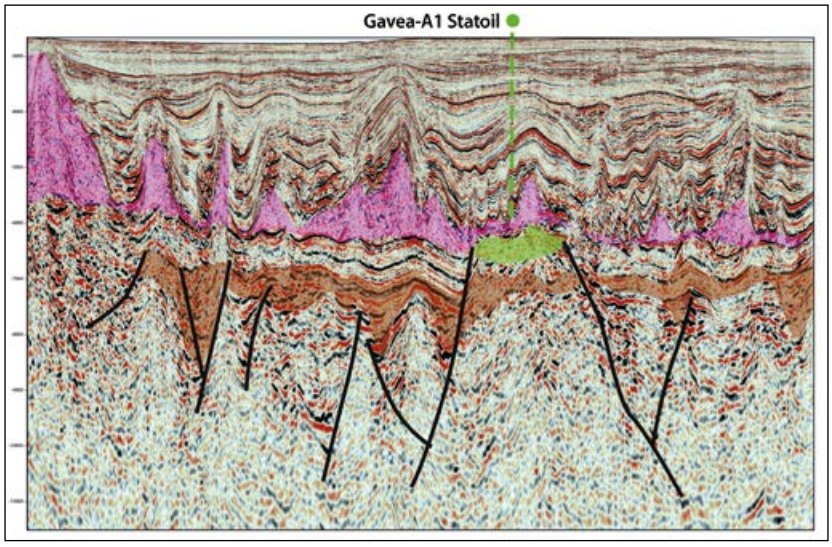
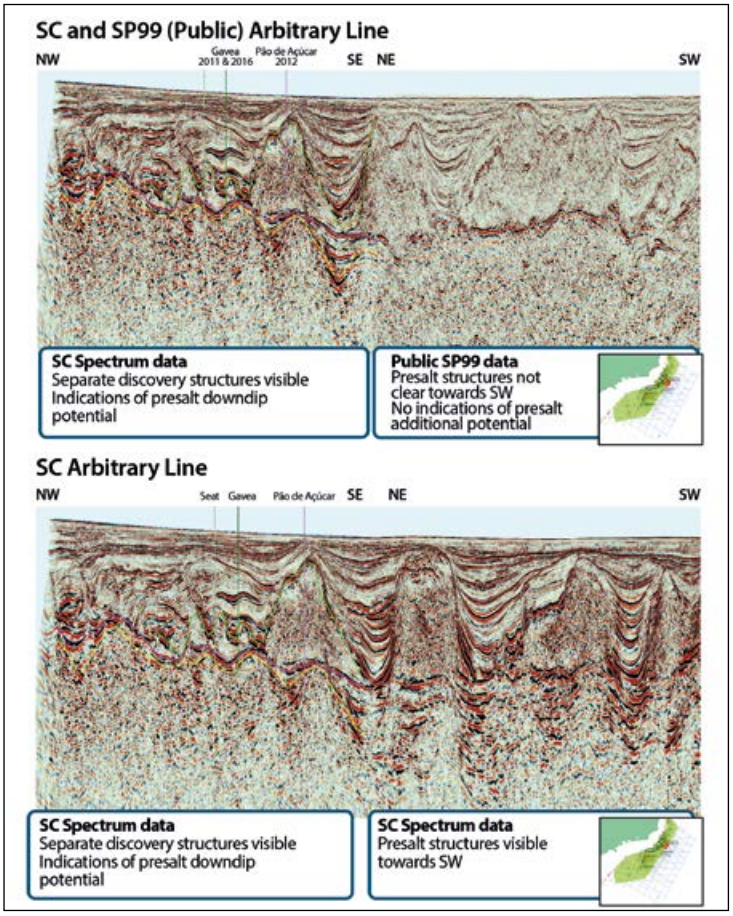


Figure 2: The 'perfect pre-salt play system' on Spectrum 2D PSDM in depth.

The recently discovered Seat, Gavea and Pão de Açúcar fields all lie within a Campos Basin block estimated to contain resources of more than 700 MMb of light oil and 3 Tcfg, as estimated by Subsea IQ. Pão de Açúcar was actually reported as one of the world's top five discoveries in 2012. The latest Gavea appraisal well (Figure 2) found a considerable 175m-thick oil column in a Macubu Formation pre-salt carbonate reservoir.

A recent Campos Basin prospectivity evaluation carried out by Spectrum has identified a significant number of untested pre-salt structures in open acreage, a very exciting prospect for any company looking to explore in this basin, as it is strongly rumoured that this area will be offered in the upcoming licensing round. Not only is large additional pre- and post-salt potential identified on available 2D and 3D datasets, but also potentially huge basin floor fans lying over mature Aptian source rock can be seen beyond the salt dome province on the only dataset available with coverage over this area.

Figure 3: Arbitrary lines illustrating the importance of using high quality seismic data to identify pre-salt leads. Note on the top figure how the pre-salt section is not imaged on publically available seismic data on the right, whereas a nearby high quality Spectrum line points to a series of potential pre-salt leads to the south-west.



Gavea and Untested Pre-salt Potential

There are three main proven play types within the syn-rift and post-rift sequences in the Campos Basin. These include the pre-salt rift play, baptised by Statoil as the 'Perfect Play System', with lacustrine enhanced reservoir quality microbial carbonates developed on basement highs created by faulting or volcanism. These are locally sourced from underlying lacustrine shales and sealed by thick evaporites, allowing for large accumulations which can be filled down to base salt spill (Figure 2). Post-rift proven plays include the Macae carbonate play and Cretaceous and Tertiary turbidite clastic plays draped over salt-induced extensional structures. These are sourced by the same syn-rift lacustrine shales, as the mature hydrocarbons can migrate to the post-rift sequence through salt withdrawal windows.

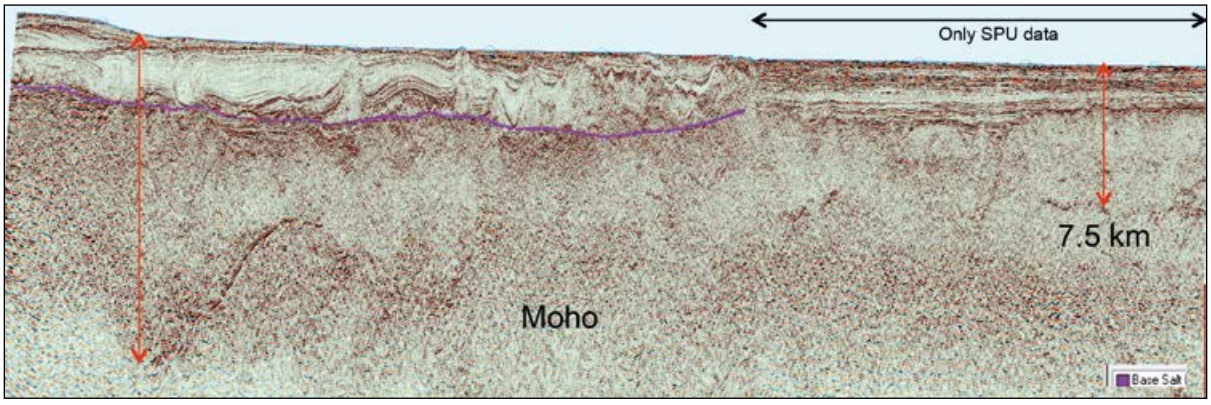


Figure 4: Regional deep focus data with unique deep imaging which extends beyond the salt dome province.

Using Spectrum seismic data it is possible to carry out a detailed analysis of the pre-salt discoveries to date (as shown by the seismic foldout example), and also to identify on-trend analogues and map a significant number of leads. These align in a series of south-west to north-east trending coquina ridges of similar size as, or larger than, the existing discoveries and, even more excitingly, they are located in open acreage. These leads are best identified on high quality PSDM seismic data (Figure 3).

Post-well Analysis

A post-well analysis of key wells with both pre- and post-salt targets showed very interesting and encouraging results. Post-salt wells have targeted carbonates, sandstones and calcarenites and have either been dry, found uncommercial hydrocarbon accumulations, or had oil accumulations with challenging compartmentalisation and low pressure conditions. One of the post-salt wells in the Campos Basin encountered thin effective oil thicknesses in the low permeability Campanian Carapebus Formation reservoir. What is exciting about these post-salt wells is actually deeper in the untested pre-salt, as the seismic data shows strong indications of pre-salt structures usually directly below the well.

A post-well review of key pre-salt wells is even more encouraging as not only are most associated with very significant discoveries, but also by reviewing their seismic characteristics a large number of undrilled analogue pre-salt structures can be mapped using the Spectrum 2D seismic grid.

Sneak Preview of Future Exploration Targets

The unique regional dataset available over the Campos Basin has the imaging quality needed to study pre-salt discoveries and leads in detail but, more importantly, it provides a unique dataset which allows a complete regional picture to be obtained, with the added bonus of revealing huge potential beyond the salt dome province.

The deep focus regional data images the Moho, allowing the interpretation of crustal architecture for improved understanding of heat flow and geothermal gradient, which in turn leads to more reliable maturity modelling (Figure 4).

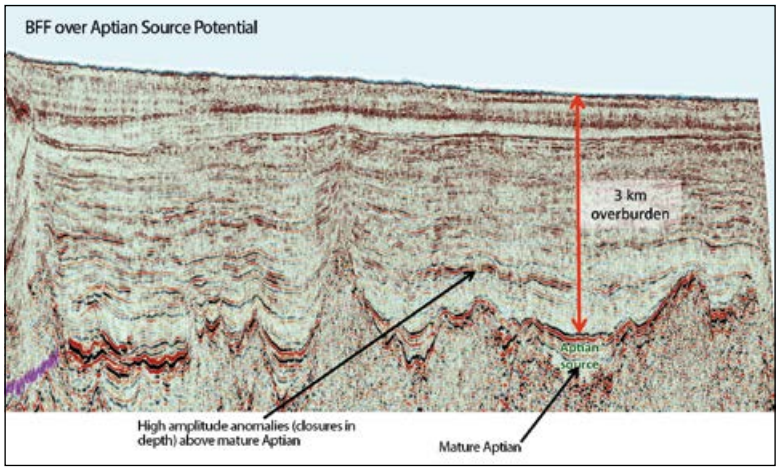
More importantly, however, a future huge potential play type is indicated beyond the salt dome province, where large structures containing basin floor fans with high amplitude anomalies overlie mature Aptian source rock. The presence of this source rock is inferred from the conjugate Gabon margin, where it is identified by the same low frequency, semi-transparent seismic character observed all along the southern Atlantic margin and repeated here in the Campos Basin. Basin modelling carried out in Gabon indicates that under similar conditions of burial depth, the Aptian source rock will be mature for oil (Figure 5).

Astonishing Promise

High quality seismic data is essential for both detailed and regional evaluation of proven pre-salt and post-salt plays, and indicates huge untested pre-salt potential in one of the most productive basins in the world. In addition, an ongoing acquisition programme aims to image below the salt dome province, where pre-salt structures similar to the main discoveries are indicated on existing data. And if that wasn't enough, the regional dataset provides an insight into future exploration targets in the form of basin floor fan structures over oil-mature Aptian source rock. The industry has just begun to realise the potential of the perfect pre-salt trapping hydrocarbon system.

In the third quarter of 2016 Spectrum will be acquiring a broadband long-streamer survey over the salt basin and out to the thick clastic sequence beyond the salt, where an abundance of high amplitude anomalies reveal a future oil domain of astonishing promise. ■

Figure 5: The seismic shows huge basin floor fan potential for future oil exploration in the Campos Basin.



Unlocking the UK North Sea's Hidden Wealth

What are the keys to revealing the remaining potential of the UK Lower Cretaceous?

HENRY MORRIS
Azinor Catalyst

The current very low level of exploration drilling in the UK North Sea should not signal that we are entering the final exploration phase. A popularly held view is that all the obvious sizeable structures have been drilled and the Paleocene has been largely exploited. So where are the widely accepted 'yet to find' resources hidden? Azinor Catalyst, a relatively new technology lead arrival, strongly believes that most of the remaining potential is probably to be found in the Lower Cretaceous and Upper Jurassic deepwater turbidite plays as well as the deeper Pre-Cretaceous high pressure/high temperature (HPHT) reservoirs.

For decades the potential of these Lower Cretaceous and Upper Jurassic deepwater turbidite sands has fascinated and intrigued geologists. Their proximity to mature world-class source rocks like the Kimmeridge Clay Formation, and proven trap and seal combinations (ultimate Chalk Group top seal), means that much of the geological risk remains primarily with finding effective reservoirs. Whilst the sands have been found and shown to work in a number of areas, they continue to prove elusive throughout much of the region.

Azinor Catalyst believe that their technical team of experts holds the key to unravelling the predicted potential of the Lower Cretaceous and Upper Jurassic deepwater plays. Through a regional understanding and the ability for large-scale interpretation, it is developing new geological and geophysical insights into the significant remaining potential of these exploration plays.

Past Results and Perspective

These deepwater turbidite plays often

The Britannia field, Central North Sea. With resources of 3-9 Bboe yet to be found, the sun is yet to set on the UKCS.

lend themselves to being a playground for structurally guided stratigraphic traps. Limited sediment supply results in the development of mini-basin 'fill and spill' depositional systems focused on the basin-axis, with turbiditic sands being deposited within hemipelagic shales. These geological models are proving themselves globally, particularly in Atlantic Margin settings; even within the UK North Sea a significant track record of exploration success has been established, with examples such as the Scapa, Goldeneye, Blake and Britannia fields in the Lower Cretaceous, and the likes of Buzzard, Golden Eagle and Brae in the Upper Jurassic. It should be noted that all of these fields have a significant stratigraphic trapping mechanism (Figure 1).

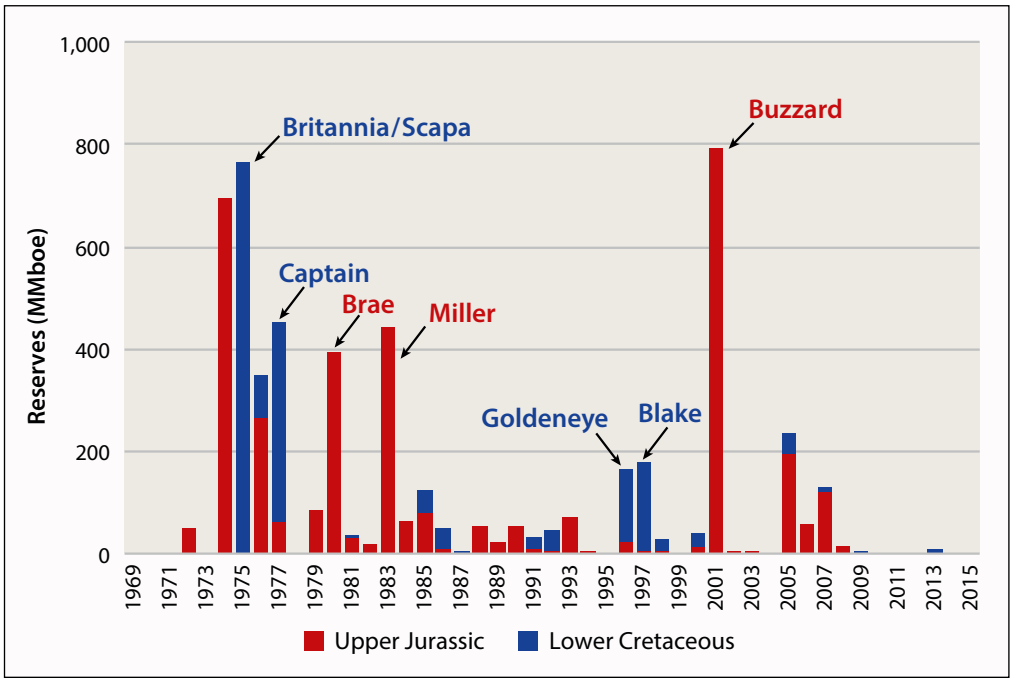


Figure 1: UK Central North Sea Lower Cretaceous and Upper Jurassic turbidite reservoir fields by discovery date.

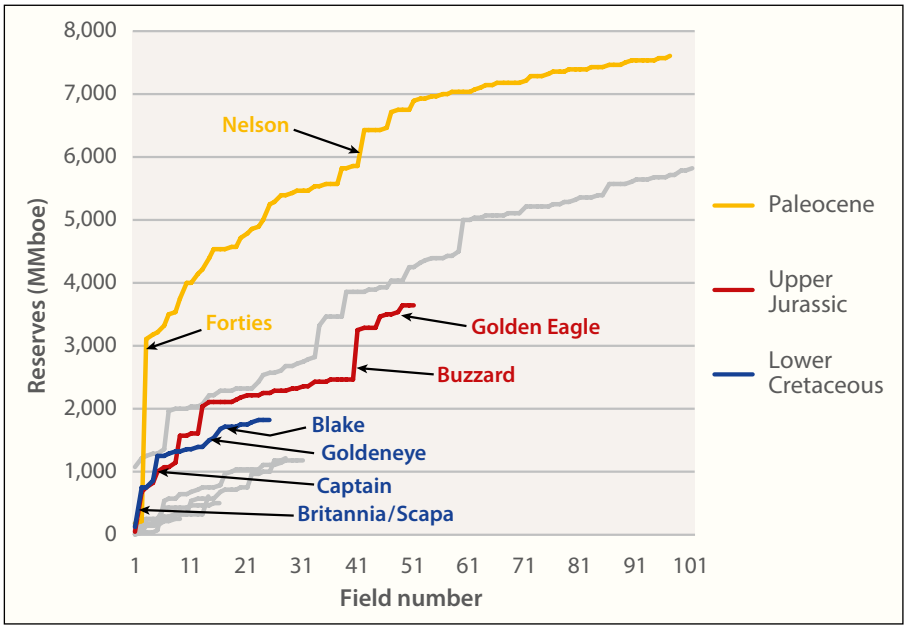
Reserves of over 1.8 MMboe have been proven in the Lower Cretaceous reservoirs, with almost all of this generated from the fields of the Moray Firth in the UK Central North Sea. Reserves are dominated by the early successes of four fields in the mid-1970s, in particular the Britannia and Captain fields. Since then more recent discoveries, such as Goldeneye and Blake in the late 1990s, have had an impact on maintaining the gradient of the creaming curve (Figure 2). It has to be acknowledged that there has been a relative lack of targeted exploration of the Lower Cretaceous turbidite plays historically in comparison to some of the other major North Sea plays at least. One of the key factors that may be driving this is a lack of obvious structures. Azinor Catalyst is in no doubt that, through targeted and forensic exploration efforts, the Lower Cretaceous can be shown to hold significant 'yet to find' potential within the UK North Sea.

Progressing Geological and Geophysical Understanding

Whilst the potential of the Lower Cretaceous has been acknowledged, a different and new perspective is required to push our play understanding forward. From a geological point of view, the use of high fidelity regional mapping has enabled the accurate reconstruction of palaeo-bathymetric surfaces and sediment drainage networks. Combining these outputs with more conventional techniques, such as isopach and structural mapping, has helped to pinpoint where restricted deepwater mass-flow sediments are likely to be found (Figure 3). Furthermore, the development of highly calibrated basin models have provided a more detailed understanding of the hydrocarbon charge and source rock characteristics, enabling the industry to push further onto the margins of the basin where many stratigraphic trapping opportunities are located.

In order to support the understanding of these geological models, Azinor Catalyst has invested in licensing over 26,000 km^2 of regional 3D broadband seismic data to help provide further quantitative geophysical

Figure 2: UK Central North Sea turbidite reservoir field creaming curves.



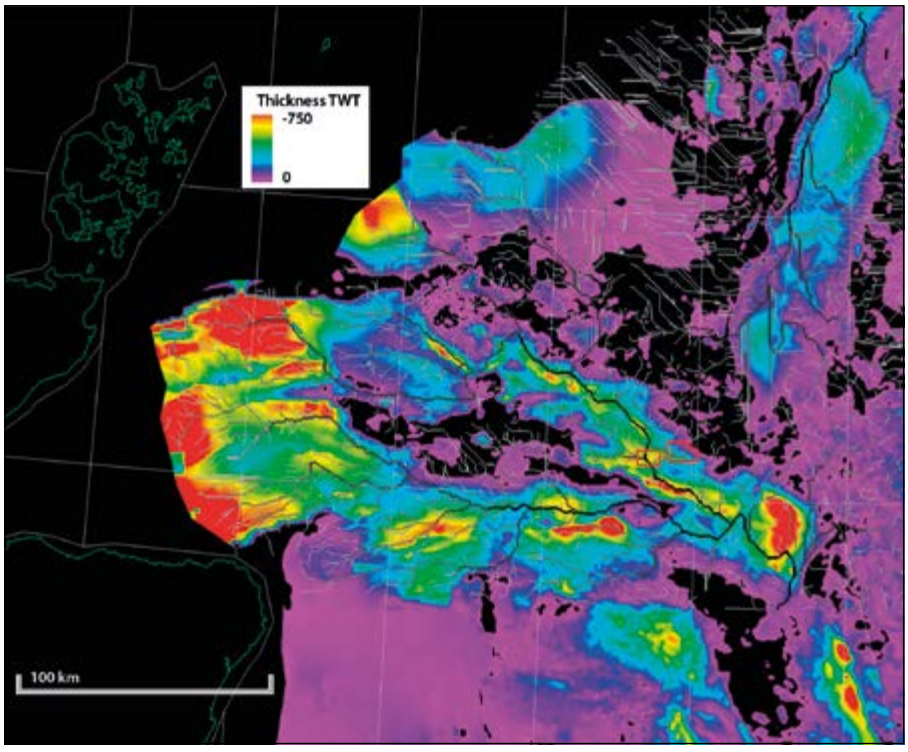


Figure 3: Moray Firth gross Lower Cretaceous isopach map overlain with palaeogeographic drainage network, UK Central North Sea.

calibration. This latest generation of seismic data provides broad-bandwidth, high signal-to-noise datasets that allow more subtle prospectivity to be delineated through robust AVO techniques and anomalies. The clarity of seismic, in conjunction with the UK North Sea's huge wealth of well control, allows the full characterisation of the rock properties, which enables the geophysicists to determine what response is caused by oil, what is water and what is background shale (Figure 4). Understanding how both the reservoir and non-reservoir rocks from different formations vary spatially and vertically makes is possible to unravel the related seismic response.

Integrating solid geological models and testing them through these advanced geophysical techniques allows for a cohesive and evidence-based approach for screening and high grading exploration opportunities, thus potentially ticking both geological and geophysical boxes.

In the past, the Lower Cretaceous has proved difficult to pin down in terms of seismic behaviour, since both the sands and shales have similar acoustic impedance values. This very low acoustic impedance contrast at the top and base reservoir interfaces results in a weak seismic response (Law, 2000), therefore introducing significant uncertainty into conventional seismic-based mapping techniques. This issue is associated with the Britannia, Goldeneye and Rochelle fields to name but a few. All these fields have excellent reservoir and fluid properties but are difficult to understand seismically using AVO and inversion. If, however, we look at the regional rock property trends we can see that this is not the case for all Lower Cretaceous reservoir rocks. It appears that there is a 'sweet spot' as the Lower Cretaceous reservoirs get shallower, maintaining higher porosities as a result of less chemical and physical alteration. This can be diagrammatically shown by a simple depth trend (Figure 4). In the shallow section shales are softer than sands, but with increased depth and physical compaction they quickly become harder than them. This then places the sands in a 'sweet spot' depth interval where we expect to see acoustic brightening associated with hydrocarbon presence. Stepping deeper again, the sands have undergone chemical alteration/compaction leading to cementation that influences the rock properties and stiffens the rock, making the sands harder than their surrounding shales once again.

Whilst this can be considered overly simplistic, in practice it highlights that there is a window where Lower Cretaceous rocks can be differentiated seismically. Encouragingly, when

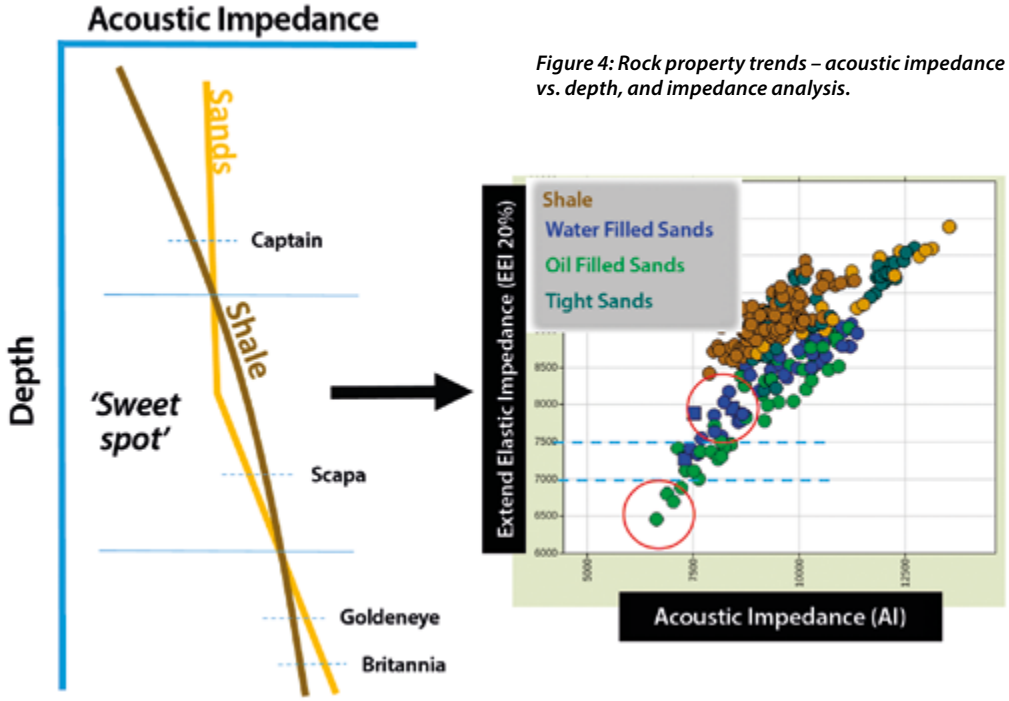


Figure 4: Rock property trends – acoustic impedance vs. depth, and impedance analysis.

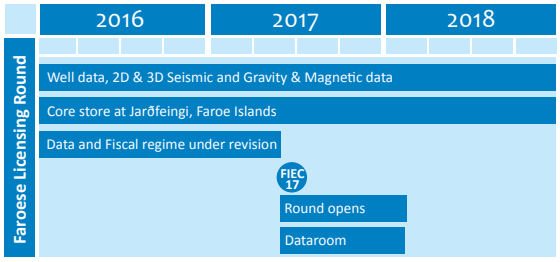
FAROESE LICENSING ROUND 2017

The Round will open at the 5th Faroese Exploration Conference
and will be open:
17 May 2017 - 17 February 2018

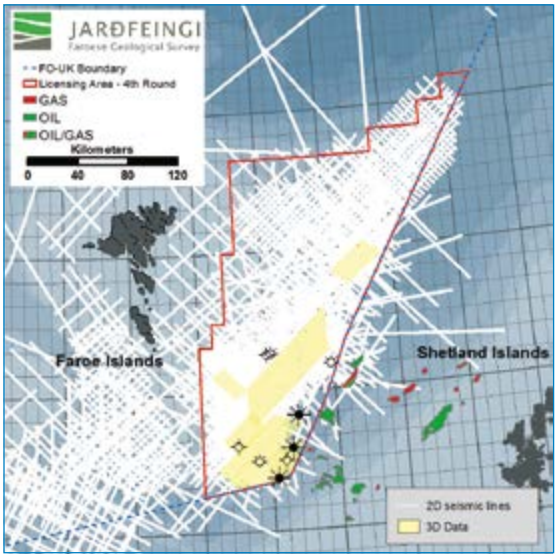
During the Round

- Data room will be open
- Possibillity to visit the core store at Jarðfeingi
- Jarðfeingi will be visiting conferences, and you are always welcome to visit our stands
- If you are interested in a formal meeting at your office, please contact us at jf@jf.fo

Timeframe



Licensing Area for the 4th Round



looking at known Lower Cretaceous fields and analogues this concept appears to hold together well. The likes of Britannia and Goldeneye represent the deeper interval, while Scapa resides in the 'sweet spot' section and the Captain field is found in the shallower interval. It is within the 'sweet spot' interval that seismic and AVO techniques can be used with the largest degree of confidence in exploration in the UK North Sea.

Using rock property and impedance analysis we see that it is possible to geophysically separate sands and fluids from background non-reservoir rocks like shale and tight sands. So, while we might not be within the shallower and softer rocks of the Paleocene, reservoir sands and hydrocarbon pay can be indicated in the Lower Cretaceous if the seismic signal-to-noise ratio is high enough. The separation of seismic AVO response from the background trend will be less than that observed in younger rocks, but it is still detectable, as illustrated by the example lines through the Lower Cretaceous Scapa field and Azinor Catalyst's Partridge prospect (Figure 5).

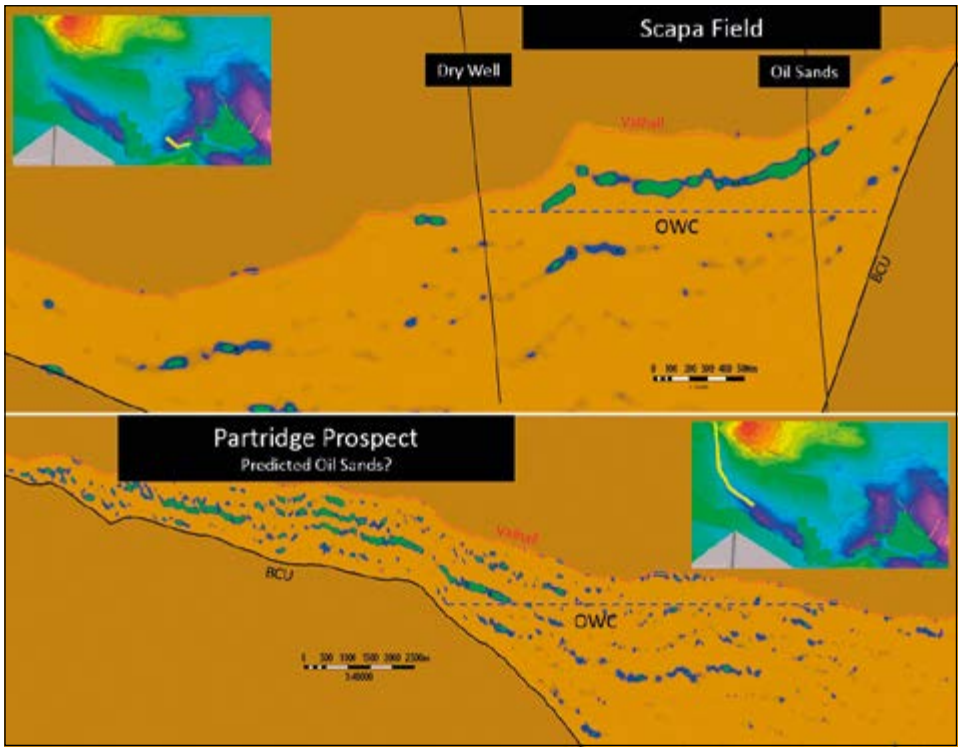


Figure 5: AVO-generated extended elastic impedance of the Scapa field and Partridge prospect.

Time to Focus…

Only 5% of all UK Continental Shelf fields and discoveries are known to be in pure stratigraphic traps; 12% in combination structural/stratigraphic traps and the rest in structural ones (Munns, 2003). In contrast, 60% of all Lower Cretaceous deepwater turbidite fields have either combination or stratigraphic trapping mechanisms. The majority of these fields have been found by accident or as a secondary target, so perhaps now is the time to focus the industry's efforts on the extensive yet-to-find potential of these stratigraphic plays.

Despite only limited amounts of discovered volumes being delivered in recent years, since the likes of Goldeneye and Blake (Lower Cretaceous) and Buzzard and Golden Eagle (Upper Jurassic), the focus for today's explorers might usefully remain in the pre-Chalk Group stratigraphy. We should not be unduly scared of targeting stratigraphic-based traps as long as these opportunities are based on well-grounded geological models and supported by robust seismic analysis.

Whilst this article has focused on the Lower Cretaceous, the same principles apply to the Upper Jurassic. Leveraging regional knowledge will provide insight and understanding and hopefully lead to significant value generation via further North Sea success.

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Jasmine field, Central North Sea.

A World of Drifting Ice

MORTEN SMELROR, Geological Survey of Norway

Ilulissat Icefjord in western Greenland offers a unique view of a scenic landscape that demonstrates active glaciological processes, where majestic icebergs calve into the fjord and out to sea.

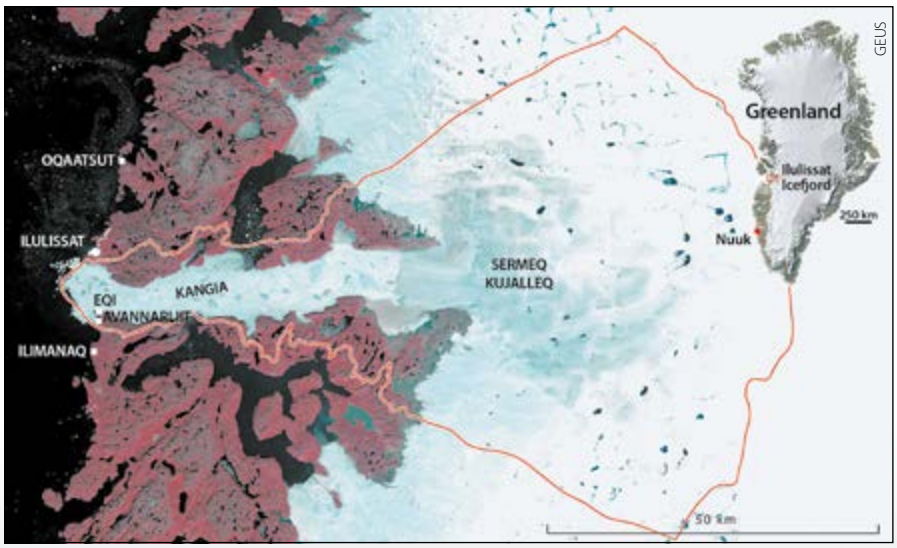
A shining metallic plate at the entrance of the wooden path leading down to the fjord cries out for our attention: "You are now entering the UNESCO World Heritage Site of Ilulissat Icefjord". And what an entrance!

Fast-Moving Glacier

Ilulissat Icefjord gives us a unique view into a beautiful landscape where glaciological processes can be seen actively at work, as a constant stream of majestic icebergs calve from the Sermeq Kujalleq glacier into Kangia fjord and on out to sea at Disko Bay. On the path leading to a scenic viewpoint we pass an interesting archaeological site at Sermeriut, with remains of the turf huts from the Thule culture. Also nearby there is evidence of middens from the Saqaaq culture, the first people to settle in the Ilulissat area some 4,400 years ago.

Sermeq Kujalleq is 3–6 km wide and is one of the fastest-moving and most productive glaciers in Greenland. It travels at an average speed of more than 40m in 24 hours and produces around 46 km³ of icebergs a year; in fact, about 10% of all ice calving from the Greenland Inland Ice comes from this glacier. Drifting icebergs fill up the bay in front of Ilulissat, the third largest town in Greenland, which has a population of 4,000 people – and many more dogs.

The largest icebergs calved by the glacier are about 1.5 km³ and can rise more than 100m above the sea surface. These giants appear as moving walls stranded at a submarine threshold at the



Map of the Ilulissat Icefjord World Heritage Site.

Huskies are important inhabitants of the societies in northern Greenland and are seen everywhere.

Morten Smelror

mouth of the fjord. Standing on the hills outside the town we get a close view of the calving glacier front and the icebergs. Knowing that the bulk of the numerous large icebergs are hidden beneath the sea surface, we can begin to picture the enormous ice masses on the move.

This fast-moving glacial stream calving into a fjord already full of icebergs is a special and very beautiful phenomenon. In 2004, Ilulissat Icefjord was included in the UNESCO World Heritage List as one of the world's most important cultural monuments and natural landscapes. The protected area covers around 4,024 km^2 and consists of land, lakes, glaciers and Kangia fjord. As with all UNESCO sites in the world, the Ilulissat Icefjord is protected and preserved for the benefit and enjoyment of future generations.

Since its acceptance as a World Heritage Site, the number of tourists visiting Ilulissat Icefjord has increased significantly. Tourism has more than doubled in just 10 years, and the area has become the prime tourist attraction in Greenland.

The bedrock around the Ilulissat Icefjord, as seen here in an exposure above Ilulissat town harbour, consists mainly of pale grey and folded gneisses and granites, with some mica schists and dark basic rocks.

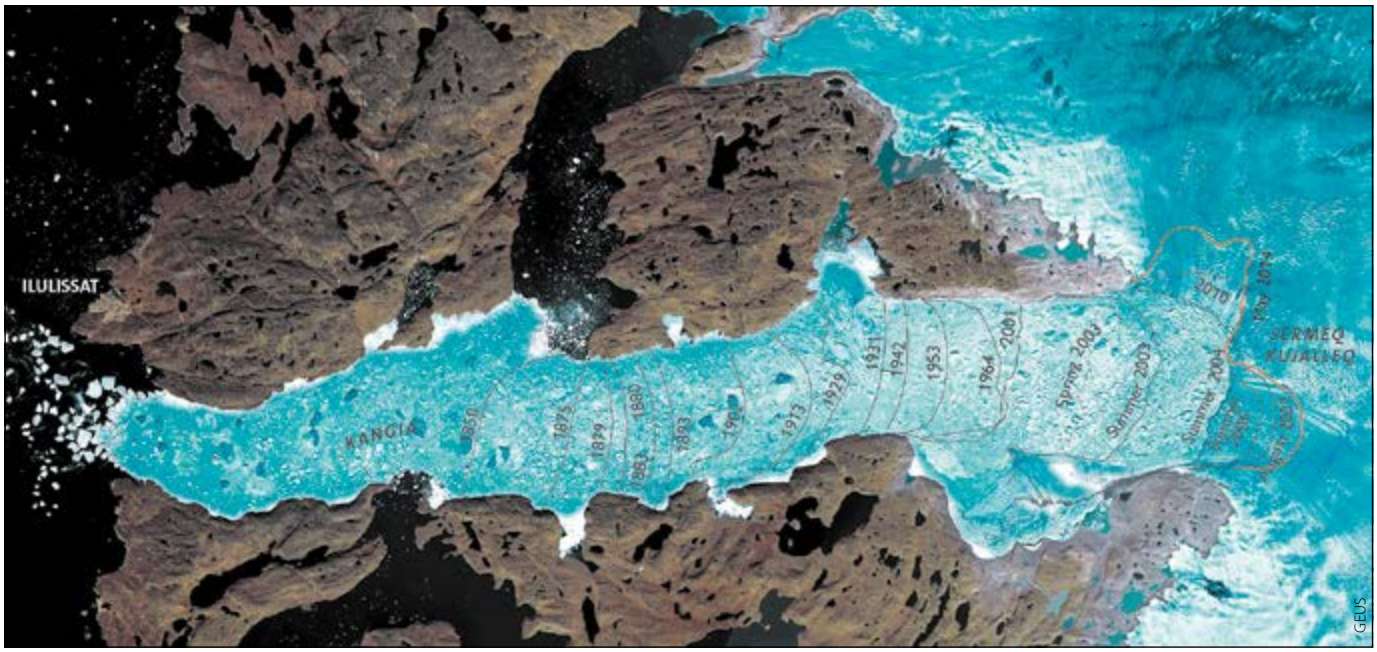
Polished Rock and Retreating Ice

About 80% of Greenland has a permanent ice cover, but at the western coasts the remains of the Precambrian Shield are widely exposed. The bedrock around the Ilulissat Icefjord consists mainly of pale grey and folded gneisses and granites, with some mica schists and dark basic rocks. Further south, in Isua, north-east of Nuuk, the capital of Greenland, some of the world's oldest rocks are found. These are 3.8 billion-year-old metamorphic rocks which contain some of the earliest signs of life on Earth.

The bedrock in the inner part of Disko Bay consists of rocks 2.5 and 1.8–1.6 billion years old, the remains of a mountain range within the large North American continent, which in Precambrian times comprised both North America and Greenland. Later, sedimentary basins formed along the coasts of the Precambrian Shield, and today Cretaceous and Cenozoic deposits fill the Nuussuaq Basin in the Vaigat and Disko Bay area.

Millions of years of moving ice have eroded and sculpted the rocks in the Icefjord area to a gentle landscape with low hills and polished bedrock surfaces. Today the Precambrian gneissic and granitic rocks in Ilulissat are extracted for construction purposes such as roads and buildings.

Sermeq Kujalleq at Ilulissat Icefjord is one of the best-explored glaciers in the world. At the end of the Little Ice Age (around 1850) the front of the glacier was located in the outermost part of Kangia Fjord and since then it has retreated step by step. Within the last 15 years in particular the glacier front has withdrawn significantly and



Since 1850 the Sermeq Kujalleq glacier front has retreated from the open water in the mouth of the fjord back to the shoreline in the inner bay.

Sermeq Kujalleq has doubled its speed. Ten years ago the glacier front was a floating tongue in the fjord, while today it is mainly land-based. During these years the size of the icebergs has also significantly diminished.

The ice front retreat is caused by rising temperatures causing increasing amounts of meltwater to percolate from the surface of the Inland Ice to the bottom of the glacier. The melt-water reduces the frictional resistance in the ice, causing the ice to flow at a higher speed. In addition, intrusions of warm oceanic water under the calving glacier have encouraged an increased retreat of the floating glacier front.

True Heaven and Dramatic Overturns

The high velocity of the Sermeq Kujalleq glacier comes from the fact that a very large drainage area of the Inland Ice is concentrated into the narrow stream that runs deep under the glacier. During the Ice Ages the forerunner of the glacier filled the Icefjord and eroded it to a depth of about 1,000m, the deepest part being between the present day glacier front at the inner shores of the fjord and the submarine threshold (the iceberg bank) at the mouth of the fjord in the west, where the water depth is 200–225m. It is here that most of the larger icebergs run aground.

The glacial erosion brings a constant supply of nutrients into the fjord and forms the basis for a rich marine life, which through the ages has been the foundation for the settlements of fishermen and hunters around the fjord. No wonder that the native Inuits look upon the sea as the 'true heaven'. When you die you go to the food-rich sea for eternity, not to the 'barren heaven'.

And sometimes the distance to 'heaven' may not be very far. When large icebergs overturn in Disko Bay they create major waves that can be dangerous to boats in the bay and people on the coast. At Sermeriut tourists have been inundated by such waves.

The characteristic igloos outside Hotel Arctic in Ilulissat offer a unique view of the majestic Icefjord.

A Room with a View

The beautiful and majestic icebergs that fill the Kangia Icefjord and strand on the ice bank south-west of Ilullisat form the most eye-catching of all the geo-touristic attractions in the area. The shifting light creates a magic setting and a room with a view over the fjord cannot be overrated here. Igloos made of alumina and supplied with flat-screens may not sound particularly exotic. But again, the unique and beautiful setting, with magic, fluctuating light under the midnight sun, will make a night in the igloos for rent at Hotel Arctic Ilulissat a memorable investment.

If you want a somewhat larger view of the Kangia Icefjord and Sermeq Kujalleq glacier you can charter an aeroplane or helicopter flight to take you for a sightseeing trip around the World Heritage area lasting for 30 minutes or an hour. And if you fancy a closer look, and want to experience some of the struggle the pioneering explorers of this large area went through, you can participate in one of the two- to ten-day trips on foot, skis or by dog-sledge that are offered by adventure companies in Ilulissat. For those who prefer a trip on the fjord to sail among drifting icebergs, there are also several alternatives to choose from.

For scientists, adventurers or just ordinary tourists, the UNESCO World Heritage Site Ilulissat Icefjord offers a unique, unmissable experience.

More Information:

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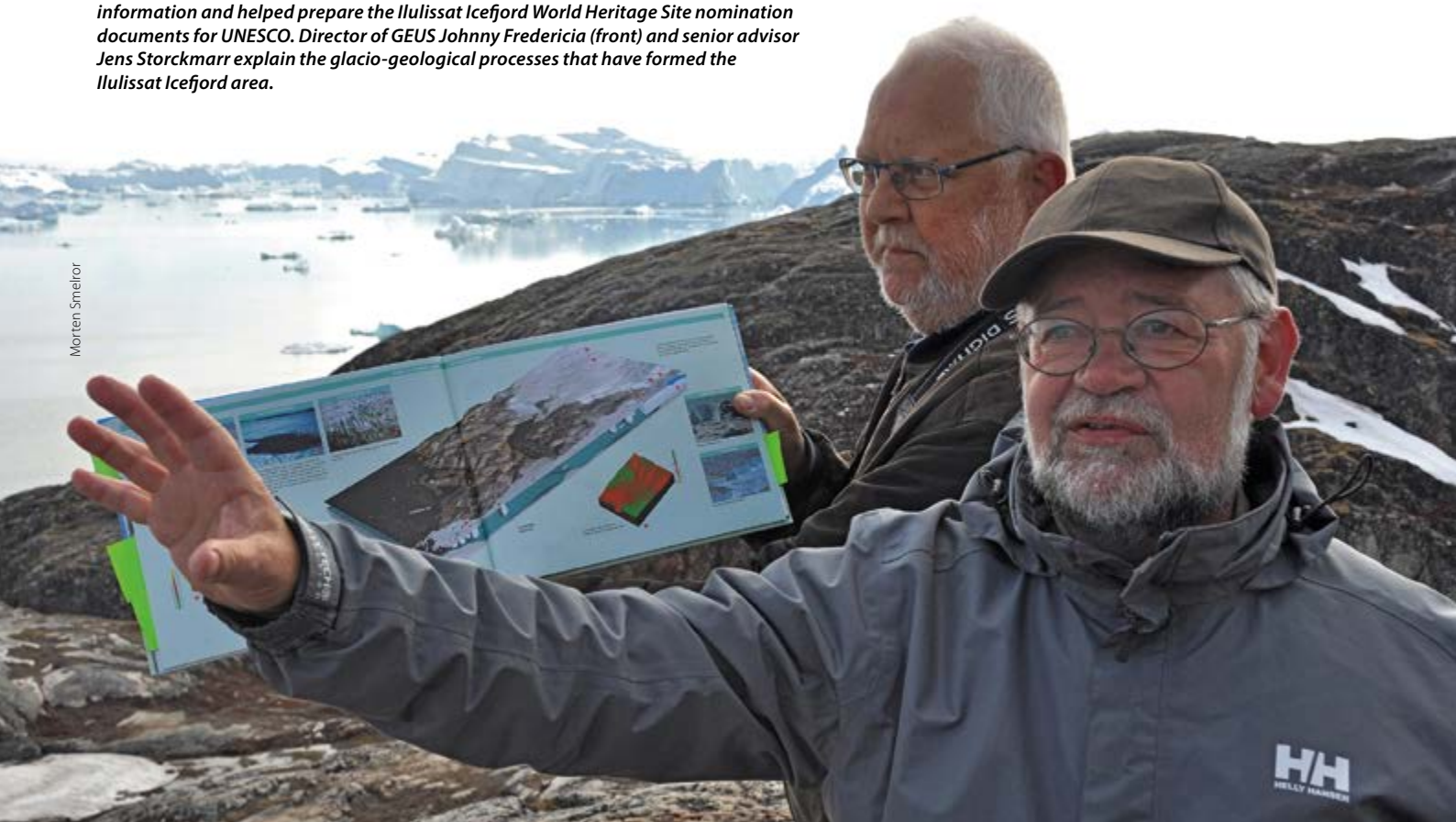
Mamartut!

'Mamartut', the name of a restaurant in Ilulissat, is Greenlandic for 'wow, it tastes good'. And it does. Halibut, ice shrimps, reindeer and musk ox, and local beer brewed from wild berries; what more can you ask for? Oh, yes, the special 'schnapps' made from half-digested wild berries picked out of grouse gizzards…

A musk ox burger beats those served at your local McDonald's, and the atmosphere created by the helpful staff, together with the local handicrafts and works of art which decorate the rooms, make a visit to the Mamartut Restaurant a highly recommended experience.

Ilulissat is the third largest town in Greenland, with around 4,000 people. In the foreground is the town's Zion Church.

The Geological Survey of Denmark and Greenland provided key scientific background information and helped prepare the Ilulissat Icefjord World Heritage Site nomination documents for UNESCO. Director of GEUS Johnny Fredericia (front) and senior advisor Jens Storckmarr explain the glacio-geological processes that have formed the Ilulissat Icefjord area.



Was the Mozambique Channel Once Scattered with Islands?

YANNIS BASSIAS
Amphore Energy Inc.

Tectonic, erosional and climatic forces interact to shape mountains. The geological story of the rocks of the Davie Ridge tell us how these forces shaped this part of the earth, pushing the mountains of west Madagascar, which once abutted what is now the coast of Somalia, southwards into the Indian Ocean.

The southwards drift of Madagascar lasted for 50 million years, from the Middle Jurassic to the Early Cretaceous, and was governed by an almost 1,000 km-long north–south fracture zone which, east of the present Davie Ridge crests, is associated with a number of deep north-west to south-east trending faults. This oblique rather than simple tectonic regime rippled and sheared the continental crust west of Madagascar, eroded and erased mountains, emerged and submerged volcanic islands and created sedimentary basins which were only fully connected when the sea finally inundated all the area between Madagascar and Mozambique in the Miocene.

Mapping Mounds and Evolutionary Bridges

In Figure 1 the present situation is compared to that close

to the Jurassic–Cretaceous boundary, around 145 million years ago. Triangles represent horst structures mapped from seismic and their position is projected back to that time. Although this is an illustration, the cluster of high mounts formed in the middle of the strait between Madagascar and Africa seem to have created a network of scattered islands that subsided later in Miocene times (Figure 1b). Did some of those islands, not just the Davie Ridge crests, remain above sea level until the Eocene? Rock analysis supports this. Detailed geological descriptions of dredges and cores along the Davie Ridge were published in the late '80s and early '90s and rock samples were recently correlated with seismic, gravimetry and airmag.

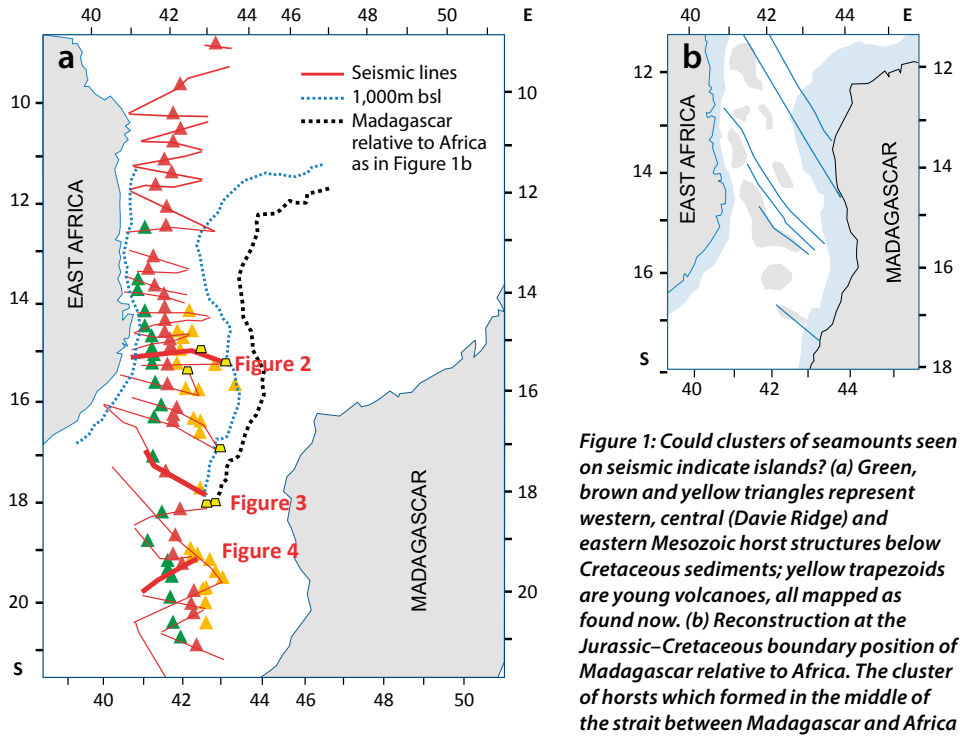


Figure 1: Could clusters of seamounts seen on seismic indicate islands? (a) Green, brown and yellow triangles represent western, central (Davie Ridge) and eastern Mesozoic horst structures below Cretaceous sediments; yellow trapezoids are young volcanoes, all mapped as found now. (b) Reconstruction at the Jurassic–Cretaceous boundary position of Madagascar relative to Africa. The cluster of horsts which formed in the middle of the strait between Madagascar and Africa seems to have favoured the creation of a network of islands that subsided in Miocene times. (Jurassic – Cretaceous boundary position of Madagascar relative to Africa close to the time of magnetic anomaly (M17) after Coffin & Rabinowiz,1987. Faults with north-west to south-east direction after Raillard, 1990 and Rusk, Bertagne & Associates, 2003.)

Understanding the surface environment has important implications for biodiversity. Zoologists still question whether 'evolutionary bridges' allowed mammalian groups to pass from Africa to Madagascar in Eocene times. The presence on Madagascar of several terrestrial mammalian groups with poor dispersion capacity across wide water barriers led several authors to suggest the existence of land-bridge connections between Africa and Madagascar during Middle Eocene to Early Miocene, (47–26 Ma), rather than assuming the rafting on vegetation mats hypothesis. This debate moved recently from classical taxonomy to genetic molecular comparative studies.

Plate reconstructions brought arguments constraining the 'evolutionary bridges' scenario, but rock descriptions from the Davie Ridge crests and flanks suggest there were long emersion periods. This in turn could indicate that until the Late Cretaceous and probably Eocene, the Rovuma Basin, today off the Mozambique and Kenyan coast, was somehow isolated from the Angoche Basin, now found off the Mozambique coast, and from the Morondava Basin, which is now off the Madagascan west coast, by a number of islands. During the Palaeogene these islands could have restricted the eastward Mozambique palaeocurrent at latitudes south of today's 19°S. It is possible that the Middle Eocene circum-Antarctic current between Australia and Antarctica, although it disrupted ocean currents worldwide and caused global cooling, could not strongly affect sea and land north of 19°S in the Mozambique Channel. Under these conditions the presence of a series of small, scattered Mesozoic-Cenozoic islands or remnants of them in the middle of the channel, combined with the eastward Mozambique palaeocurrent and wind circulation in the Palaeogene, favours the migration of mammalian groups from Africa to Madagascar.

Evidences of Emersion

Late Jurassic to Miocene formations and structures in the Madagascar Channel are visible on seismic. However, knowledge of the nature of the rocks and their crystals and the erosion that had a hand in shaping the peaks is not available without sampling, dredging, coring or drilling.

Dredge sampling of the sedimentary blanket of the Davie Ridge has revealed that the volcanic crests of the northern part of the ridge (around 14°S) remained close to or above sea-level for long periods and were covered by Miocene breccia, conglomerates and carbonates (Figure 2). Meanwhile, the crystalline basement of the crests at the median parts of the ridge (between 15° and 16°S) has been shown to have been eroded and there are outcrops of arkosic sediments, recrystallised pelites and flysch-like black psammitic beds, Upper Eocene bioturbated calcareous sandstones and high energy calcareous breccia below Late Miocene oozes (Figure 3). The southern crests of the ridge (between 17° and 19°S) were covered by highly altered basaltic breccia cemented in a carbonate matrix and by Middle Eocene platform carbonates below Early Miocene limestone.

The Paleocene is absent on the ridge and was not found by DSDP Leg 25, implying that a major unconformity has to be considered between the Cretaceous and the Paleocene. The local distensions which accompanied the drift of Madagascar and the lithospheric fissuring were both transgressive southwards, inducing either the first Cretaceous pelagic sedimentation or hypabyssal to subaerial volcanic activity. The northern part of the ridge around 14°S remained close to sea level until the Miocene.

Volcanic activity was present at the northern and southern parts of the ridge although in the middle, around 16°S, the eroded crystalline basement was not penetrated by volcanics, and Late Cretaceous sedimentation was prominent on the eastern flanks. Eocene outcrops are better exposed at the southern parts of the ridge between 17°S and 19°S.

The Roles of Compression and Erosion

With a 1,000 km drift of Madagascar southwards along the fracture zone between 165 and 120 Ma, an average drift (half spreading rate) of 22 mm per year should yield extremely high convergent rates on the transpressional segments of the fracture zone. This amount of shortening should be sufficient to uplift large blocks, tens of kilometres across, over thousands of metres, a process which has been examined in depth at the San Andreas fault. Consequently, the origin of some push-up blocks east of the Davie Ridge may be related not only to listric but also to convergent wrench faults and flower-like structures if a wedge tectonic system was present. Similar extensional and compressional structures were recognised north-east of the Davie Ridge on the Madagascar side, between 12° and 14°S as well as west of the Davie Ridge on the African side, at around 15°S.

The shaping of the mountains depends as much on the destructive forces of erosion as on the constructive power of tectonics. In Cretaceous times erosion of the mountains is thought to have removed large quantities of rock but the resultant uplift replaced about 80% of the mass removed. From seismic lines we estimate that the missing parts of folds together with vertical displacement suggest that the removed mass represents about one second of folded Jurassic and Karoo, that led to about 0.8 seconds, or around 1,500m, of isostatic uplift (Figure 3). A very general estimation indicates that 100m could be removed through erosion every 10 million years at an average low rate of 0.01 mm/yr.

The process of erosion around the volcanic islands was later influenced by deep faulting and sliding, affecting unstable slopes at depths that can exceed five kilometres.

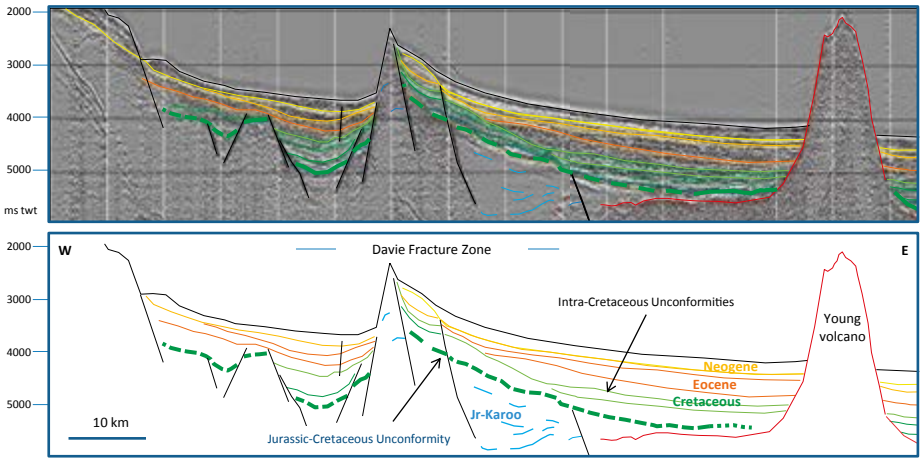


Figure 2: The eroded crystalline basement was dredged from depths of 2,450 to 1,875 mbsl and recovered recrystallised pelites, arkosic laminites with clasts of gneisses, lithified black psammitic beds and calcareous sandstones covered by Middle to Late Eocene carbonates and Pleistocene oozes. The Angoche Basin is situated east of the western flank of the ridge. Today the vertical fault displacement at the western flank of the ridge exceeds 1 sec twt. The eastern slopes of the ridge denote several unconformities and possible later mass-slides. The absence of onlap around the volcano in the east indicates a young age. (For line of section see Figure 1.)

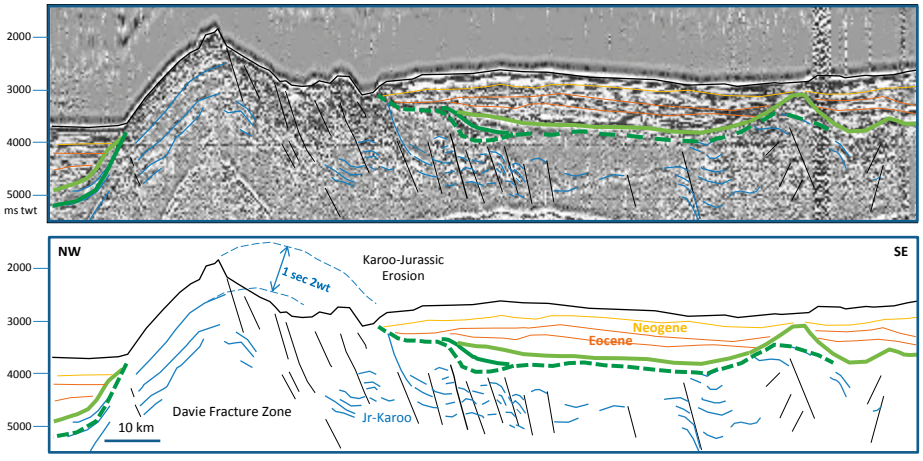


Figure 3: The large volumes of sediments deposited on the flanks of the ridge derive from the erosion that affected the Jurassic mountains during Cretaceous-Eocene times. (For line of section see Figure 1.)

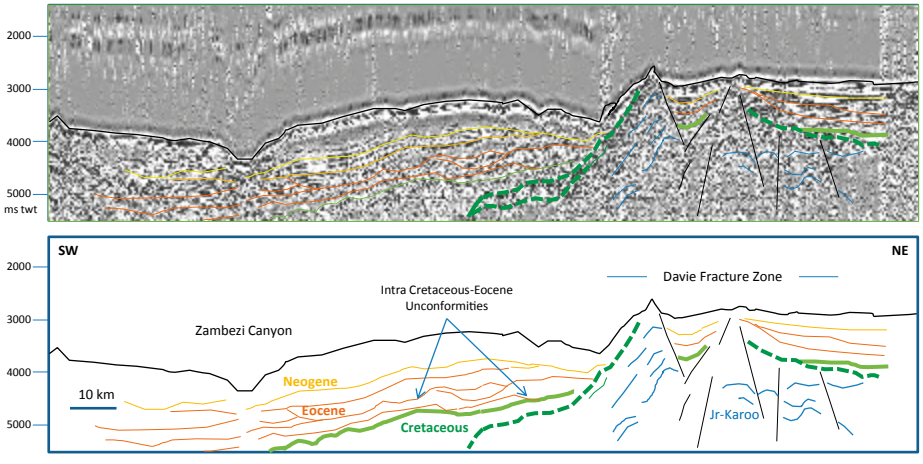


Figure 4: This section shows that the Zambezi canyon was also fed by the eroded Davie Fracture Zone. (For line of section see Figure 1.)

The occurrence of such large slides on the flanks of the Davie Ridge is connected with dissolution features of the carbonate terraces and platforms, and may be influenced by Cenozoic high-amplitude fluctuations of the eustatic level.

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The Role of Magma Underplating

Part of this uplift may be related to magma underplating as well as to compression and erosion. Up and down movements of several hundreds of metres at plate edges can be explained by the mantle influence. Several cases of continental 'bobbing' during Cretaceous times have been observed around the globe. Mantle is, in fact, able to lift the surface by hundreds of metres, easily enough to cause an apparent drop in sea level. In the case of the Mozambique Channel, basalts were emplaced after cessation of the southwards movement of Madagascar, apparently at a time of quiet when India separated from Madagascar at around 83 Ma. These basalts have alkaline affinities and were emplaced along pre-existing zones of weakness of the fracture zone under hypabyssal to subaerial conditions and in some cases suffered hydrothermalism. The crustal thickness between Africa and Madagascar seems to have inhibited the emplacement of huge volumes of magma along the fracture zone but in turn this could have favoured a Cretaceous uplift.

The Role of Eustasy

A sea level drop of a few hundred metres due to Middle Cretaceous eustatic changes would narrow the channel only slightly to reveal few islands. However, the combined effects of tectonic activity, sediment accumulation/compaction and eustasy on accommodation changes can be important on a regional scale, with rates varying from several to tens of metres per million years. The Cenomanian–Turonian interval was punctuated by large and rapid sea level drops. High-magnitude and short duration changes (tens of metres in <100,000 years) are known, resulting in 'absolute' rates of sea level change in the order of 150–1,000 m/Ma.

The rise in sea level due to sea floor rise as a result of oceanic crust global events did not compensate for uplift along the Davie Ridge. From the Eocene and through the early Miocene, water retreat left deposits of limestone and chalk, while basalts were eroded and brecciated and the fragments were deposited in a carbonate matrix, dated by nannoplanktons to be Middle Eocene. The presence of limestones and chalks at the southern parts of the ridge can be explained by this mechanism. It is important to note that these rocks were dredged at present depths of between 2,450 and 600m, which do not represent the shallow depths of deposition.

From the Miocene these islands started to sink to finally form present-day seamounts, atolls and islands.

Hydrocarbon Implications

The Cretaceous ocean floor rise, although helped by an increase in carbon dioxide, a Middle Cretaceous important greenhouse episode and the deposition of limestone, did not compensate for the large uplift due to compression and folding which has been observed in several parts of Gondwana, including the Cretaceous Mozambique Channel. Many geological processes have taken place between East Africa and Madagascar since Jurassic times, and although today the channel is a huge marine environment, these processes can be observed in the rock history. Even if the amplitude of lithospheric thinning was the guiding mechanism for volcanic activity along the Davie Fracture Zone, both the basement reactivation and the volcanic activity along the fracture zone were controlled by the amplitude of uplift and erosion. From a petroleum exploration standpoint, the size of this uplift may have enormous consequences for the Mesozoic depositional environments of the Mozambique Channel.

The Majunga and Rovuma Basins were probably isolated from the Angoche and Lacerda Basins and from the Morondava Basin with distinctly different sedimentary and diagenetic histories until the Middle Miocene, which has important implications for hydrocarbon exploration.

The presence of a series of small, scattered Mesozoic–Cenozoic islands in the middle of the channel, across which mammalian groups could migrate from Africa to Madagascar, brings some new support onto the land-bridges theory. There was perhaps an initial period of around 20 million years, until the Jurassic–Cretaceous boundary, when biotic exchange would have been present between western and eastern Gondwana, followed by a second period during the Eocene that preserved emerged parts of the Davie Ridge and of its eastern slopes.

It is clear that the Mozambique Channel still holds a number of secrets and there is scope for considerable further research.

Acknowledgements

Cruise MD39 was funded by the Territoire des Terres Australes et Antarctiques Françaises in 1984. Seismic has been available courtesy of CNRS-IPGS/GeoAzur. Rock geology was based on 63 cores and 15 dredges recovered during the R/V Marion Dufresne *cruise (MD39) in 1984 and the* R/V Suroit *cruise (SU2) in 1979. Dredged rocks and cores from the Davie Ridge are preserved in the Marine Rock collection of the National Museum of Natural History in Paris.*

See online for references ■

The beautiful island of Nosy Komba, Madagascar.

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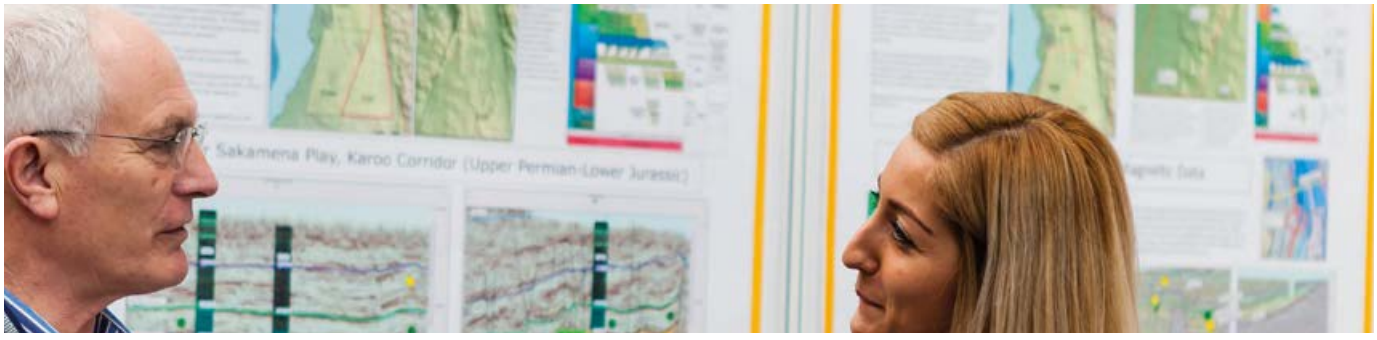

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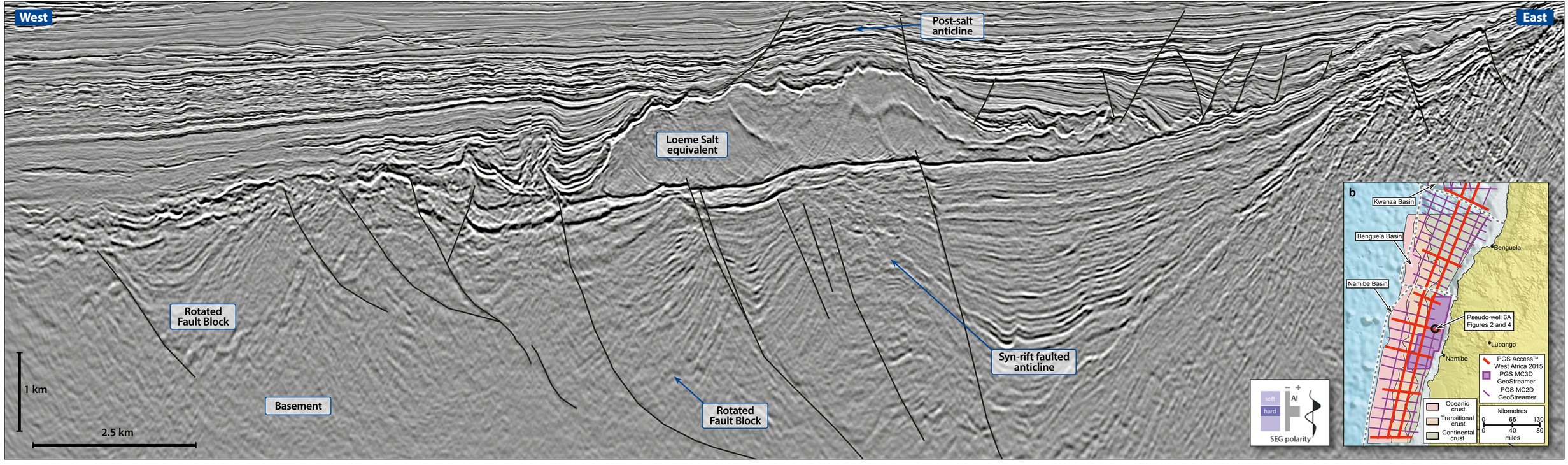
Unlocking an Angolan Frontier

With renewed anticipation of a licence round offering open acreage across large prospective blocks, is it now time to explore this attractive region?

PGS dual-sensor broadband GeoStreamer™ data has identified significant syn- and post-rift potential in the Namibe Basin. This article aims to use the superior imaging offered by GeoStreamer to present an interpretation of the tectono-stratigraphic elements and prospectivity of the Namibe Basin, a frontier region with no wells. It furthermore seeks to address some of the challenges that have occurred in analogous hydrocarbon provinces such as the neighbouring Kwanza Basin, offshore Angola.

The section below identifies some of the key features and structures that have been revealed by GeoStreamer data in the Namibe Basin.

Figure 1:
(a) Location of map in Figure 1.
(b) Map of the Namibe and Benguela Basins and location of PGS survey (inset in seismic below).



The Namibe Basin

WILLIAM REID and
AVRIL ASHFIELD, PGS

Compelling seismic evidence for a significant unexploited hydrocarbon province located offshore southern Angola.

The Namibe Basin represents a significant unexploited hydrocarbon province located offshore southern Angola (Figure 1a). During the Late Jurassic–Early Cretaceous the eastern Atlantic margin of this part of West Africa developed as the conjugate margin to the prolific hydrocarbon-bearing Santos and Campos Basins. Although recent research describes the conjugate margins of Kwanza/Campos and Namibe/Santos as asymmetrical (Unternehr et al., 2010) with each basin containing slightly different petroleum elements, discoveries of supergiant oil fields such as Lula in the Santos Basin and Linguado in the Campos Basin have meant previously overlooked pre-salt targets of the eastern Atlantic margin have been re-assessed (Koch et al., 2013).

The resulting exploration of the eastern Atlantic margin has been rapid with significant discoveries made in neighbouring Angolan basins, such as Ombovo in Kwanza and Hivoua in Congo. The acquisition of several recent 2D and 3D dual-sensor broadband GeoStreamer surveys by PGS (Figure 1b, preceding page) provides a unique opportunity to unravel and de-risk the complex structural and stratigraphic history of the Angolan margin.

As no wells have been drilled in the Namibe Basin, stratigraphy is mainly inferred from the analogous Kwanza Basin.

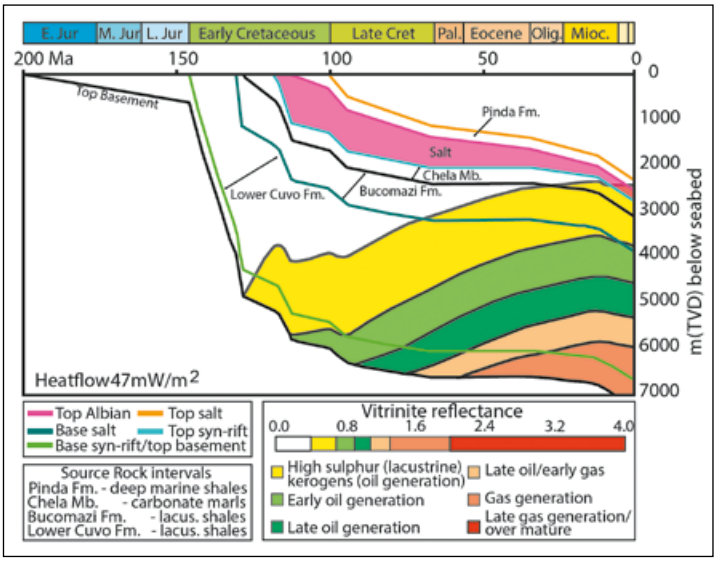


Figure 2: Burial history modelling of Pseudo-well 6A at 47mW/m², representing average regional heat flow.

Source Potential

Source rocks for the Namibe Basin are expected to occur predominantly in the syn-rift and sag phase sections with secondary early post-rift sources.

Regional heat flows from Angola and Namibia show a range of 24–68mW/m² (IGI, Integrated Geochemical Interpretation, 2015). Using an average regional heat flow of 47mW/m² (Figure 2) the syn-rift source rock equivalents of the Upper Cuvo (Bucomazi Formation) and Lower Cuvo lacustrine shales show a variable maturation with the Lower Cuvo Formation, reaching early gas/condensate maturity in the lower interval and oil maturity in the upper interval. The Bucomazi Formation is oil mature when modelled as a high sulphur kerogen type.

Other source rocks may exist in the form of sag phase equivalents to the Upper Cuvo Formation (Chela Member) transgressive shallow marine clastics/carbonate marls, and post-rift Pinda Formation equivalent deep marine shales.

Modelling of hydrocarbon maturation and expulsion suggests that the Lower Cuvo Formation would have begun to expel oil from the early Eocene. The base of the Bucomazi Formation as shown in Figure 2 is expected to have barely expelled hydrocarbons since the Quaternary. The transformation ratio through time implies that all hydrocarbons would have been generated at the base of the Lower Cuvo Formation and that generation would have occurred by varying amounts throughout the entire formation.

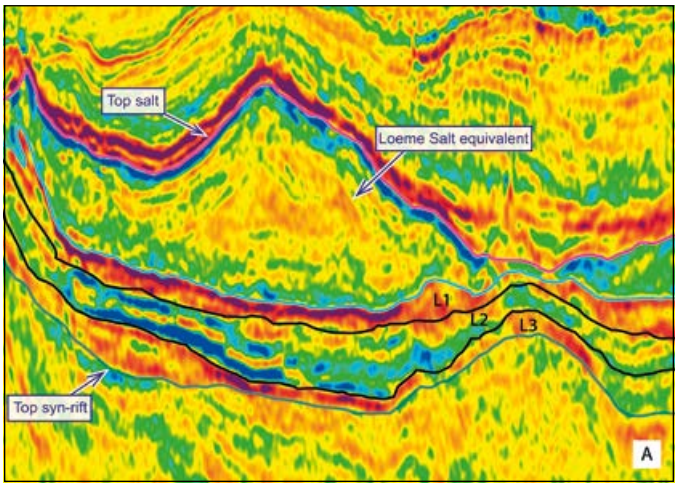
Reservoirs and Seals

The interpretation of 2D and 3D GeoStreamer data has allowed for seismic facies to be delineated and analogues to be drawn from similar seismic facies observed in the Kwanza Basin. Syn-rift reservoirs are therefore likely to exist as formation equivalents to the Lower Cuvo Formation deep marine sandstones, Upper Cuvo Formation fluvial to lagoonal facies and carbonates of the Bucomazi Formation. Post-rift reservoirs are expected to be comprised of shallow marine sandstones of the Iabe Formation, the Pinda Formation (Binga Member) carbonates, and deep marine sandstones of the Landana Formation.

The presence of the Loeme Salt is well known in the Kwanza Basin, where it acts as the main seal for fields such as Orca/Baleia. Seismic imaging and interpretation has shown that the Loeme Salt equivalent is more extensive in the Namibe Basin than previously identified in conjugate margin reconstructions (Torsvik et al., 2009). Syn-rift seal in the Namibe Basin is therefore likely to be provided by the evaporites of the Aptian Loeme Salt Formation equivalent (Figures 3 and 4). Where salt is absent, intra-formational marine shales of the Bucomazi, Pinda, Iabe and Landana formations would likely represent alternative seals.

Traps and Structures

The Namibe GeoStreamer seismic data shows multiple



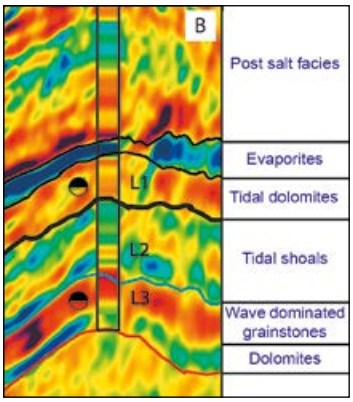


Figure 3: (A) A proxy for relative acoustic impedance in the Namibe Basin in which distinctive layers of alternating high and low impedance are observed: L1 is a high impedance layer, L2 a low impedance layer and L3 another high impedance layer. (B) Relative acoustic impedance from pre-stack inversion of 2D GeoStreamer data over the Baleia-1 pre-salt discovery in the Kwanza Basin. Intervals of high and low impedance (L1 to L3) correlate closely to varying carbonate facies in the well. The similarity of impedance between these two areas provide encouragement that similar prospective pre-salt carbonate reservoirs may be present in the Namibe Basin.

trap types present in the syn-rift and sag phase as well as the post-rift sections (Figures 3 and 4 and foldout on previous page). Syn-rift and sag phase traps include tilted fault blocks with potential stacked reservoirs in the Lower Cuvo equivalent; carbonate build-up associated with the sag phase (Figure 3); four-way dip closures; and syn-rift stratigraphic pinch-outs of the Lower Cuvo equivalent. There are also multiple trap types in the post-rift, which are more commonly associated with halokinesis and include post-salt anticlinal closures, stacked channel complexes, and stratigraphic pinch-out traps (see Figure 4 and the foldout on previous page).

Challenges of CO_2 Contamination

Recent exploration wells in the southern Kwanza Basin have encountered high concentrations of CO_2 in pre-salt reservoirs which have been geochemically typed to mantle melts that are interpreted to have displaced an earlier oil charge (Bump et al., 2016). The presence of >20% CO_2 in hydrocarbon reservoirs is rare (Santos Neto et al., 2012) and geographically unpredictable, often with CO_2 wells being adjacent to successful exploration wells (Bump et al., 2016).

An initial study of the Namibe Basin has been undertaken as part of the PGS Access™ West Africa 2015 report, in which Bouguer gravity data and magnetic survey data combined with 2D GeoStreamer data have identified a transitional zone (Figure 1b) where gravity modelling suggests localised areas of raised Moho or exhumed mantle. Using PGS MC2D GeoStreamer data, a number of syn-rift basins have been identified which are isolated from such areas of raised Moho/exhumed mantle. Mantle derived CO_2 may either be sourced via deep-seated faults penetrating the Moho or through shallow exhumed mantle degassing. Interpretation of the PGS GeoStreamer data shows these syn-rift basins to be isolated from exhumed mantle by basement highs (e.g. Figure 4) and with faults which detach prior to the Mohorovicic discontinuity, suggesting a lower risk for CO_2 contamination in these areas.

Significant Potential

PGS dual-sensor broadband GeoStreamer data helps to identify significant syn- and post-rift potential in the Namibe Basin. Open acreage and an anticipated licence round make the Namibe Basin highly attractive for frontier exploration.

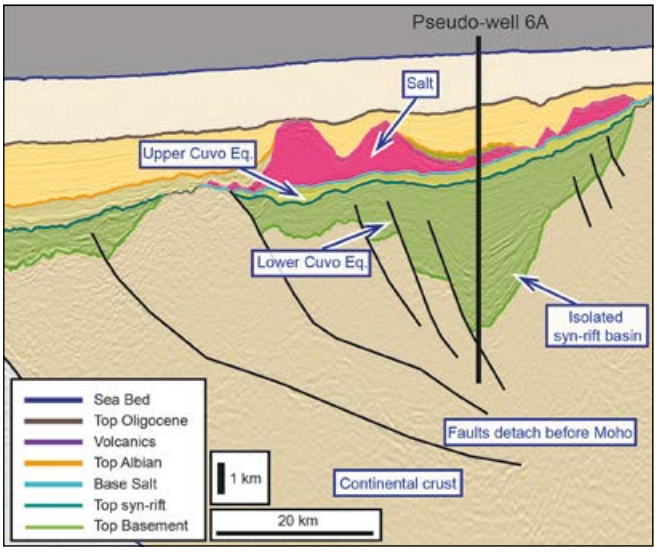
Potential leads have been identifed throughout the Namibe Basin including stacked carbonate and clastic reservoirs in the syn-rift and sag phase, large 4-way dip closures and multiple syn- and post-rift stratigraphic traps.

Potential oil prone sources are likely to be provided by equivalents to the syn-rift Lower Cuvo lacustrine shales, sag phase Upper Cuvo Formation and post-rift Pinda Formation deep marine shales. Basin modelling suggests that complete generation and expulsion of hydrocarbons will have occurred for the Lower Cuvo Formation with partial expulsion from shallower sources.

Seismic imaging and interpretation have shown the Loeme Salt equivalent to be the most likely seal as it is more extensive than previously identified in conjugate margin reconstructions.

With no well data available in the Namibe Basin, the MultiClient MC2D and MC3D PGS GeoStreamer data, combined with gravity and magnetics, provides the perfect platform to de-risk and unlock the prospectivity of the frontier Namibe Basin. ■

Figure 4. PGS GeoStreamer 2D seismic section with deep interpretation guided by gravity modelling. Syn-rift basin shown to be isolated from area of possible shallow mantle CO_2.



Taking the Plunge

How nodes can navigate ocean bottom seismic into the mainstream

VIDAR HOVLAND and JOHN THOMPSON
of Norwegian start-up company **inApril** explain why they took the plunge into the ocean bottom seismic market.

On the way to the seabed: Venator ocean bottom node system in action.

It is sometimes said that it took nearly 30 years for towed-streamer 3D marine seismic data acquisition to truly establish itself as an indispensable, cost-effective instrument in the offshore E&P toolbox. By the same measure, we should soon be seeing the full potential of ocean bottom seismic (OBS) technology in oil and gas operations being realised.

Many of the issues that complicated the acceptance of 3D marine seismic, such as the cost and complexity of the operation, competing techniques and data processing challenges, have been in play during the evolution of OBS services. There have been some false dawns along the way, but arguably we have now reached a tipping point. The case for wider adoption of available OBS technology looks more certain than ever, even in the prevailing low cost oil price environment. Strides are now being made in developing ocean bottom node (OBN) technology and operations, to which inApril intends to contribute further. These have not only largely settled the debate between the competing claims of ocean bottom cable (OBC) and OBN, but have cleared the way for a sustainable market in OBS services.

A Little History

The modern era of ocean bottom seismic data acquisition is usually associated with GSI's Joe Sanders and Fred Barr, whose work on OBC technology was recognised in 1995 by the SEG with the prestigious Virgil Kauffman Gold Medal. However, as far back as the 1950s, 'bay cable' systems of OBC, essentially a shallow water extension of land seismic cable systems using hydrophones, were in use. They were limited to around 10m water depth by the ghost reflections from the water surface accompanying each reflection wavelet. Sanders and Barr resolved this issue and others with the introduction of dual sensor acquisition using combined hydrophone and geophone sensors in the cable.

Seabed cables connected to a vessel (later to a series of data collection buoys) could operate in much deeper water. The technique was first conceived as a method of surveying in obstructed areas offshore inaccessible to towed-streamer systems. But the high resolution, multi-component data, including both pressure and shear wave, plus accurate positioning, made the technique a candidate for 4D seismic reservoir monitoring projects and, thanks to the full azimuth coverage possible, for resolving complex subsea geology, such as subsalt in the Gulf of Mexico.

For a time in the 1990s marine geophysical contractors such as WesternGeco and PGS both added OBC crews to their capability. Plenty of oil companies were convinced by the superior data results of OBS acquisition. However, following the 1999–2000 oil industry crisis they did not invest heavily in the technology, and PGS dropped its interest entirely.

The problem was being able to maintain a sustainable business. This stemmed from two main issues. One was the competition from towed-streamer acquisition, particularly in the 4D seismic arena. Seismic vessel contractors showed that they could cost-effectively provide repeatable surveys for reservoir seismic monitoring using improvements in

SUMIC nodes ready for deployment with the help of ROVs over the Tommeliten field in 1993.

navigation and positioning. Secondly, OBC could never lose its label as expensive, operationally complicated and time-consuming. Reliability was another concern given the vulnerability of cable being laid on the seabed. Norwegian company RXT in the early 2000s had some success in answering some of the critics with its system based on ION's VectorSeis Ocean system. It enabled the first fully digital seabed recording based on MEMS technology.

Evolution of OBN Acquisition

Since the 2008 oil industry E&P market downturn OBC projects have seen a significant decline with no investment in new equipment by the remaining operators. However, the appetite for OBS acquisition continues to steadily increase, and is actually eating into the dominant share of the total marine seismic held by towed streamers. Estimates by inApril and others suggest that OBS represented 14% of the total global seismic expenditure in 2014 and was probably more in 2015. By contrast, in 2006 the OBS share of the market has only been 6%. The growth is attributable to the increasing number of OBN projects around the world as its advantages over OBC have been understood.

Evolution of node-based seabed seismic acquisition can be traced back to the late 1980s. This was when researchers in Statoil, principally Eivind Berg, developed the SUMIC (SUbsea seisMIC) technique of placing four-component sensors on the seabed which would enable the potentially valuable shear waves as well as pressure waves to be recorded. The idea was to allow geoscientists to characterise offshore sequences of sedimentary rocks and contained fluids with greater reliability, and it worked. An account of this development by Lasse Amundsen and Martin Landrø can be found in *GEO ExPro* Vol. 5, No. 4, 2005.

In 1993 the SUMIC four-component autonomous node was tested on the Tommeliten Field, where resolution of 3D towed-streamer seismic was strongly obscured by gas chimneys. The very first section of P-to-S converted data obtained from the horizontal in-line component resulted in a high-quality seismic image. A subsequent test on the Valhall field by Amoco, operator at the time, resolved a similar issue.

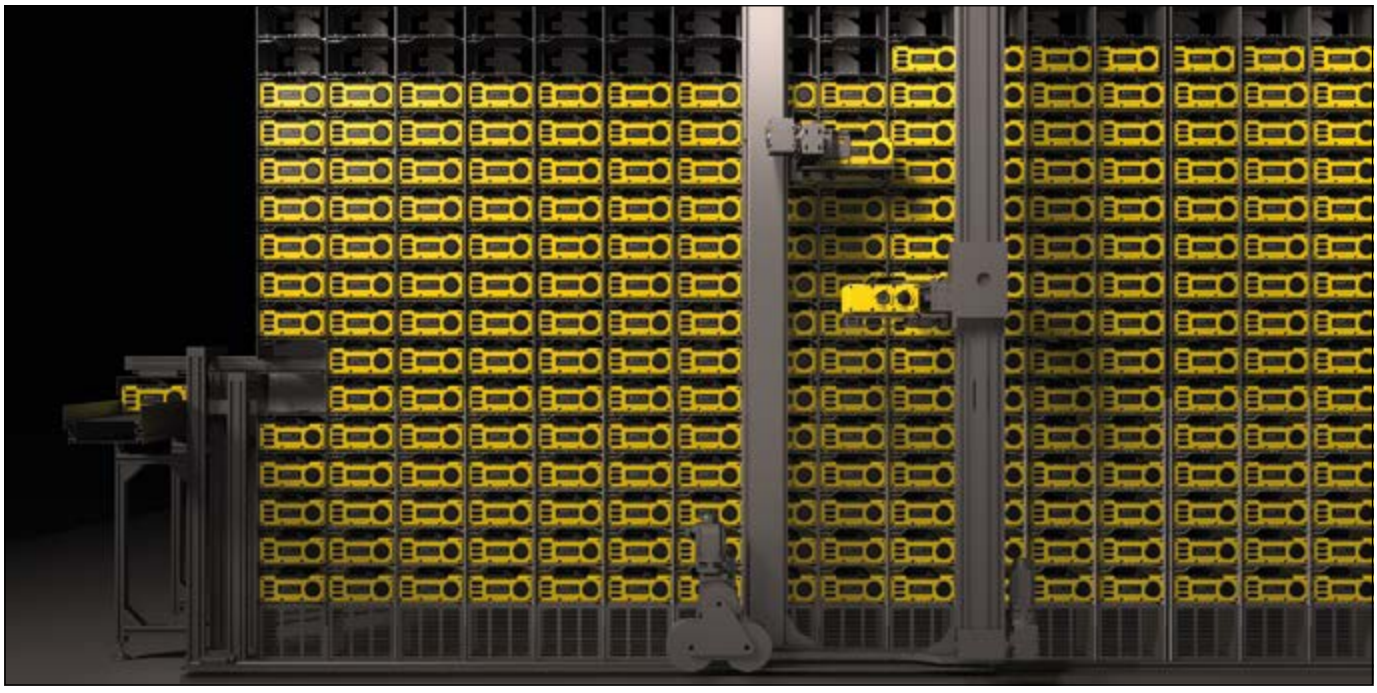
In 1999, Eivind Berg and his colleagues James Martin and Bjørnar Svenning received the very same Virgil Kauffman Gold Medal awarded to Sanders and Barr. Berg went on to be the technical inspiration behind the first dedicated node-based seismic acquisition company, SeaBed Geophysical. In 2003/2004 it carried out a reportedly successful survey for Pemex at the Cantarell field using remotely operated vehicles (ROVs) to deploy more than 1,500 nodes over a total of 230 km^2. It was the company's one and only survey before being taken over by SeaBird Exploration. In 2008 SeaBird took possession of a dedicated vessel that continues to operate today with the same basic technology solution, now under the aegis of Seabed Geosolutions, the Fugro/CGG joint venture.

Versatile and Reliable

Over the last decade, a number of contractors and equipment manufacturers, notably FairfieldNodal, have shown how the versatility and reliability of OBNs can trump OBC operations. Almost without exception major oil companies are stipulating nodes for OBS projects worldwide.

The industry's early hesitation focused mainly on the recording reliability of the nodes, and unlike cable systems, shooting was blind. In other words data could only be checked when the nodes were retrieved, so recording was something of an act of faith.

Bjørnar Svenning, Eivind Berg and James Martin won the 1999 SEG Kauffman Gold Medal for demonstrating that high-quality, high-density marine shear-wave data can be acquired by recording converted waves at the seabed.



Fully automated and space-efficient storage system.

Those reservations have been largely overcome with improved electronics, batteries, recording media and clocks. A reliability of 98% has been claimed for node recorders. Larger spreads can be deployed more efficiently than cable and provide just as good data. There is also a huge built-in redundancy. The failure of an occasional node does not compromise a spread as can be the case with cable.

Even though node-based systems have essentially won the contest for the OBS space, industry demand has proved to be sporadic, mainly deterred by acquisition costs. This was what prompted the establishment of inApril in 2012 with a team who, with career-long experience of the marine seismic industry, believed that a next generation node-based system could create a more sustainable market for OBS. The goal was to provide OBS quality data at dramatically reduced cost, putting more equipment on the seabed with a step change in deployment and recovery efficiency. The result would reduce operating and capital costs for oil companies and contractors in the market for OBS. In a low oil price environment this has become particularly significant. If the price is right, oil companies are likely to look more favourably on reservoir-targeted seismic imaging that can help improve existing oil production rather than embark on new exploration with long lead times before any output revenue. Hence the route to a sustainable OBS market.

Venator nodes on the assembly line.

Just as important, inApril's mission was to introduce an OBN system capable of winning market share in the exploration arena. For example, cost-effective full-azimuth data for complex geology projects will be feasible. This is where towed-streamers have struggled to offer wide-azimuth and similar, very costly, solutions involving multi-vessel operations and/or the sailing of many lines in different directions.

Rethinking the System

The company's starting point was to rethink the whole OBN technical operation and business. The first conclusion was that inApril would not be a contractor, but would instead supply complete systems, including containerised solutions, flexible enough to be installed on many vessel types. Next came the operational and cost issues that have prevented wider adoption of OBN systems.

The main 'disruptive' difference in the performance of inApril's new Venator system comes from its initial design as a node-on-a-rope, fully integrated system with safe and reliable hands-free operation. A deployment and

recovery speed up to 5 knots is possible with nodes at 25m spacing, which is significantly faster than conventional OBN operations, and unlike any other system, the spacing of the nodes can be varied on the rope to suit the geometry of the survey. Some 10,000 nodes can be carried on a single vessel, and are equipped to perform down to water depths of 3,000m. For deeper water and ROV deployment, there is no requirement to change nodes.

The Venator A3000 nodes themselves have exceptional 100-day battery life, which is very important for deep water ROV deployment. The unique built-in acoustics (transponder) allows continuous deployment and recovery during operation with no need to stop the process to attach or remove external positioning devices, as is the case with existing systems.

The nodes have also been designed for optimal, space-saving storage through the automated stacking system. This is facilitated by having the battery charger built into the node, so there are no bulky battery chargers to clog up the storage area. All A3000 nodes are pressure tested to their full depth before leaving the factory and should never be opened on board the vessel.

Engineer monitoring a factory test of inApril´s ocean bottom nodes.

These and other features resulted from designing the Venator system in collaboration with leading Norwegian companies specialising in industrial automation and advanced data management. The full package is expected to reduce the cost of OBN seismic acquisition by up to 70% in some cases and a commensurate reduction of Capex for oil industry customers of up to 50%. Hopefully this will help to focus more oil companies' and contractors' attention on the possibilities of OBN seismic applications. The first commercial trial of the Venator system is due to take place in the Caspian Sea in October. ■

Codes and Ciphers

Simultaneous Source Separation PART II

JOHAN O. A. ROBERTSSON and DIRK-JAN VAN MANEN
ETH Zurich, Institute of Geophysics, Switzerland;
LASSE AMUNDSEN and MARTIN LANDRØ

Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things.

Sir Isaac Newton

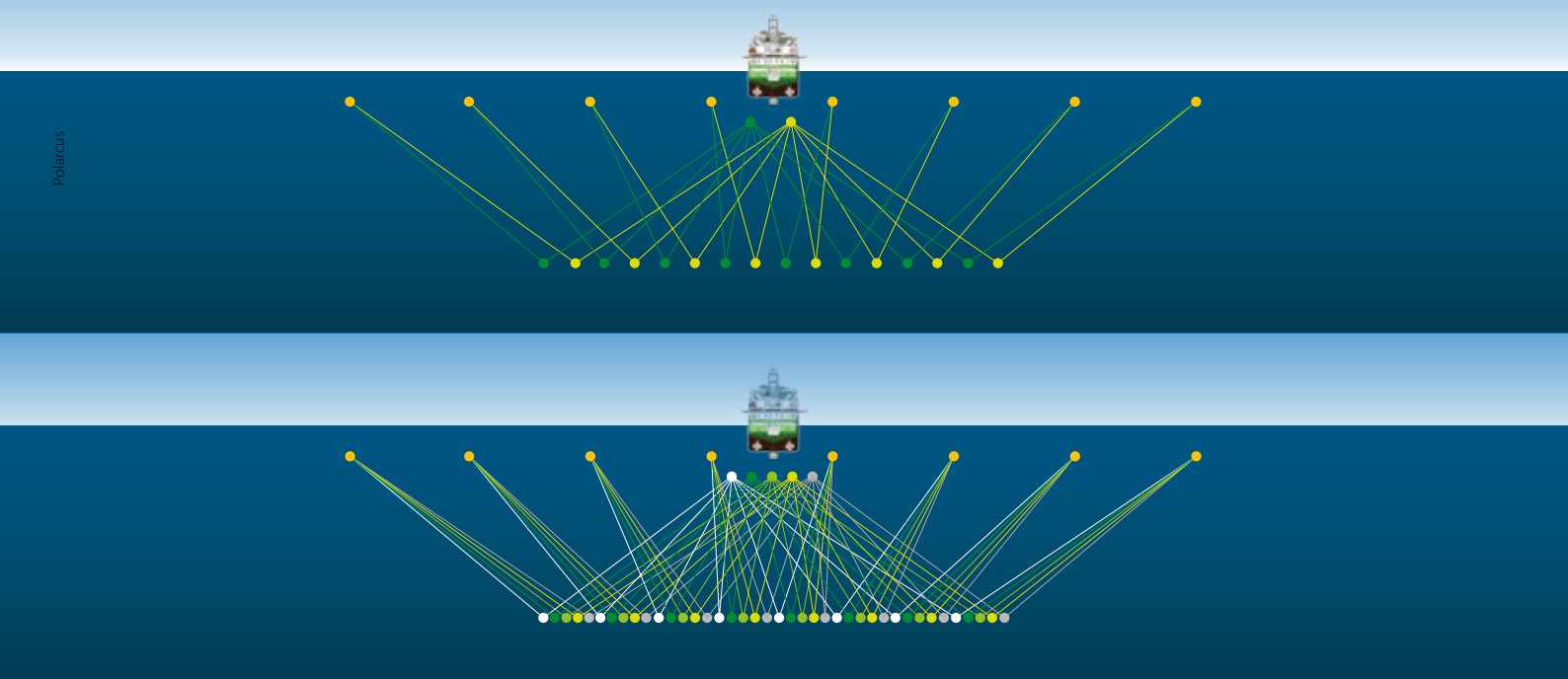
Marine seismic data acquisition is changing rapidly. One of these developments is the use of so-called 'simultaneous sources', where multiple seismic sources that intentionally interfere with one another are activated simultaneously. Proposed and demonstrated over 15 years ago, the subject of marine simultaneous sources saw long fallow periods when nothing seemed to happen until the uptake of wide-azimuth surveys and, more recently, when the industry needed to improve the way in which geophysicists deliver high quality data while maintaining viability in a cost-focused market. The goal is to challenge conventional thinking and explore what could be the solutions of the future.

Traditionally, seismic data have been acquired sequentially: an impulsive source is fired and data are recorded until the energy that comes back has diminished and all reflections of interest have been captured, after which a new shot at a different location is fired. Being able to acquire data from several sources at the same time is clearly highly desirable, as the example acquisition configuration in Figure 1 suggests. Not only would it allow us to cut expensive acquisition time drastically, but it would better sample the wavefield on the source side, which typically is much more sparsely sampled than the distribution of receiver positions. It would also allow for better illumination of the target from a wide range of azimuths and would acquire more data from the wavefield in areas with surface obstructions. In addition, for some applications such as 3D VSP acquisition, or marine seismic surveying in environmentally sensitive areas, reducing the duration of the survey is critical in order to save costs external to the seismic acquisition itself (e.g., down-time of a producing well) or to minimise the impact on marine life (e.g., avoiding mating or spawning seasons of fish species).

Simultaneous Source Seismic Data Acquisition

Simultaneous sources have a long history in land seismic acquisition, dating back at least to the early 1980s.

Figure 1: Example of using multiple sources on one vessel to increase cross-line sampling density. Top: In conventional sequential shooting, one source (green) is fired at a first location yielding the subsurface points dotted green and the second source (yellow) is fired at a second location, typically 25m away, giving the subsurface points dotted yellow. In simultaneous shooting, both sources are fired together, thus improving the cross-line trace density. Bottom: By extending the concept to a five source configuration a significant increase in data density is achieved. The challenge for the geophysicist is to intelligently 'encode' the sources so that the overlapping data measurements can be 'decoded' into data that would be acquired from each individual source.



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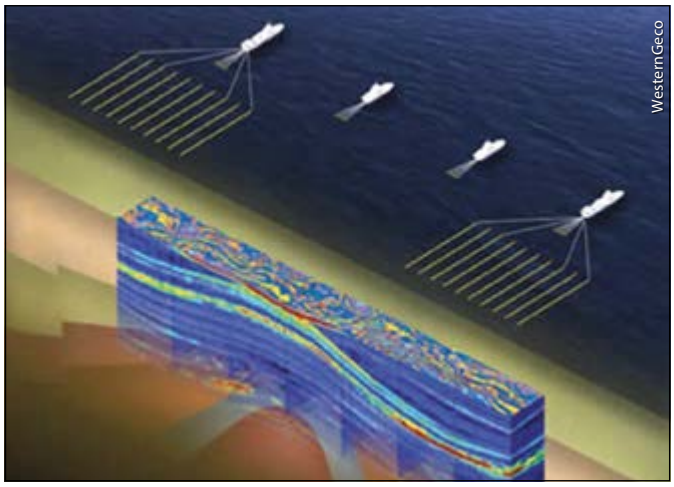


Figure 2: Four-vessel approach to wide-azimuth seismic utilises two recording vessels towing streamers with sources plus two source-only vessels. The distance between each vessel is typically 1,200m (Moldovenau et al., 2008).

Commonly used on land are vibroseis sources, which offer the possibility of illuminating the subsurface with source signal sweeps designed to 'share' the use of certain frequency bands, avoiding simultaneous interference at a given time from different sources. By carefully choosing source sweep functions, activation times and locations of different vibroseis sources, it is possible to mitigate interference between sources. Such approaches are often referred to as slip-sweep acquisition techniques. Moreover, it is also possible to design sweeps that are mutually orthogonal to each other such that the response from different sources can be isolated after acquisition through simple cross-correlation procedures with sweep signals from individual sources.

The use of simultaneous source acquisition in marine seismic applications is more recent, as marine seismic sources (i.e. airguns) do not appear to yield the same benefits in providing orthogonal properties as land seismic vibroseis sources do, at least not at first glance.

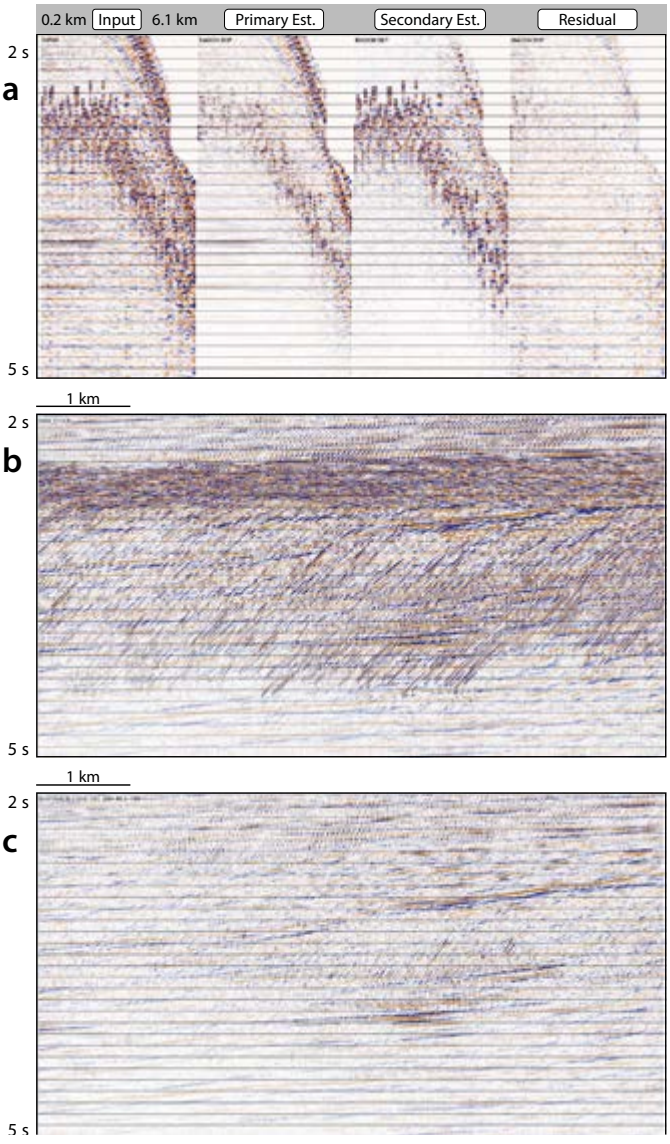
Western Geophysical was among the early proponents of marine simultaneous source seismic acquisition, and suggested that separation was carried out as a pre-processing step by assuming that the reflections caused by the interfering sources have different characteristics. Beasley et al. (1998) exploited the fact that, provided that the subsurface structure is approximately layered, a simple simultaneous source separation scheme can be achieved, for instance, by having one source vessel behind the spread acquiring data simultaneously with the source towed by the streamer vessel in front of the spread. Simultaneous source data recorded in such a fashion is straightforward to separate after a frequency-wave number (fk) transform, as the source in front of the spread generates data with only positive wave numbers, whereas the source behind only generates negative wave numbers.

The Stochastic Approach

Another method for enabling or enhancing separability is to make the delay times between interfering sources incoherent (Lynn et al., 1987). Since the shot time is known for each source, they can be lined up coherently for a specific source in, for instance, a common receiver gather or a common offset gather, where all arrivals from all other simultaneously firing sources will appear incoherent. To a first approximation it may be sufficient to just process the data for such a shot gather to a final image, relying on the processing chain to attenuate the random interference from the simultaneous sources. However, it is, of course, possible to achieve better results, for instance through using random noise attenuation to separate the coherent signal from the apparently incoherent signal (Stefani et al., 2007).

In recent years, with elaborate acquisition schemes to, for example, acquire wide azimuth data with multiple source and receiver vessels (Figure 2), simultaneous source acquisition has become a hot topic of research and several authors have described methods that separate 'random dithered sources' through sophisticated inversion approaches which exploit the

Figure 3: Simultaneous source acquisition separation result from a dataset from the Gulf of Mexico. (a) A CMP gather of input, primary estimate, secondary estimate and residual. (b) A stack section without secondary suppression. (c) Same section as in b), but with secondary suppression and subsequent diversity noise attenuation. (Reproduced from Akerberg et al., 2008. Chevron is thanked for the permission to show the dataset.)



sparse nature of seismic data in the time-domain (i.e., seismic traces can be thought of as a subset of discrete reflections with 'quiet periods' in between). Figure 3 illustrates the results using such an approach by co-workers at Chevron and presented in a paper by Akerberg et al. (2008).

A different approach to simultaneous source separation has been to modify the source signature emitted by airgun sources, which comprise several (typically three) sub-arrays along which multiple clusters of smaller airguns are located. As, in contrast to land vibroseis sources, it is not possible to design arbitrary source signatures for marine airgun sources, in principle one has the ability to choose firing time (and amplitude i.e., volume) of individual airgun elements within the array, meaning it is possible to choose source signatures that are dispersed as opposed to focused in a single peak. Such approaches have been proposed to reduce the environmental impact in the past (Ziolkowski, 1987) but also for simultaneous source shooting. Abma et al. (2015) suggested using a library of 'popcorn' source sequences to encode multiple airgun sources such that the responses can be separated after simultaneous source acquisition by correlation with the corresponding source signatures, following a practice that is similar to land simultaneous source acquisition. The principle is based on the fact that the cross-correlation between two (infinite) random sequences is zero whereas the autocorrelation is a spike. It is also possible to choose binary encoding sequences with better or optimal orthogonality properties such as Kasami sequences (discussed in Part I) to encode marine airgun arrays (Robertsson et al., 2012). Mueller et al. (2015) propose to use a combination of random dithers from shot to shot with deterministically encoded source sequences at each shot point.

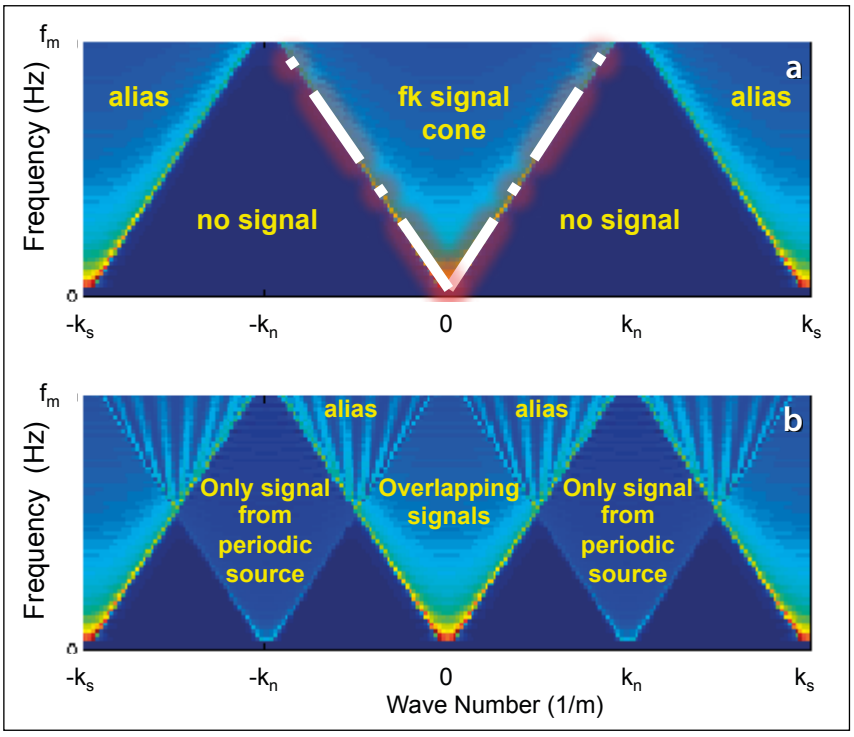


Figure 4: (a) In geosciences, we plot time-offset data (not shown) in frequency-wave number (fk) diagrams to examine the direction and apparent velocity 2πf/k of seismic waves. Here f_m is the maximum frequency; k_s the spatial sampling frequency; and $k_n = k_s/2$ is the spatial Nyquist frequency. Typically, seismic data plots into the fk signal cone bounded by the dashed white line, determined by the water speed. Observe that there is plenty of 'space' in fk that has no signal. This is utilised in seismic apparition by designing periodic source sequences that place seismic energy into this empty space. (b) For two sources shot simultaneously, the seismic apparition technique samples two source wavefields, sampled at spatial frequencies k_s and $k_s/2$ respectively. The cone centred around k=0 contains information about both source wavefields (overlapping signals). The cones centred around k_n, however, only contain information from the source that has been fired in a periodic way. By intelligent data processing, the data from the two sources can be decoded.

Recently, there has been industry interest in exploring the feasibility of marine vibroseis sources, as they would, among other things, appear to provide more degrees of freedom to optimise mutually orthogonal source functions beyond just binary orthogonal sequences, which would allow for a step change in simultaneous source separation of marine seismic data. However, we believe the engineering challenges of a marine vibroseis source are immense and the robustness and ability to provide the broad spectrum of the marine airgun array are very hard to match using other source technologies.

The Deterministic Approach: Seismic Apparition

A recent development, referred to as 'seismic apparition', suggests an alternative approach to deterministic simultaneous source acquisition. Robertsson et al. (2016) show that by using simple modulation functions from shot to shot (e.g., a simple short time delay or an amplitude variation), the recorded data on a common receiver gather or a common offset gather will be deterministically mapped onto known parts of, for example, the *fk*-space outside the conventional 'signal cone' where conventional data is strictly located (Figure 4a). The signal cone contains all propagating seismic energy with apparent velocities between water velocity (straight lines with apparent slowness of +-1/1,500 s/m in *fk*-space) and infinite velocity (i.e., vertically arriving events plotting on a vertical line with wave number 0). The shot modulation generates multiple new signal cones that are offset along the wave number axis thereby populating the *fk*-space much better and enabling exact simultaneous source separation below a certain frequency (Figure 4b). Robertsson et al. (2016) referred to the process as 'wavefield apparition' or 'signal apparition' in the meaning of 'the act of becoming visible'. In the spectral domain, the wavefield caused by the periodic source sequence is nearly 'ghostly apparent' and isolated.

The word 'spectrum' was introduced by Newton (1672) in relation to his studies of the decomposition of white light into a band of light colours, when passed through a glass prism (Figure 5). This word seems to be a variant of the Latin word 'spectre', which means 'ghostly apparition'. A critical observation and insight in the 'seismic apparition' approach is that partially shifting energy along the *k*-axis is sufficient as long as the source variations are known, as the shifted energy fully predicts the energy that was left behind in the 'conventional' signal cone. Following this

methodology, simultaneously emitting sources can be exactly separated using a simple modulation scheme where, for instance, amplitudes and/or firing times are varied deterministically from shot to shot in a periodic pattern.

Call for Revolution?

It has been suggested that simultaneous source separation is an unnecessary step as all that matters is the spatial and temporal spectrum of the energy that illuminates the subsurface. It has been argued that as long as the conventional approach of regarding seismic data as a sequence of single shot records is abandoned, it would be possible to create images of the subsurface from the total energy that illuminates it, whether from surface-related multiples or simultaneously emitting sources. Although such a philosophy appears appealing it would call for a revolution in the way that seismic data are processed and imaged, quite different from the conventional approach of imaging based on the separation of the velocity model-building step from the imaging step, introduced by Jon Claerbout in the 1960s.

Other Applications

Finally, simultaneous source acquisition has other applications of interest to seismic imaging. In particular, in modelling and inversion the computational cost can be reduced proportionally if it were possible to generate the response to multiple sources during a single finite difference simulation, for example. Although there are some promising developments on the horizon, the silver bullet to crack this problem has not yet appeared. The key to unlock this grand challenge may well lie somewhere amongst the approaches discussed in this pair of articles.

References available online. ■

Figure 5: The word 'spectrum', from the Latin word 'spectre' which means 'ghostly apparition', was introduced by Newton (1672) in relation to his studies of the decomposition of white light into a band of light colours, when passed through a glass prism. Prior to Newton's work, people believed that colour was a mixture of light and darkness, and that prisms coloured light. To show that they did not, Newton refracted the light back into single white light. 'Seismic apparition' is a buzz phrase, introduced by two of the authors in relation to simultaneous source separation. Engraving after a picture by John Adam Houston (1811–1884), ca. 1870.

Doha

The Pearl of Qatar

Over the last 70 years, Doha has risen from the sands of the desert to become a major, glamorous regional power.

ELEANOR ARCHER

Qatar is a peninsula 160 km long and up to 100 km wide,, lying halfway down the Arabian Gulf and joined on its only land border to Saudi Arabia in the south. As the financial hub of the country, over half the population of Qatar now lives in its capital city, Doha, although Qatari nationals are a small minority of its inhabitants, with large numbers of citizens coming from all over the world and particularly from south-east and south Asian countries.

Pearls and Poverty

Originally a small settlement called 'Al-Bida,' the the part of Qatar which is present-day Doha has possibly been inhabited since as early as 4000 BC. By the 8th century, the area had become a fishing and pearl trading centre. A reasonably large town must have existed here at the time, as excavations have discovered 9th-century mosques and a fort. However, there is little trace today of these early inhabitants, or indeed the Portuguese or Ottoman Empire rulers who followed in the 16th, 17th and 19th centuries.

The Al-Thani family, a branch of the ancient Tamim tribe of central Arabia, currentl y leads the country, and has been in power since the mid-18th century, when they settled in Al-Bida and made it the capital. The Ottomans officially renounced sovereignty over Qatar in 1913, and the Al Thani family signed a treaty with Britain, putting Qatar under British 'protection' until independence in 1971.

Despite the pearl industry, the Al-Bida area was never affluent, and there was widespread poverty and malnutrition, as well as frequent skirmishes with their neighbours in Bahrain.. With the collapse of the pearl market in the 1920s, due to the introduction of Japanese cultured pearls, followed by the Great Depression of the 1930s which made pearls an unaffordable luxury item, this poverty increased. The disruption of food supplies caused by the First World War further prolonged this period of economic hardship in the country.

Jane Whaley

The Souq Waqif is the social heart of Doha. Built to replace the old market in 2003, it cleverly resembles a 19th-century souq, with mud-rendered shops, exposed timber beams and some beautifully restored original Qatari buildings. It's a wonderful place to sit in the cool of the evening and watch the world go by.

Economic Growth

In 1935 the Anglo-Iranian Oil company was granted a concession to explore for oil onshore Qatar. Operating as Qatar Petroleum Co. it made the first discovery, Dukhan 1, in 1940, but due to WWII the first crude exports did not occur until 1949, marking a financial turning point for the country. In 1952, Shell Co. Qatar acquired exploration rights to most of the offshore territory, and in the mid-1970s the government took over these companies, and the oil and gas industry in Qatar was nationalised.

Today's Doha has been built primarily on the revenue the country has made from its oil and natural gas industries, turning Qatar into one of the richest per capita countries in the world. Qatar Petroleum, Qatargas and RasGas all hold their headquarters in the city.

In line with this economic growth, a hugely accelerated modernisation of the capital has taken place since the 1950s. Most traditional architecture in the Old Doha districts was demolished to make space for new buildings. By 2011, more than 50 glamorous towers were under construction in Doha. One of the more major projects launched by the government was 'The Pearl-Qatar', an artificial island available for ownership by foreign nationals (the first land in Qatar to be

Jane Whaley

Doha's modern skyline.

so) providing over 32 km of new coastline, and an anticipated 18,831 dwellings and 45,000 residents by 2018. The Pearl is one of the many waterfront attractions, where locals and tourists can stroll along the promenade in the cooler months, admiring the views across the waterfront of traditional dhows amongst the backdrop of the West Bay's skyscrapers.

Traditional dhows on the modern waterfront.

In 2014 it was announced that Qatar would be spending $65 billion on new infrastructure projects in upcoming years, partly in readiness for hosting the 2022 World Cup. This preparation includes the building of three stadiums and a new metro system. In line with this, Doha has been developing as a growing tourist destination to rival its emirate neighbours, with many high class hotels catering for the visitors that fly in to attend some of the high profile events the city holds. Shopping in particular has developed as a popular past time for both locals and tourists, with lavish malls catering for all needs. Of note is the Italian-inspired Villaggio mall, which offers shoppers the opportunity to sail past high end stores on a gondola underneath painted clouded skies.

Traditions Endure

The rise in financial income has had an influence not only on the architecture of the city, but also social reforms. Education in particular has gone through continuing change since the first school was opened in 1952. Doha now proudly contains Education City, which comprises facilities from school to university level, including international Qatari branches of esteemed institutions such as University College London and Virginia Commonwealth University, as well as the locally owned Qatar Faculty of Islamic Studies. It also acts as a forum from which universities can share research with businesses and institutions.

Whilst there may be physically little left of the past, the roots of the country have not been lost in the traditions of the Qatari people in Doha today. The clearest display of these ongoing traditions can be seen in the winding alleys of the Souq Waqif. A souq, or market, has been on the site for centuries as a trading point for the Bedu and was redeveloped in the 1970s to resemble a 19th-century souq. Despite modern development, the souq continues the traditions of the country, and is a place to buy beautifully embroidered traditional dress, spices and incense, gold, and even camels and Arabian horses. It also contains the falcon market and hospital, demonstrating the important role the sport of falconry has always had in Qatari society, while the gold souq continues to be the destination for buying lavish jewellery. ■

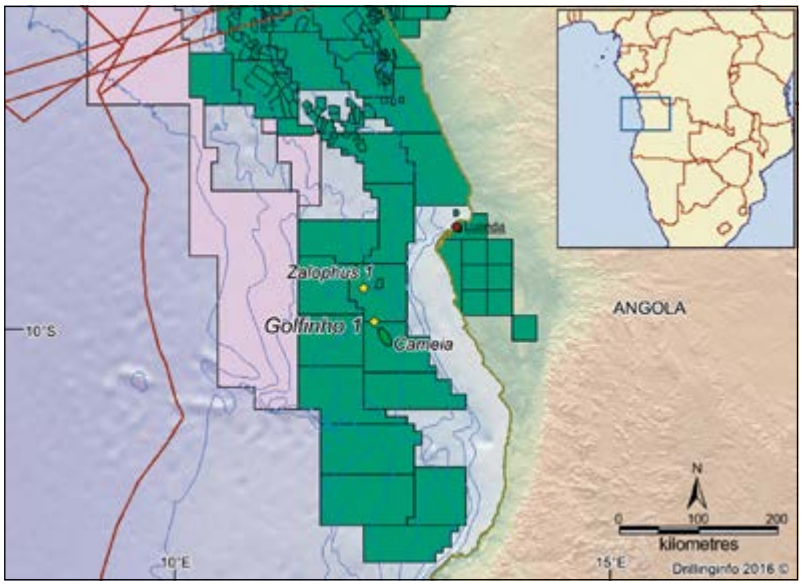
Angola: Another Pre-Salt Find

Since the Cameia discovery in 2012 confirmed the presence of an expansive pre-salt hydrocarbon reservoir in the deepwater offshore **Angola**, there has been a continuing flow of finds at this level in the country. The latest of these, new field wildcat **Golfinho 1** in Block 20/11, was announced by **Cobalt** after drilling completed in June this year. It followed on from the Zalophus 1 NFW, also drilled by the *SSV Catarina* earlier in the year, which discovered gas and condensate in 44m net pay in the pre-salt on the same block. Sonangol estimates in-place resources to be 813 MMboe, 313 MMbc and 2.8 Tcfg.

Golfinho, thought to be an oil discovery, lies on the southern part of Block 20/11, about 70 km south of Zalophus and along trend with Cameia, in about 1,700m of water. Cobalt say that early analysis of the Golfinho well results indicates potential for another large mound feature with similar fluid and reservoir properties to Cameia, which is a very large 4-way dip closure in an Aptian carbonate reservoir, located immediately below the base of the salt.

Cobalt has drilled eight NFWs over Block 20/11 and Block 21/09 since 2012, making seven discoveries, an 88% success rate, and estimates it has discovered about 1.3 Bb of gross resources in these blocks offshore Angola.

With the drilling of Golfinho, the company has met its work commitments under the current PSC. The company had been looking to farm-out its 40% stake in the blocks to Sonangol P&P, but this transaction terminated in August and Cobalt is now looking for new interested parties. Equity in Block 20/11 is split between operator Cobalt (40%), BP (30%) and Sonangol P&P (30%). ■



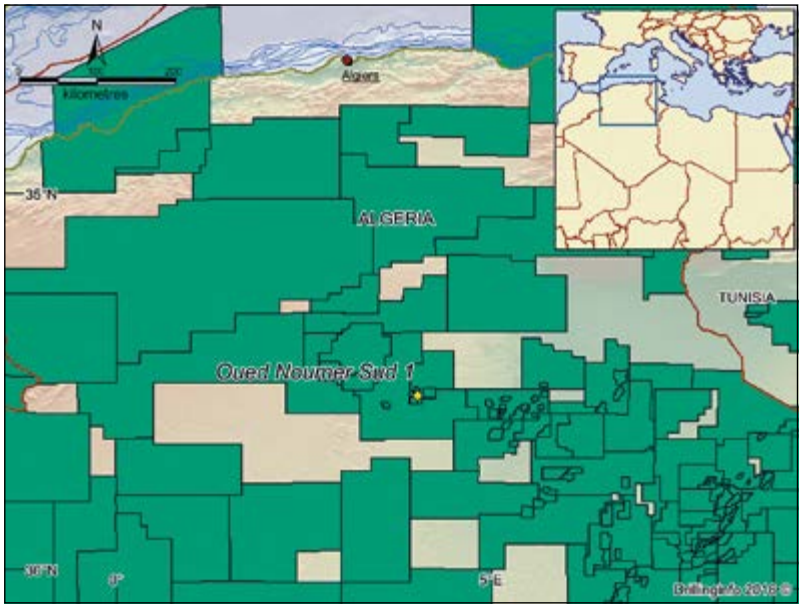
Algeria: Triassic Discovery

During early June 2016, **Sonatrach** made an oil and gas discovery in **Algeria** with its **Oued Noumer Sud 1 (ONRS 1)** new field wildcat. The discovery is located on the Zelfana exploration licence, about 200 km south of the capital, Algiers, in the northern part of the **Oued Mya Basin**.

The Oued Mya Basin lies in north-central Algeria and is one of the most important petroliferous basins in the country, after the Ghadames and Illizi basins. The stratigraphic section consists of about 5,000m of Palaeozoic and Mesozoic sediments. Exploration in this basin started in 1956 and it contains a number of important fields, including Berkaoui, Benkahla, Aitkheir and Oued Noumer. Oued Noumer Sud 1 lies to the south of the Oued Noumer oil field, which was discovered in 1969, about 30 km west of the town of Ghardaia. On stream since December 1985, Oued Noumer has a system recovering gas, a 50 km gas-gathering pipeline and a three-train compression plant with processing lines for dehydration and gas-oil separation.

ONRS 1 was spudded on 13 March 2016 and drilled using the *ENAFOR #51* rig. It reached a TD of 2,950m in the Ordovician micro-conglomerate on 1 May 2016. A cased-hole DST of the Triassic T2A interval between 2,743–2,760m was carried out by Schlumberger. The well flowed at a maximum rate of 3,722 bopd and 4.6 MMcfgpd, on a 32/64" choke and at a WHP of 2,180 psi. Production tubing has now been set at 2,715m.

Sonatrach was awarded Zelfana in September 2015 and operates the licence with 100% equity. ■

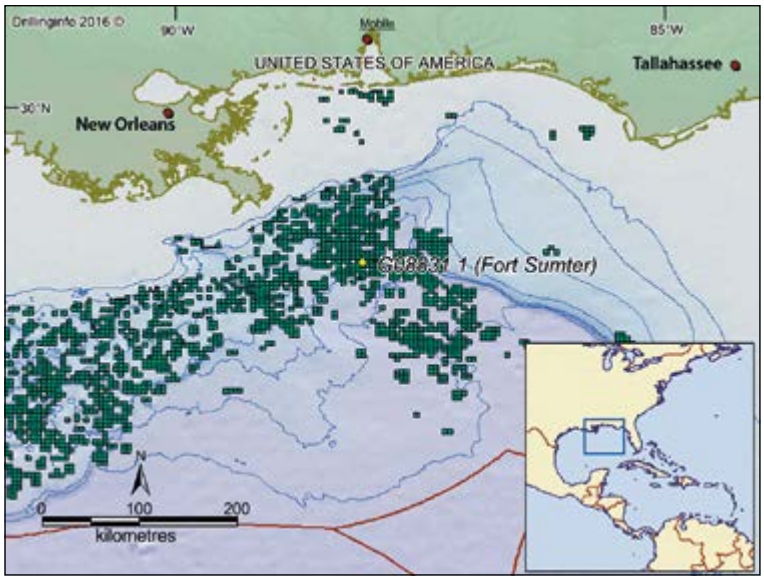


US: Mississippi Canyon Discovery

On 28 July 2016, **Shell** announced that it had made a hydrocarbon discovery with the **Fort Sumter** discovery well (G08831 1), situated in the 23 km^2 **Mississippi Canyon Block MC 566** in the **Gulf of Mexico** Basin, approximately 117 km south-east of New Orleans. The well, which was spudded on 13 September 2015, was drilled in a water depth of 2,152m to a TVD of 8,539m measured depth. An appraisal sidetrack well was subsequently drilled, reaching TD of 8,900m on 1 February 2016. The initial recoverable resources for the Fort Sumter discovery well have been estimated at over 125 MMboe. Shell believes that its proximity to highly prospective acreage to the south-east makes Fort Sumter particularly significant.

The Fort Sumter discovery lies in an offshore extension of the prolific onshore Northlet Jurassic play, which is characterised by high pressures and well temperatures, and where good quality oil is found in high quality Jurassic sandstone reservoirs. Other recent offshore Norphlet exploration successes for Shell include the Appomattox (2010) and Vicksburg (2013) discoveries, which lie about 25 km to the north-east, and the 2014 Rydberg find, 15 km to the east-north-east. It brings the total resources added by exploration in the Gulf of Mexico for Shell since 2010 to around 1.3 Bboe. These discoveries are expected to be produced through Shell's Appomattox project, which is currently under construction. The project is comprised of a semi-submersible, four-column production host platform. Its subsea system will feature six drill centres as well as 15 producing wells and five water injection wells.

Shell is the operator and sole interest-holder in the lower portion of MC 566. BP is the operator of the upper portion, with Shell holding 100% of the equity. ■



Promoting the UKCS

The UK Oil and Gas Authority was recently set up as the regulator for both onshore and offshore oil and gas operations in the United Kingdom. Director of Exploration, Production and Decommissioning, Gunther Newcombe, tells us about its work and aims.

What is the remit of the OGA and how long has it been in existence?

The OGA was established in April 2015 as an Executive Agency of the Department for Business, Energy and Industrial Strategy (formerly known as DECC) following the publication of Sir Ian Wood's report, *UK Continental Shelf (UKCS) Maximising Recovery Review*, in early 2014. The fluctuations in oil price since have created a challenging economic environment right across the operator and service sector chain, impacting on companies and on employees personally affected by the global downturn. This has underlined the need for a structural change in the way the UK oil and gas industry does business and galvanised a collaborative approach from government, industry and the OGA.

The overarching objective of the OGA is clear: to maximise economic recovery (MER) from the UKCS, supported by the MER UK Strategy which came into force in March 2016. Part of this is through our role as a regulator, licensing onshore and offshore oil and gas and carbon storage in a flexible and pragmatic way, but it's about much more than that. We want to influence wider industry culture and behaviours, encouraging collaboration and promoting the UKCS as a basin still very much open for business and investment.

In October 2016 the OGA will be established as an independent government company, which formalises our position as a strong and effective authority with a full suite of regulatory powers including the ability to participate in meetings, access data, provide dispute resolution and introduce a range of sanctions and fines up to £1 million. Like the industry, we are bound by the obligations of the MER UK Strategy. We will continue to deliver on our priorities to drive collaboration, and to promote the remaining prospectivity of the UKCS, using our powers to have a positive, transformational effect.

Gunther started his 35-year career with BP as a well-site engineer and geologist and has worked in London, Germany, China, Aberdeen, Norway, Indonesia, Houston and Venezuela.

How are the OGA and government working to best help the industry?

We recognise exploration is key to revitalising the UKCS – it helps protect jobs, skills and the supply chain. Exploration drilling levels remain very low and we are working with industry to reverse this trend. High success rates and notable discoveries in the last 12 months highlight the remaining prospectivity within the UKCS.

Following the 2015 UK government-funded seismic shoot, which acquired more than 40,000 line-kilometres of new and reprocessed data from the Rockall and Mid-North Sea High (MNSH) areas, the data was made freely available in April 2016 and more than 7,000 data packages were subsequently downloaded by 65 companies and 14 universities, and provided on hard disk to many others. The success of this project led to the government awarding another £20 million for a second seismic shoot this summer. Following engagement with industry, the areas of South West Britain and the East Shetland Platform were selected. These surveys are expected to finish later this year and the data is scheduled for release to industry in Q2 2017.

As part of the 21st Century Exploration Roadmap project, we completed and published a rigorous analysis of the root cause of failed wells drilled in the Moray Firth and Central North Sea between 2003 and 2013. This highlighted the opportunity for significant improvement in technical work to avoid drilling poor prospects and prompted us to further implement a rigorous pre- and post-drill evaluation quality assurance process with operators in order to share lessons learnt from dry-hole analysis.

To support the next generation of geoscience professionals, we have provided £700,000 towards the development of a new 3D visualisation facility at the Lyell Centre at Heriot-Watt University in Edinburgh. It will benefit from state-of-the-art equipment for interpreting complex geological and engineering data. In addition, we have awarded £750,000 to support three post-doctoral appointments at Aberdeen, Heriot-Watt and Durham Universities.

Tell us about the recent OGA licence competition.

This competition was announced by the then Prime Minister, David Cameron, in January 2016 as part of a package of government support measures for the oil and gas industry. It was designed to encourage geoscientists to develop innovative interpretations and products using the data acquired during last year's successful £20 million government-funded seismic surveys of the Rockall Basin and MNSH areas.

Following more than 60 applications from around the world, £200,000 was awarded to nine companies for feasibility studies and last month an additional £213,000 was awarded to three of those companies to complete their projects. The

successful schemes included a hand-contoured depth-to-basement model of the Rockall and MNSH areas to provide insight into the foundation of the geological basement; a not-for-profit consultancy's research focusing on source rock geochemistry; and finally, a small start-up integrating rock physics into the interpretation of the MNSH data set.

Despite the global downturn in the oil and gas industry, the overwhelmingly positive response to this competition highlights the tenacity and talent of the global geoscience community. All the projects submitted will provide greater insight into our understanding of the Rockall Trough and Mid-North Sea High areas, while adding value to our evaluation of 29th Offshore Licensing Round applications.

Given the high quality of the technical work delivered by all applicants, there is also the option for products to be integrated into other OGA exploration initiatives, such as the production of regional geological maps, to proactively influence and incentivise exploration on the UKCS.

How will the new Innovate Licence help?

The 'Innovate Licence' has been developed by the MER UK Exploration Board working in collaboration with OGA, the Department for Business, Energy and Industrial Strategy and an industry task group represented by a range of companies. Launched in time for the 29th Offshore Licensing Round, it replaces the four types of licences that were previously available within the UKCS. Feedback we received from industry highlighted the need for a change.

The Innovate Licence, which has a maximum period of nine years, offers a more flexible and pragmatic approach to licensing with potentially three sub-phases of activity and work commitments. We will work closely with licence holders to ensure appropriate work programmes are managed and delivered during each phase.

Is looking after assets important in ensuring MER?

A key outcome of the Wood Report was the establishment of an Asset Stewardship Strategy that sets clear expectations for industry on critical stewardship factors and enables us to work with each joint venture partnership to make certain they are met. The objective is to ensure that the OGA, operators and licensees are provided with the data, information, guidance and performance improvement steps required to undertake stewardship of their assets and infrastructure, consistent with the obligations set out by the MER UK Strategy.

Asset stewardship has four strategic elements, which include setting best practice stewardship expectations; a rationalised industry data survey to remove complexity and duplication; utilising UKCS data to benchmark assets for production efficiency, OPEX and decommissioning costs; and stewardship reviews between the OGA, operators and licensees.

Stewardship expectations and the rationalised industry data survey are expected to begin in the last quarter of 2016, with the first full cycle of asset stewardship, including reviews and benchmarking, complete by 4Q 2017. ■

Some Basic Facts

Oil is still no. 1, but renewables are picking up fast – very fast.

Global energy consumption grew by only 1.0% in 2015. This is in line with 2014 (1.1%), but considerably slower than over the last decade (1.9%). In spite of this there was a solid growth in the use of oil, gas and renewable energy (solar and wind) – all according to *BP Statistical Review of World Energy 2015*.

Coal is losing out with a reduction in consumption of 1.8%, and its share of primary energy is reduced to its lowest level since 2005. Coal being the worst polluter, this is good news for global emissions of CO_2, and China is leading the way. Over the next five years, coal production will be reduced by 500 million tons a year, according to *enerdata.net*. This means a reduction in CO_2 emissions of about 1 billion tons for China alone. The world's total emissions are 35 billion tons per year.

The use of renewable energy in power generation grew by **15.2%**, only slightly less than the average growth over the previous 10 years of 15.9%. If growth continues at the stunning rate of 15% for the next 20 years, it means that the use of renewables will multiply itself 16 times by 2035. It is also noteworthy that China had an increase in its use of renewables of 20.9%. Worldwide, renewables account for 6.7% of global power generation.

Needless to say, the change in energy mix means a lot for the carbon budget. And we do see the positive results right now: last year global emissions rose by only 0.1%. Less coal and more renewables explain this fact.

Amongst fossil fuels, oil accounted for **32.9%** of global energy consumption in 2015, and global oil *consumption* grew by 1.9 MMbopd. Interestingly, global *production* grew by 2.8 MMbopd to a total of **91.7 MMbopd**. The US remained the world's largest oil producer with 12.7 MMbopd, some 600 Mbo ahead of Saudi Arabia. For comparison, the US used 19.4 MMbopd out of a world total consumption of 95 MMbopd.

You can spend days analysing the data provided by the *BP Statistical Review of World Energy*. To me it seems obvious that renewables are to be reckoned with in the (near) future.

Halfdan Carstens

The growth in the use of renewables is phenomenal. The last 10 years have seen an increase of 15% in every year.

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.

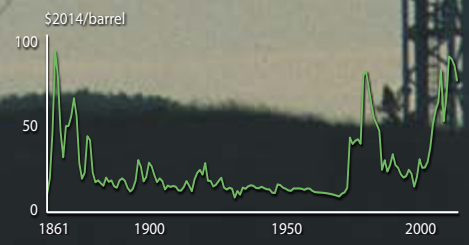
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

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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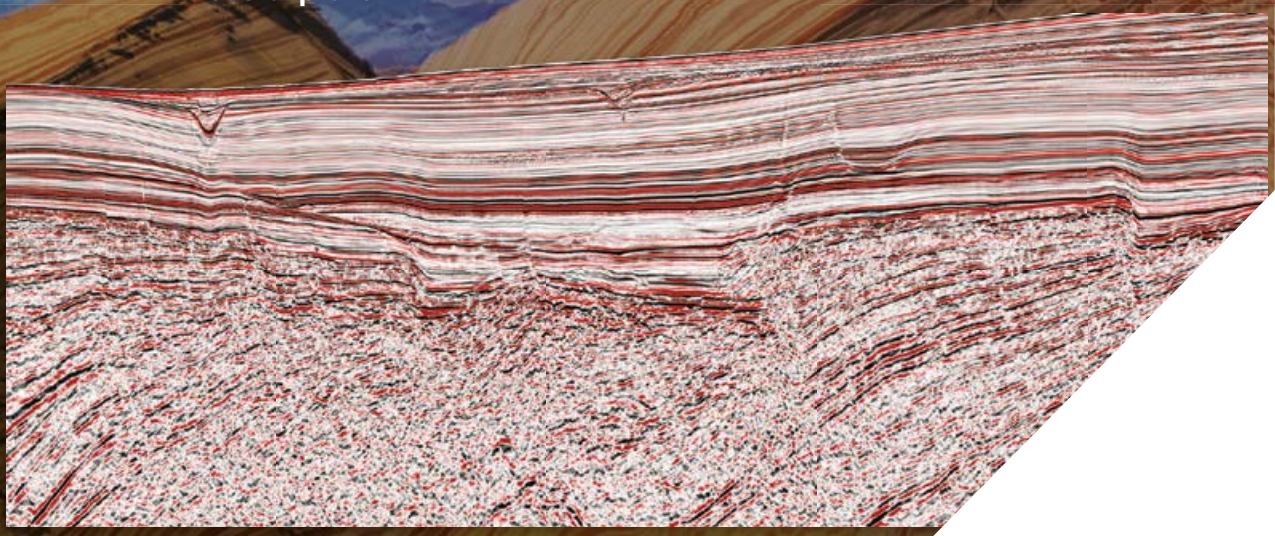
TGS has over 34,000 km of 2D seismic data and a DSDP well package available in Namibia. Last year TGS completed reprocessing of over 10,000 km of the N2R93RE15 survey and has completed an initial phase of reprocessing of Walvis-11RE16 using Clari-Fi™ Broadband technology. The deeper plays are even more clearly illuminated and Atlantic rifting features more visible, now in high resolution broadband clarity.

Let's explore.



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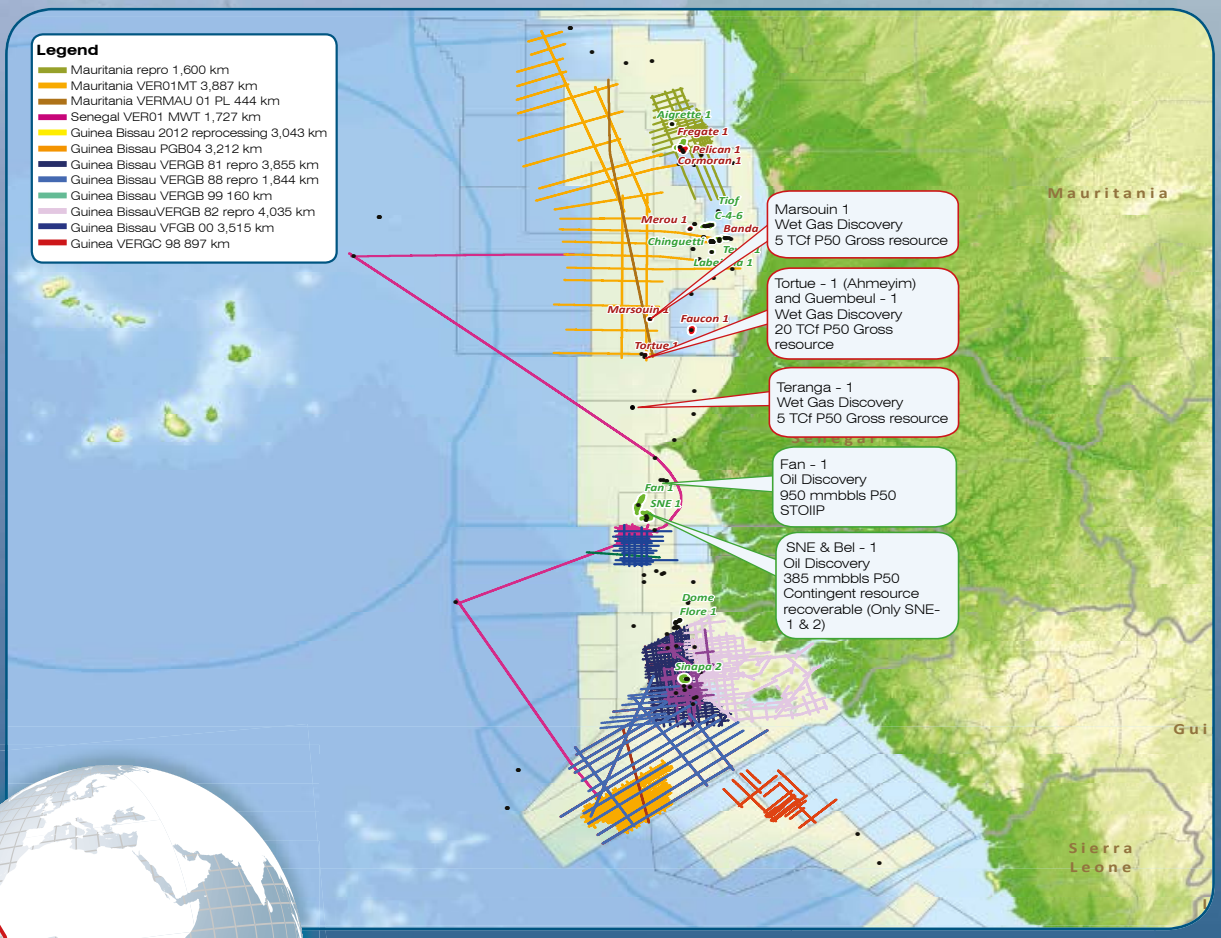

Recent hydrocarbon discoveries in the deep water offshore Mauritania and Senegal have significantly de-risked Cretaceous clastic plays along the North West African margin and opened up the outboard petroleum system. Spectrum's highly competitive seismic data packages in the region provide an excellent regional view for future exploration.

Spectrum 2D seismic data reveals substantial continuation of prospectivity offshore North West Africa, including a diverse range of plays, extensive fairways and numerous deep water fans and shelf leads. There remains great potential for further gas and oil discovery across this margin.

spectrumgeo.com
mc-uk@spectrumgeo.com
+44 1483 730201

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