VOL. 12, NO. 4 – 2015

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

geoexpro.com

EXPLORATION

North Korea
Hydrocarbon Exploration and Potential

HISTORY OF OIL

North Sea: A Golden Celebration

TECHNOLOGY EXPLAINED

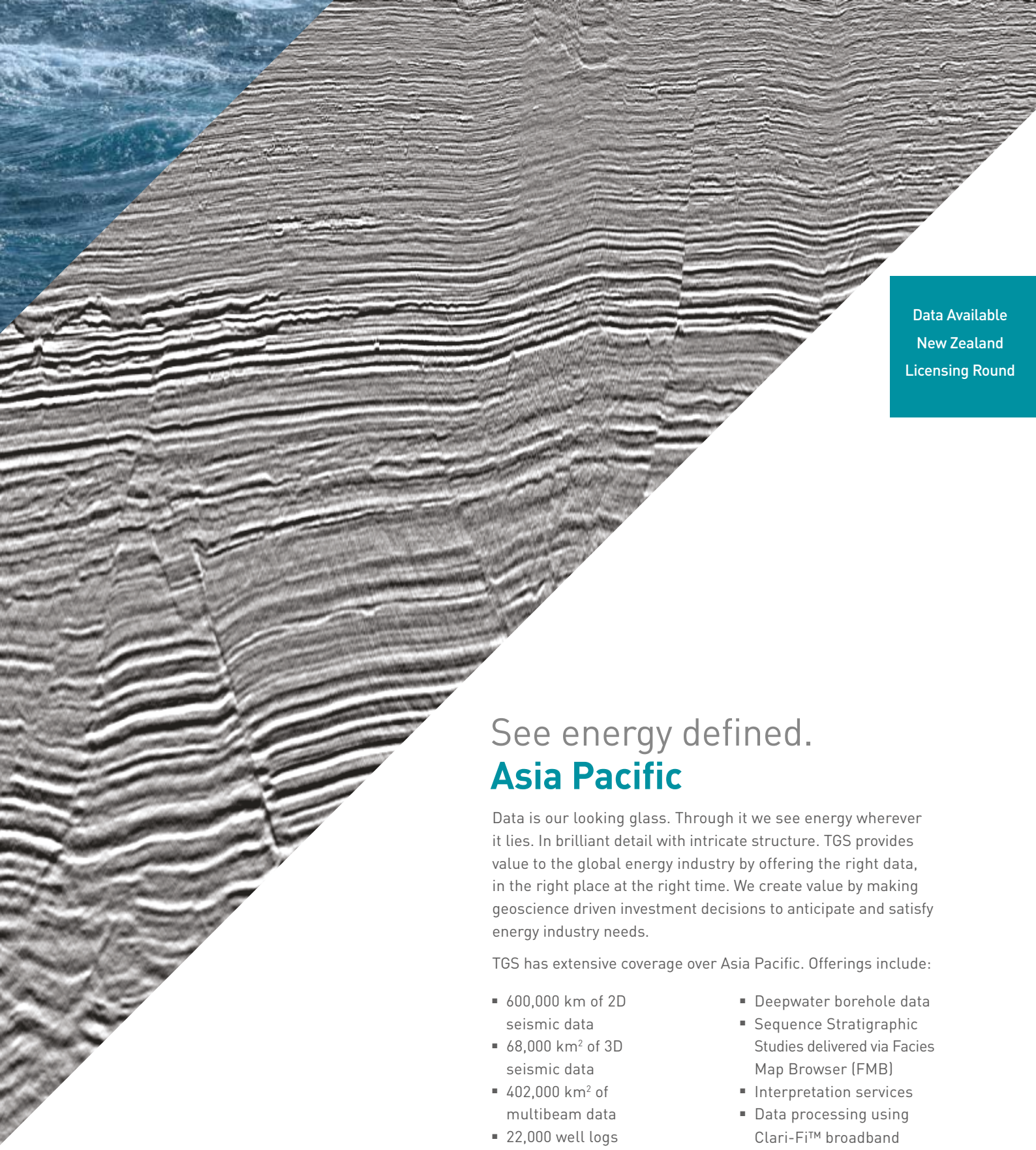
The Pain and Sorrow of Reservoir Modeling

INDUSTRY ISSUES

A Tightrope Across the Arctic

GEOTOURISM

The Active Volcanoes of Hawaii



Data Available
New Zealand
Licensing Round

See energy defined.
Asia Pacific

Data is our looking glass. Through it we see energy wherever it lies. In brilliant detail with intricate structure. TGS provides value to the global energy industry by offering the right data, in the right place at the right time. We create value by making geoscience driven investment decisions to anticipate and satisfy energy industry needs.

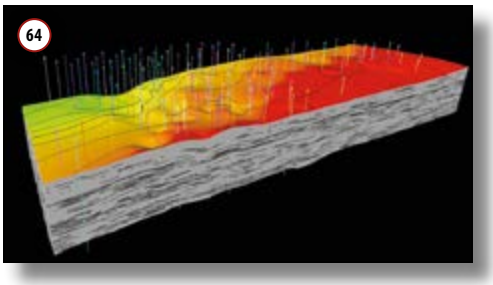
TGS has extensive coverage over Asia Pacific. Offerings include:

- 600,000 km of 2D seismic data
- 68,000 km^2 of 3D seismic data
- 402,000 km^2 of multibeam data
- 22,000 well logs
- Gravity and magnetic data
- Deepwater borehole data
- Sequence Stratigraphic Studies delivered via Facies Map Browser (FMB)
- Interpretation services
- Data processing using Clari-Fi™ broadband processing technology

See the energy at TGS.com

TGS

GEOExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED



Are we producing the right reservoir models?

CONTENTS Vol. 12 No. 4

This edition of *GEO ExPro* Magazine focuses on Frontier Exploration, South East Asia and New Technologies.

COLUMNS

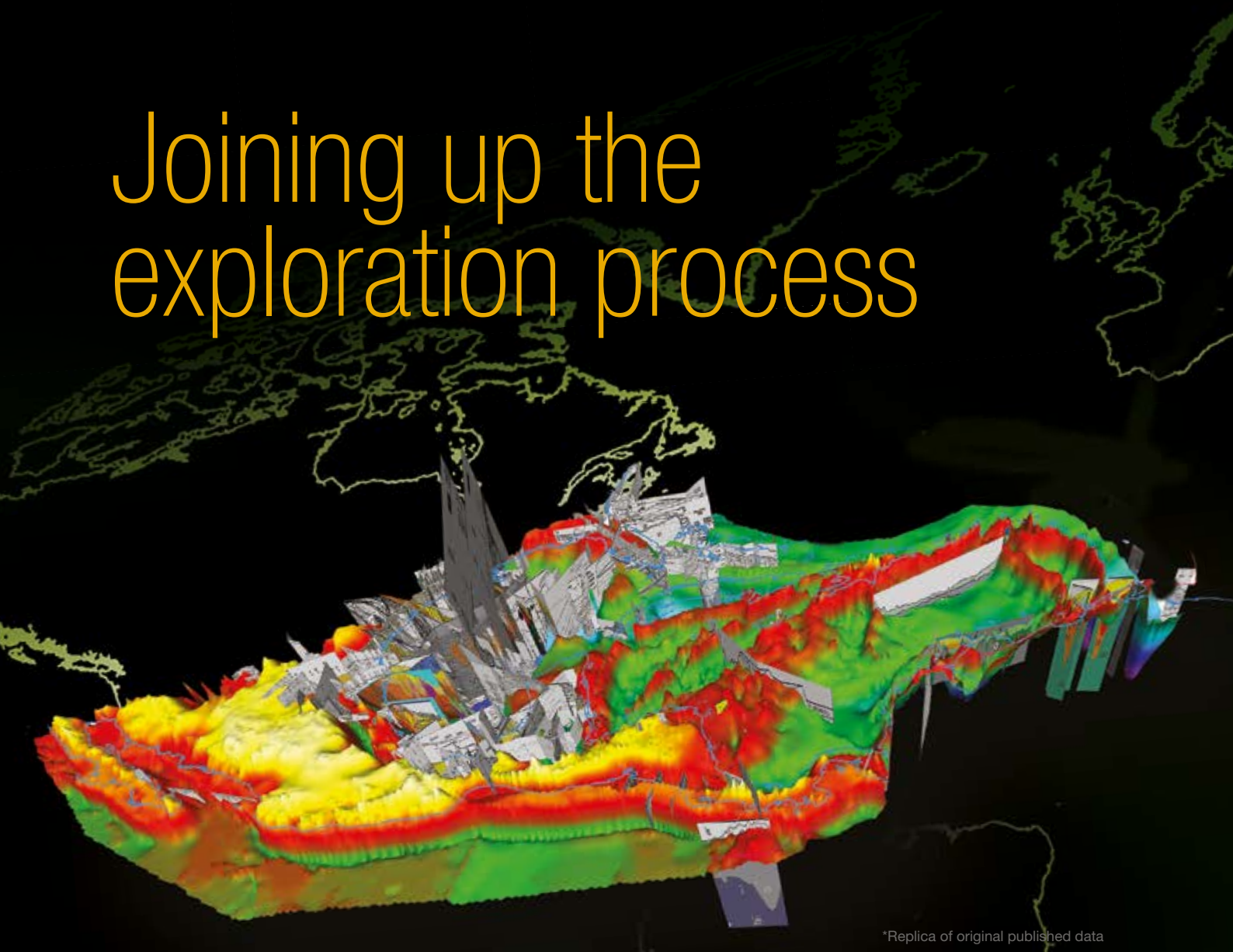
5 Editorial
6 Market Update
8 Regional Update
10 Update
16 Licensing Opportunities
18 A Minute to Read
52 GEO Media: 'Strata' Smith Enters the Digital Age
54 GEO Profile: Reg Nelson – A True Explorer
68 GEO Tourism: The Active Volcanoes of Hawai'i
74 History of Oil: A Golden Celebration for Silver Seas
86 Recent Advances in Technology: Gas Hydrates in Outer Space (2)
90 What I Do: The Stratigrapher
92 Exploration Update
94 GEO Media: The Morality of a Zealot
96 Q&A: Putting Science into Policy
98 Hot Spot: Sarawak Discoveries Boost Malaysia
100 Global Resource Management

FEATURES

22 Cover Story: North Korea – Hydrocarbon Exploration and Potential
28 New Technologies: Smart Fields – People, Processes and Technology
32 Industry Issues: Walking an Arctic Tightrope
36 Seismic Foldout: Offshore Mauritania and Senegal
42 Technology Explained: Simplifying Digital Rock Physics Workflows
46 Exploration: Waking up to Papua New Guinea
58 Seismic Foldout: Driven to Success on the Seismic Superhighway
64 Reservoir Management: The Pain and Sorrow of Reservoir Modeling
80 Seismic Foldout: Gulf of Mexico – Post Well Analysis

Papua New Guinea bears little resemblance to most of the world's petroleum terranes.

Joining up the exploration process



*Replica of original published data

Unlocking a region's full hydrocarbon potential requires a comprehensive understanding of subsurface structure. The Neftex Regional Frameworks Module delivers unique, isochronous depth grids for key stratigraphic surfaces, bringing vital insight into mega-regional depth structure trends.

As the first Neftex offering deliverable in Landmark's DecisionSpace® Geosciences software, the module provides a robust framework into which proprietary data can be dynamically added. This forms a powerful basis for essential play analysis on a regional scale.

Support faster, more integrated exploration

Contact us today:
Website: **www.neftex.com**
Halliburton I Landmark: **www.landmarksoftware.com**
Email: **enquiries@neftex.com**
Tel: **+44 (0)1235 442699**
LinkedIn: **linkedin.com/company/Neftex**
Neftex • 97 Jubilee Avenue • OX14 4RW • UK

HALLIBURTON
Landmark

neftex

Iran Returns to the Market

In July, Iran signed an historic agreement deal with the US, UK, France, Germany, Russia and China, which will have significant impact on the hydrocarbon industry. In return for assenting to strict limits on its nuclear program, sanctions that have effectively stopped Iran from exporting its oil will be lifted. Most commentators think it will not take many months before Iranian barrels arrive on an already overstocked oil market.

Sitting on the fourth largest oil reserves in the world and the second largest of natural gas – 157 Bbo and 1,193 Tcfg respectively – Iran has plenty of potential. It also has a stockpile of about 70 MMbo in storage which can be released almost immediately, and a number of large fields eagerly waiting to come on stream. However, many of these have fallen into decline due to lack of investment, and Iran will have to spend heavily on infrastructure in order to begin to export the oil. It will also need to look seriously at its license terms, which are somewhat outdated. However, with the level of interest there appears to be from international companies, Iran could easily be supplying over 700 Mbopd to the world market within the next two years.

What effect will this potential influx have on the already pressurized price of oil? The United States is managing to produce more shale oil with ever-decreasing costs, while OPEC is increasing production to try to maintain its market share. In July it pumped 1.4 MMbopd above its agreed target, the majority from Saudi Arabia. This oversupply has already had a knock-on effect on exploration in expensive frontier regions like deep water and the Arctic; Wood Mackenzie claims that major oil and gas companies have shelved 46 large projects worth billions of dollars in recent months.

With worldwide demand continuing to decrease, Iranian oil will only add to the existing glut. It looks as though the oil price will not be heading upwards any time soon. ■

Jane Whaley
Editor in Chief

NORTH KOREA: HYDROCARBON POTENTIAL AND EXPLORATION

Despite the low levels of motor vehicle ownership, North Korea is traversed by good roads between major urban conurbations, passing through spectacular scenery such as the Ahobiryong mountain range to the west of the east coast seaport of Wonsan. Relatively unexplored, the country offers low cost, low risk exploration opportunities.

Inset: North Sea hydrocarbon exploration is 50 years old.

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

GEO EXPro is published bimonthly for a base subscription rate of GBP 60 a year (6 issues).
We encourage readers to alert us to news for possible publication and to submit articles for publication.

Cover Photograph:
Main Image: Mike Rego
Inset: BP plc

Layout: Bookcraft Ltd.
Print: NXT Oslo Reklamebyrå

issn 1744-8743

Increasing the Glut

Previously the world's fourth-largest oil exporter, Iran is back in the game.

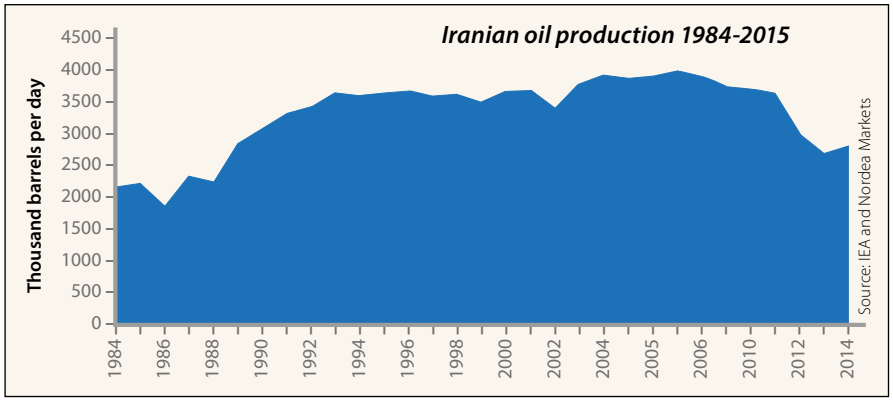
In Vienna on July 14, 2015, after many days of intensive talks, Iran and the P5+1 group – the United States, Britain, France, China, Russia and Germany – reached a conclusion on the Joint Comprehensive Plan of Action (JCPOA), which will put limits on Iran's nuclear program in exchange for the removal of sanctions against the country.

The thorny questions for the oil market now are how fast Iran can ramp up production; how many barrels of oil can return to the market; and how will the oil market and prices react. Nobody knows for sure and estimates differ substantially.

Iran was the fourth-largest oil exporting country in 2012 and holds the fourth-largest proven oil reserves, but sanctions imposed by the US and the EU in late 2011 and the summer of 2012 cut exports sharply. Although Iran had been subject to four earlier rounds of UN sanctions, the tougher measures imposed by the US and the EU severely hampered the country's ability to export its oil, which also affected its production. These sanctions targeted Iran's petroleum imports and exports, prohibited large-scale investment in the country's oil and gas sector and cut off Iran's access to European and US sources for financial transactions.

Additional sanctions were implemented against institutions targeting the Central Bank of Iran, while the EU imposed an embargo on Iranian oil and banned European Protection and Indemnity Clubs from providing Iranian oil tankers with insurance and reinsurance, which hit Iranian exports particularly hard, as European insurers underwrite the majority of insurance policies for the global tanker fleet. The lack of adequate insurance blocked the sales of Iranian crude, and buyers of Iranian oil such as the EU, Japan, China, South Korea and India replaced the Iranian barrels with higher import volumes from Saudi Arabia, Kuwait, Nigeria, Angola and Iraq.

Iranian exports of crude and condensate dropped from 2.6 MMbpd in 2011 to 1.3 MMbpd by 2013 and production fell from 3.7 MMbpd to 2.5 MMbpd in the same period. In 2014 exports increased modestly to average 1.4 MMbpd.



Quick Return to Production Expected

A fairly quick return to production of the locked-in Iranian oil – expected to reach about 800 Mbpd by later 2016 – will increase the supply glut in the market and postpone a potential price recovery. In addition, Iran may have as much as 70 MMb of crude and condensates in storage; if these stockpiles are released, Iranian oil will reach the market quite fast, increasing the downward pressure on prices.

Although the potential lifting of sanctions is to a certain extent already priced into the oil market, we can expect to see an immediate drop in short term prices and a significantly flatter price path going forward. With the Iranian nuclear deal signed we expect that the Brent crude will trade closer to US$70/barrel in 2016, rather than our current forecast of US$75/barrel. ■

Sources: EIA, IEA, FT and BBC

Thina Margrethe Saltvedt

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 creates multi-client data libraries in worldwide mature and frontier basins to provide upstream companies opportunities to evaluate hydrocarbon potential of those areas. We offer integrated technical solutions to our multi-client surveys by applying state-of-the-art geophysical technologies ranging from survey design, data acquisition, advanced processing to interpretation.

BGP Multi-Client Worldwide Data Library

Vessel of BGP Marine

Strongly supported by BGP Marine, which has six vessels available to work on BGP Multi-Client commercial projects:

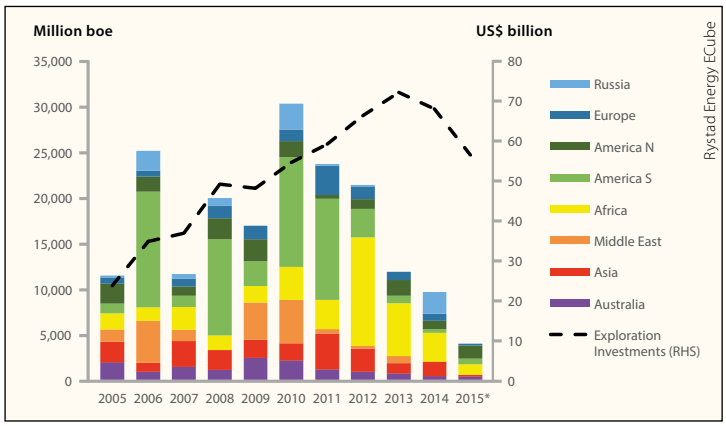
- ***BGP Challenger***
- ***BGP Dong Fang Kan Tan No. 1***
- ***BGP Dong Fang Kan Tan No. 2***
- ***BGP Explorer***
- ***BGP Pioneer***
- ***BGP Prospector***

Contact us for more information:

Tel : +86 22 66225013
Fax: +86 22 66225058
Email: multiclient@bgp.com.cn
Web : www.bgp.com.cn

The Need For New Frontier Exploration

Over the last years offshore exploration activity has been at a historic high, without any significant corresponding discoveries. The result is a considerable increase in the global average discovery cost.



*Global offshore discovered volumes per continent and discovery year and exploration investments (RHS) *Includes discovery volumes until the end of June 2015.*

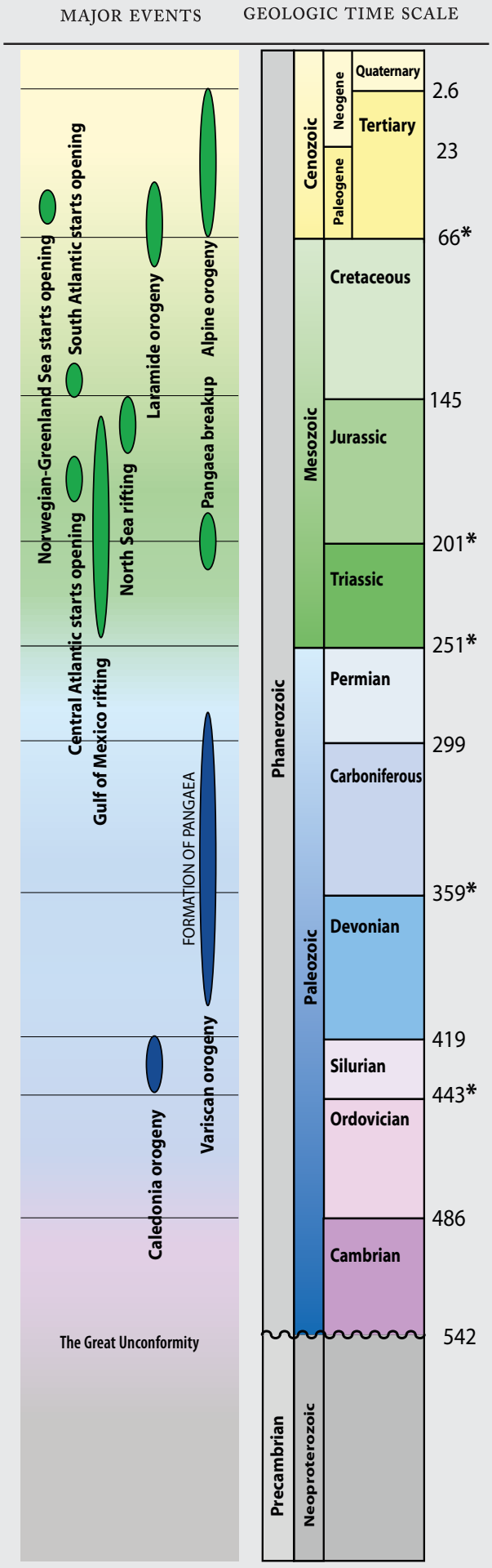
During 2013 and 2014, global offshore exploration activity, measured in investments, peaked at US$~70 billion, representing a 40% increase compared to the 2009 level. Despite the growth in investment, the yearly global discovered offshore volumes decreased during this same period. In 2010 ~30 Bboe of new offshore resources were discovered, while in 2014 the number was reduced to ~9 Bboe. The trend seems to continue into 2015, with 4 Bboe of discovered resources during the first six months of the year. The main discoveries of 2015 have been the Tortue West gas discovery in Mauritania and the Cheek oil discovery in Mexico.

In terms of discovered volumes over the last decade, two regions stand out: South America and Africa. South America is driven by the exploration success in Brazil, where Petrobras and other companies have opened up a new frontier by targeting sub-salt prospects. In Africa the new volumes primarily come from exploration success in Mozambique and Tanzania.

From 2005 to 2014, the yearly investment related to offshore exploration increased from US$25 billion to US$68 billion. The increase in investment is a combination of higher activity as well as inflation. In 2005 the average cost per exploration well was US$34 million; by 2010 the same costs had increased to US$75 million and again to US$95 million by 2014. Rising unit costs and lower exploration performances have resulted in lower profitability for exploration. The average discovery cost per boe for the years 2008-2012 was US$2.5/boe, which was surpassed by US$7/boe in 2014.

The disappointing exploration results that we have observed over the last couple of years are important to reflect on. If exploration is going to be commercial at a time of low oil prices, the trend needs to be turned. Based on experience, frontier exploration has proven successful and may be one way to turn around the current trend. ■

Espen Erlingsen, Rystad Energy



AWG: A Common Love of Earth Science

The Association for Women Geoscientists (AWG) is an international organization devoted to enhancing the quality and level of participation of women in geosciences and to introduce girls and young women to geoscience careers. Membership is open to anyone who supports AWG's goals – men as well as women – and the membership includes professionals from industry, government, museums, academia and education, plus students and retirees.

Members' diverse interests and expertise cover the entire spectrum of geoscience disciplines and career paths, providing unexcelled networking and mentoring opportunities. The membership is brought together by a common love of earth science and the desire to ensure rewarding opportunities for women in the geosciences.

The organization is mostly US based at the moment, but is very keen to encourage international membership and to foster relationships with geological organizations worldwide.

AWG's Mission

The purpose of AWG is threefold: to ENCOURAGE the participation of women in the geosciences, to EXCHANGE educational, technical, and professional information, and to ENHANCE the professional growth and advancement of women in the geosciences. To promote these aims, the AWG Foundation was created to fund the educational programs of the association.

To follow its mission to encourage women geoscientists, the AWG, through the Foundation, funds geologic field trips for pre-college girls and also awards scholarships to geoscience Masters and Doctoral candidates to cover expenses associated with finishing their theses or dissertations. SAGE (AWG's Student Awards for Geosciences Excellence program, funded by the Foundation) presents awards to students for outstanding geoscience projects in science fairs and other events. The AWG has also produced Career Profiles, a booklet of short biographies of women geoscientists, available from the AWG website, which presents women role models from different lifestyles and a variety of geoscience careers.

The AWG's newspaper, *Gaea*, is published four times a year, and is an important tool in the AWG's mission to exchange information. The newsletter profiles the successes of women geoscientists and AWG Award winners, addresses issues which concern women in geoscience careers, provides a forum for discussion, and publishes employment and position opening advertisements. Another feature of the information exchange focus is the Distinguished Lecturer Program, which provides a list of women geoscientists willing to lecture or conduct workshops on diverse geoscience topics. The organization also maintains a presence at many major conventions.

AWG field trips provide unique opportunities for members and friends to study geology in interesting places around the world – the 2015 field trip was held in Puerto Rico. AWG's local chapters provide frequent technical presentations, social gatherings and field trips, providing opportunities to mentor or learn from other members.

To enhance the professional growth and advancement of women in the geosciences, AWG is affiliated with societies such as the American Association of Petroleum Geologists and the Geological Society of America. Recently, AWG has been working with other leading women's groups to fund and sponsor short courses and reception events for career development and networking at various conventions, and it also provides a free Resume Review Service for students and young professionals. AWG provides opportunities for women to exercise their leadership skills as chapter officers or members of the Board of Directors of the AWG or the Foundation, as well as in committee work.

Awards and Scholarships

AWG, through the support of the Foundation and donors, provides several awards and scholarships to deserving women across the globe. Its first award, the Outstanding Educator Award, was established in 1988 to honor well-established college or university teachers who have played a significant role in the education and support of women geoscientists both within and outside the classroom. Since then, twenty new awards for both students and professionals have been added, ranging from $250 to $2000. Most recently, AWG developed the AWG Professional Excellence Awards, which go to women who throughout their careers have made distinguished contributions.

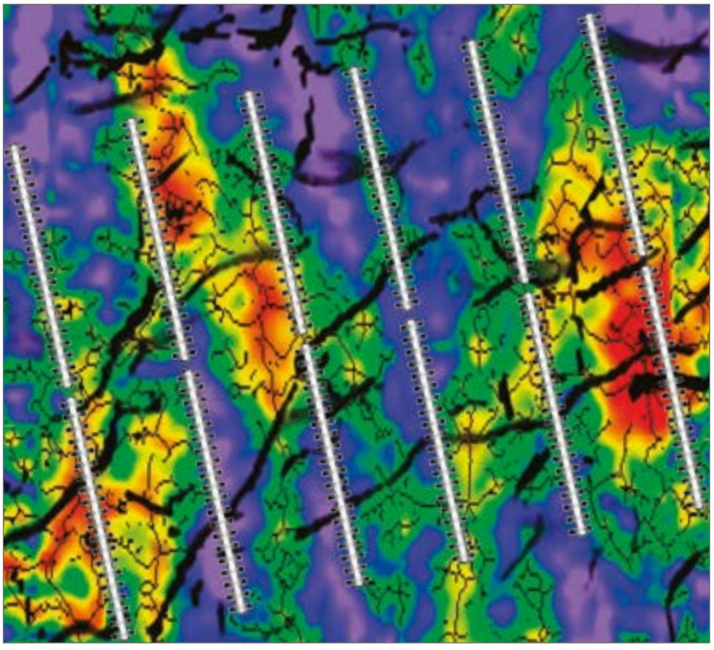
If you are interested in joining AWG, or want to apply or nominate someone deserving for an award, or make a donation to the Foundation, visit www.awg.org for more information. ■

Blair Schneider

Members of the AWG Executive Committee and Board of Directors at the fall 2014 Board Meeting in Vancouver.

SEISMIC on DEMAND

3D design to image 12 planned Utica wells from a pad in Eastern Ohio. Vibroseis source positions are confined to roads to optimize acquisition efficiency. Receiver positions are evenly distributed in a hex array using AutoSeis® recording nodes.



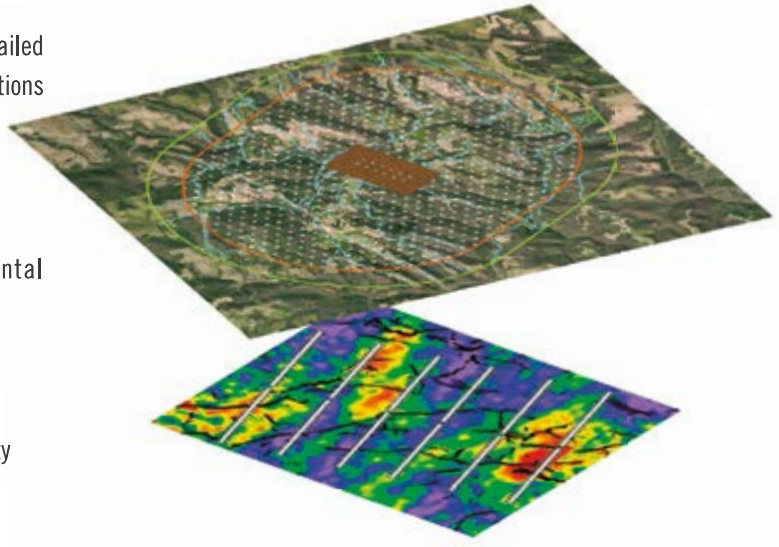
High resolution fault and fracture information can be provided by the integration of 3D seismic attributes and patented processing of ambient seismic. Quick delivery of seismic attributes allows for customized well planning and optimized completion design.

FAST. ACTIONABLE. AFFORDABLE.

Fast and affordable – Global's SEISMIC on DEMAND brings detailed geoscience information to the operational world of drilling, completions and production, in a practical and useful way.

- Innovative 3D design makes acquisition fast and affordable – days in the field rather than months
- Nodal acquisition is fast and leaves minimal environmental footprint – easier permitting; happier landowners
- Acquire both active and ambient seismic to maximize the understanding of faults, fractures and stress fields
- Quick delivery of high-resolution fault images and rock property attributes - timely and actionable information
- Affordable data for customized well plans and optimized completion designs

SEISMIC on DEMAND makes high-resolution seismic a practical choice for pad-based operations.



Global's innovative seismic acquisition and quick delivery of 3D and ambient seismic attributes provides detailed and actionable information for well planning and completion design.

For more information:
www.globalgeophysical.com/DEMANDSEISMIC or
Contact us at **DEMANDSEISMIC@globalgeophysical.com**

Visit us at SPE ATCE #2555

Global Geophysical Services
tel +1 713-972-9200 **www.globalgeophysical.com**

Global℠ Geophysical Services

Seismic to Boost Mexican Exploration

Despite being labeled as 'historic' and 'ground-breaking', Mexico's first ever offering of oil and gas blocks to private and foreign investors proved to be less than spectacular.

Last year the Mexican government passed major reforms which ended the 75-year monopoly held by state-owned Pemex, but the first phase of the much heralded 'Rondo Uno' resulted in the award of just two of the 14 blocks on offer. Shallow water Blocks 2 and 7, off the coast of Mexican cities Veracruz and Tabasco respectively, were both awarded in July to a consortium made up of operator Talos Energy, Sierra Oil & Gas, both with a 45% stake, and Premier Oil with 10%. Eight of the blocks on offer did not receive any bids.

Learning Process

The Mexicans are viewing this as a learning process – in fact they purposely kept back some of the more prospective blocks for later, with the promising deepwater area to be included in the fourth phase of the round, probably in 2016. The Phase 1 blocks had an estimated less than 40% chance of exploration success, which may explain the lack of interest in the present climate. However, the process itself may have been partly at fault, considered by many as inflexible with regards to pre-tax profits when accepting bids; four bids were rejected on the basis that they did not meet the minimum profit-sharing requirement, set at 40%.

A number of changes have therefore been made in preparation for the second phase of Round One, due September 30. Five contracts for nine oil fields are on offer and the Mexican National Hydrocarbons Commission estimates they could contain 355 MMboe, with proven discoveries of light crude oil. In order to attract more bidders, there has been a reduction in the required corporate guarantee, which has now been set at 18 times the value of the minimum work commitment required by each contract.

Plenty of Seismic Available

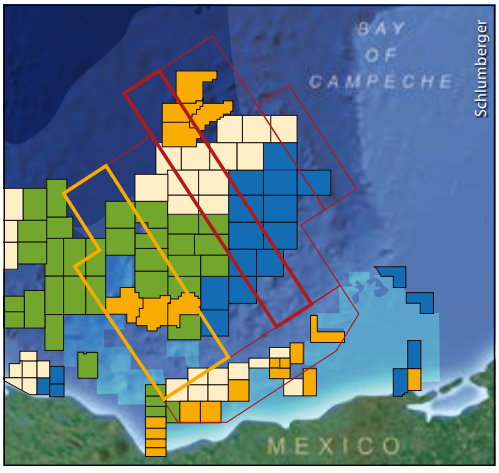
With this promising arena opening up to foreign investment, and expecting better take-up of blocks in forthcoming rounds, seismic companies have been acquiring data and enhancing their offerings in the Mexican Gulf. Spectrum, PGS and Schlumberger are collaborating to acquire 80,000–100,000 km of modern, long-offset 2D data which will encompass all the major hydrocarbon provinces offshore Mexico, includes areas on offer in Rondo Uno.

The acquisition program is designed to allow delivery of the highest-quality data in the shortest timeframe to clients. Mexico is a tremendous investment environment and this collaboration will help support further industry investment into this highly prospective area. Surveying started in June, and final products will be available in November.

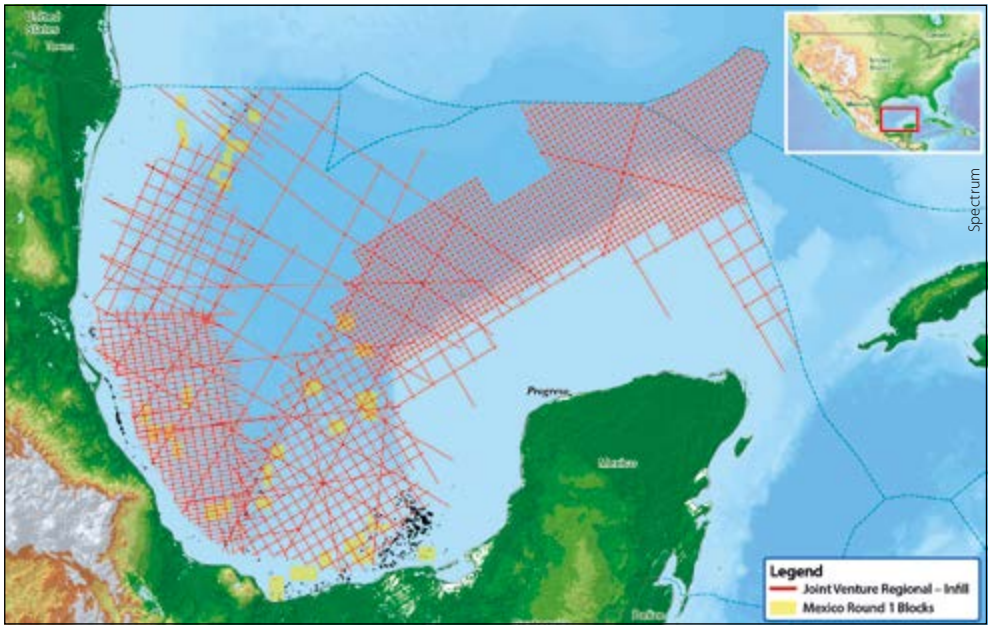
Similarly, ION Geophysical announced in August that fast-track pre-stack time migrated (PSTM) data from the first phase of its MexicoSPAN™ program was available, including more than 22,000 km of deep-imaged 2D seismic data.

Also in August, Schlumberger announced that it had launched the industry's first multiclient wide-azimuth survey offshore Mexico. This covers 80,000 km^2 in the Campeche Basin and will be acquired using two fleets of WesternGeco vessels, including Amazon Class, the world's first purpose-designed 3D seismic vessels. The Campeche Basin has a number of features like near-salt and subsalt structures and complex-faulted and deep-thrusted structures, best imaged with wide-azimuth seismic. ■

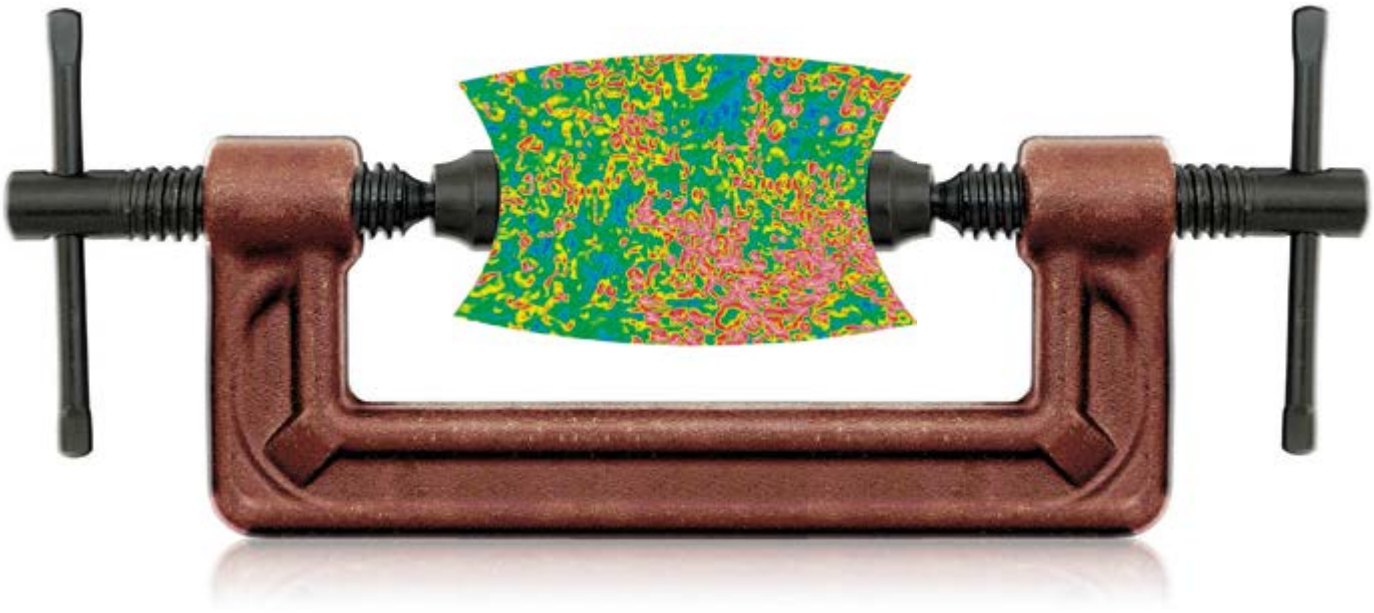
Schlumberger's broadband 3D wide-azimuth survey.



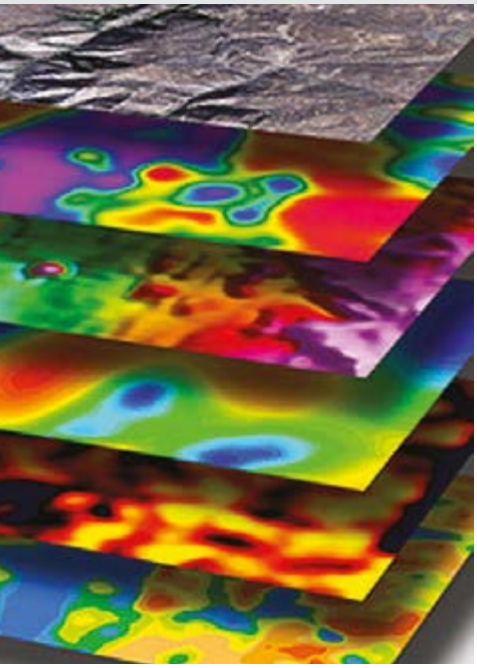
Coverage of the Spectrum, PGS and Schlumberger 2D survey.



Squeeze the Most Out of Your Existing Data



SEISMIC • WELL LOGS & CORES • POTENTIAL FIELDS • ELECTROMAGNETIC • RADIOMETRIC • REMOTE SENSING



Keep Exploring with the neoSCAN

Low prices and tight budgets don't mean you need to stop exploring. The neoSCAN™ helps you get the most out of your legacy G&G investments by integrating existing data with additional publicly available, multi-physics datasets. In under 100 days and for less than 50 cents per acre, neoSCANs deliver the interpretive products you need to help identify potential exploration leads. Moreover, predictive analytics methods are applied on all neoSCAN projects, providing rich insights that can be used to highgrade acreage in underexplored areas.

Don't feel squeezed by low prices and tight budgets. Let NEOS relieve the pressure.

Seismic to Simulation… and Beyond

Emerson Process Management has recently increased its full reservoir lifecycle capabilities through the acquisition of flow assurance and production optimization software company Yggdrasil and the incorporation of its solutions within the Roxar reservoir management software portfolio.

Predicting oil and gas field behaviors is a difficult yet crucial task for multidisciplinary teams consisting of geophysicists, geologists, reservoir engineers and other decision-makers. By offering Roxar software and services for workflows from geological modeling to reservoir simulation, Emerson helps its customers make informed decisions on where to drill, production strategies and how to maximize oil and gas recovery throughout a prospect lifecycle.

Uncertainty Management

The Roxar reservoir management software portfolio is a key element of Emerson Process Management, a leader in facilitating businesses to automate their production, processing and distribution in many industries, including oil and gas. Founded in 1890, Emerson is a global Fortune 500 company, currently with some 115,000 employees working to develop the point 'where technology and engineering come together to create solutions for the benefit of customers'.

With Roxar reservoir management software, Emerson has the opportunity to go beyond its traditional seismic to simulation domain. By combining its software and services with other Emerson oilfield technologies, the company is able to offer systems for day-to-day reservoir management decision-making and action-taking consistent with an operator's overall reservoir strategy. These systems will act as the 'brains' for complex process management in the entire reservoir life cycle, from field development and optimization of production from individual wells, through to allocation of production.

Uncertainty management is an essential component in the workflows for this strategy, so a focus area for Emerson is enabling this to happen through the complete seismic to simulation process, which may include alternative seismic interpretations and multiple realizations of the reservoir model. The Emerson software module Roxar Tempest ENABLE allows users to create ensemble-based prediction workflows and better quantify uncertainty in production forecasts. The innovations in this software are the results of a Total Uncertainty Management program undertaken with Statoil, together with long-term collaboration on the development of statistical algorithms with the Department of Mathematical Sciences at the UK's Durham University.

Entire Reservoir Lifecycle Solutions

Consistent with its aim to assist oil companies with their reservoir management decision-making throughout the reservoir lifecycle, Emerson has recently strengthened its upstream capabilities through the acquisition of Norwegian company Yggdrasil, a provider of integrated flow assurance and production optimization software, known as METTE. This solution provides operators with flow performance calculations for wells and flow lines, integrated field modeling for life-of-field simulation and optimization, and virtual metering for the allocation of production to wells. The hardware descriptions and outputs generated through METTE can be easily linked with leading reservoir simulators in the market, including the Roxar Tempest MORE simulator. Key benefits to operators include flexible production performance calculations, fast network simulation and improved life-of-field integrated flow assurance.

Emerson will incorporate Yggdrasil's METTE solution into the Roxar reservoir management software portfolio, effectively expanding the company's software solutions to the entire exploration and development of a reservoir, from seismic interpretation and modeling to reservoir simulation and production, thus enabling operators to continuously monitor production and forecast future reservoir performance. The result is a completely integrated production modeling system that can be used to refine and develop production strategies and field development concepts.

Kjetil Fagervik, Managing Director of Roxar Software Solutions at Emerson Process Management, told *GEO ExPro* magazine that Emerson believes it is important to respond to market developments, and that combining complementary solutions in this way will help clients to align their modeling, uncertainty quantification and simulation data with production, and thus optimize their field development and production plans. Ultimately, this will enable them to increase oil and gas recovery despite today's challenging environment. ■

Kjetil Fagervik, Managing Director of Roxar Software Solutions.

Emerson

Dolphin geophysical

DOLPHIN BREAKS OWN WIDE-TOW RECORD!

New Survey Configuration 12 x 150m x 8100m

Dolphin's record ultra-wide-tow configurations are achieved by the industry leading pulling power of our fleet, ensuring safe, fast and efficient operations.

Contact Dolphin now and benefit from the outstanding performance of the Dolphin HC3D Fleet: **info@dolphingeo.com**

Delivering Powerful Solutions

www.dolphingeo.com

Established Areas Sustain Industry Growth

KEN WHITE

Gulf of Mexico

All unleased acreage in Western Gulf available

As part of President Obama's strategy to expand safe and responsible domestic energy production, the Bureau of Ocean Energy Management (BOEM) is offering 21.9 million acres (88,626 km^2) offshore Texas for oil and gas exploration and development in a lease sale that includes all available unleased areas in the Western Gulf of Mexico Planning Area. Western Gulf of Mexico Lease Sale 246, held in New Orleans, Louisiana, on August 19th, 2015, was the eighth offshore sale under the Administration's Outer Continental Shelf Oil and Gas Leasing Program for 2012–2017 (Five-Year Program). It includes approximately 4,083 blocks located up to 250 nautical miles (463 km) offshore, in water depths ranging from five to 3,340m.

The decision to hold this sale follows extensive environmental analysis, public comment and consideration of the best scientific information available. The terms of the sale include stipulations to protect biologically sensitive resources, mitigate potential adverse effects on protected species and avoid potential conflicts associated with oil and gas development in the region. This sale builds on the first seven sales in the current Five Year Program, which offered more than 60 million acres (242,810 km^2) and netted nearly US$ 2.9 billion for American taxpayers. ■

Brazil

13th round finally gets the go-ahead

Brazil's CNPE – the country's energy policy board – has published Resolution 1/2015 in the Diaro Oficial da Uniao. This finally allows the Agência Nacional do Petróleo (ANP) to hold its Round 13, expected to be held October 7-8, 2015. It will be Brazil's first auction of oil and gas concessions since 2013.

To date 266 blocks are approved for inclusion, 182 of which are onshore and 84 offshore, along with 11 marginal fields, a total of 277 blocks. Onshore areas include the Amazonas, Parnaíba, Recconcavo and Potiguar Basins while offshore blocks are located in the Sergipe-Alagoas, Jacuípe, Espirito Santo, Campos, Camamu-Almada and Pelotas Basins.

Energy Minister Eduardo Braga has indicated the government expects to net up to 2 billion reais (US$ 630m) in signature bonuses. Any participation by Petrobras is likely to be marginal as the state-run producer moves to cut investments and focus on the deepwater fields it is developing. Fresh foreign investment would be a welcome boost for an industry buffeted by a corruption scandal surrounding Petrobras and its contractors, six-year-low crude prices and a stagnant local economy. The terms for the auction, including the areas to be offered, are expected to be published within the next few weeks. While upfront fees paid by successful bidders are predicted to be lower than in past auctions, requirements to hire local labor and use Brazilian-made parts, which make operating in the country more expensive, will remain in place, according to one official. ■

Australia

29 blocks offered in 2015 annual release

The 2015 Australian Offshore Petroleum Exploration Acreage Release has opened. The release comprises 29 nominated areas across eight basins off the Northern Territory, the Territory of Ashmore and Cartier, Western Australia, South Australia, Victoria and Tasmania. In total 23 blocks are available for work program bidding and six for cash bidding, to be held in three rounds: two work programs and one cash bid round.

The 12 areas in the first work program round, which closes on October 29th, 2015, are NT15-1, W15-2, AC15-1, AC15-2, AC15-3, W15-5, W15-13, W15-16, W15-17, W15-18, V15-2, and V15-3, while Work Program Round 2 covers areas W15-3, W15-4, W15-6, W15-7, W15-8, W15-14, S15-1, V15-1, T15-1, T15-2, and T15-3, with bids due to close on April 21st, 2016.

The Cash Bid Round includes NT15-2, W15-1, W15-9, W15-10, W15-11, and W15-12. The prequalification deadline is October 15th, 2015, and cash bid closure date is February 4th, 2016.

The release areas have been selected to offer a variety of investment opportunities, as they are located in a range of water depths and vary in size and level of existing geological knowledge. All release areas are supported by pre-competitive geological and geophysical data and analysis undertaken by Geoscience Australia, and information is available on third party rights or other considerations that may impact upon future petroleum activities in a release area. ■

Any *time*. Any *place*. Any *prospect*.

Sedimentary basins covered by Getech's 32 *Regional Reports*

Getech's *Regional Reports* provide focussed assessments of the exploration risks and opportunities in the world's frontier and underexplored basins.

New in 2015

Tectonic Evolution of Mexico

Detailed mapping of the regional structural framework and crustal architecture, based on Getech's unique gravity and magnetic data, constrains a fully tested plate model which reveals the tectonic evolution of Mexico.

Tectonics and Source Rock Potential of the Southern Caribbean Margin

If you are exploring for hydrocarbons in the Caribbean waters of Venezuela and Colombia then this *Regional Report* from Getech will give you the tools to better understand the basis for, and impacts of, the differing tectonic models of the Caribbean.

Getech's *Regional Reports*

Fuelled by our extensive data and powered by *Globe*, our flagship New Ventures platform. The cost effective solution in Plate-to-Prospect exploration.

For further information contact Getech:

Getech, Leeds, UK +44 113 322 2200
info@getech.com

Getech, Houston, US +1 713 979 9900
www.getech.com/regional-reports

getech

Senior Level Africa Conference

Global Pacific & Partners, in joint venture with **ITE Group** plc, hosts the **22nd Africa Oil Week/Africa Upstream Conference** 2015 on October 26–30 in Cape Town, South Africa – the most senior-level annual oil and gas-LNG event held in, on and for Africa. This is a meeting with a global reputation, and one of the few top world-class conferences held annually at a continental-level in the international industry calendar, with an outstanding 100+ speaker line-up from governments, leading companies, and key players inside Africa's oil/gas-LNG industry value chain.

The 17th **Scramble for Africa: Strategy Briefing**, held in Cape Town on the Monday of the conference, provides unrivaled insights into the continent's fast-changing corporate upstream oil and gas game. Also on October 26 is the 13th Africa Independents Forum, which focuses on new and fast-growing corporate players in Africa.

About 40 African governments with African national oil companies, licensing agencies and over 1,000 key senior executives of oil and gas companies involved in Africa are typically present annually, alongside 160 exhibitors. Attendees benefit from extensive networking occasions. Conference bookings are open and being secured already, with sponsor positions and exhibition booths also being allocated. ■

Milestone in Angolan Production

French supermajor **Total** has been in **Angola** for over 60 years, having started exploration in the country in the Kwanza and Lower Congo Basins in 1952. Today, Total E&P Angola is active in the most productive areas of the country, with more than 1,700 workers, but the jewel in the crown is deepwater **Block 17**, located about 135 km off Angola's northern coast in water depths of between 1,100m and 1,400m.

The block, one of the first deep-offshore blocks licensed in Angola, is home to the giant Girassol Field, discovered in 1996, with base-case reserves of about 630 MMbo. It came on stream in 2001 using a subsea facility tied back to a Floating Production Storage and Offloading unit (FPSO) which can handle up to 200,000 bopd. There have been 14 discoveries so far on the block, including the 1 Bbo in place Dalia field. The fields, all named after flowers, are producing through three further FPSOs.

Earlier this year Total announced that it had achieved another significant milestone in Block 17 – the cumulative production of two billion barrels from the block, with daily production of over 700,000 bo. ■

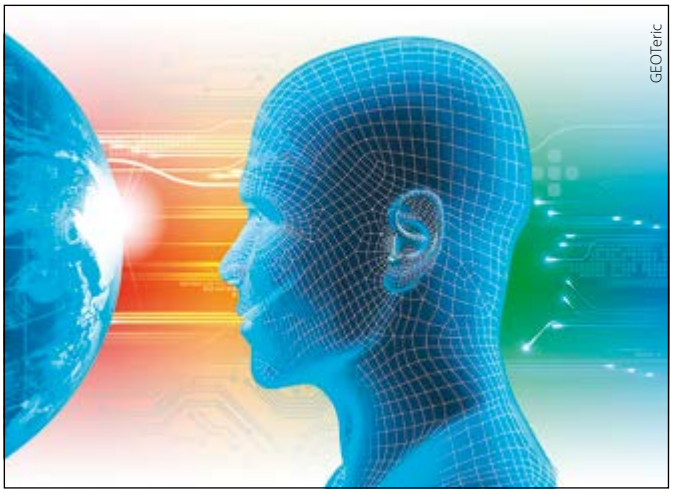
The Girassol FPSO

Cognitive Interpretation

In the hydrocarbon industry, billions are spent on acquiring and processing the best quality seismic data possible, in order to make informed decisions when drilling wells and producing oil and gas. With the vast quantities of data generated, it is easy for interpreters to get into a 'cognitive overload' situation – leading to confusion rather than understanding, and often wasting time and money as well.

Computers are able to give us rapid, high resolution, objective and fully volumetric results. However, interpretation of these results involves matching what we see with what we know a geological feature looks like. This is a complex challenge that no computer can carry out as efficiently or as effectively as the human brain, 40% of which is devoted to visual cognition, which is why making full use of it is vital in next generation interpretation systems.

To help us see the geology before we interpret it, **GeoTeric** have developed a seismic interpretation software package that harnesses our geological and geophysical expertise to maximum effect. It is different from previous interpretation technologies as it combines the power of computational approaches with an appreciation of the importance of the human element in interpretation – hence the label **Cognitive Interpretation**. This does not replace conventional interpretation systems but instead reveals the geology *before* interpretation. ■



Glowing Globes

Geoscience requires 3D thinking, so how better to show your ideas than on a large, glowing, moving globe? That is certainly what geoscience consultancy **Getech** decided when they were looking for a stunning visual display on their exhibition stands to catch the eye of passing geoscientists at conferences like the AAPG annual meeting.

OmniGlobe provided the answer. Images are projected in full color onto a spherical screen over a meter in diameter – and not just images. Videos and animations can also be shown and interactivity is an option through a touch screen. Commonly used in museums and educational establishments to display facets of the earth and solar system, subjects can include anything of global scope, including geophysical and meteorological data, climate, ecology, demographics, geopolitics or history. In fact any message looks good on a big dynamic, glowing ball!

When Getech were looking for an attention-grabbing way to demonstrate their global databases, Omni-Globe provided the perfect solution. As Dirk Cuthbertson, Marketing Manager for Getech, explained: "The OmniGlobe is the ideal way for Getech to showcase its gravity and magnetic data, plate model, paleogeographies and climate model results. It was striking to see the number of people walking past the OmniGlobe who would gradually slow to a stop and then stare, slightly open-mouthed, at what was being shown." ■

New Caribbean Geophysical Study

An understanding of regional geology is vital for targeted and successful exploration. With this in mind, and with the consent of all Caribbean countries, **Geology Without Limits (GWL)** will soon commence a new 40,000 line km 2D Pan-Caribe geophysical study. Scheduled to commence in 4Q 2015, long offset reflection seismic, refraction, gravity and magnetic data will all be acquired, integrated and interpreted. First results will be available in January 2016.

The objectives of the study are to provide high quality, deeply imaged exploration seismic data integrated with gravity and magnetic data; to reveal the major elements of the Earth's crustal architecture; to provide new insights into the evolutionary model of this region; and to offer a regional interpretation which describes the geological history and indicates active petroleum systems.

The survey is being undertaken in co-operation with a number of national scientific institutes and universities, and will be conducted with the support of the governments of the countries involved. Spec Partners Ltd is assisting GWL on the **2D Pan-Caribe Study**.

GWL has past experience of carrying out such studies in the Arctic seas as well as the Black Sea. Planned studies include the Caspian Sea, East Mediterranean Sea and the South China Sea. ■

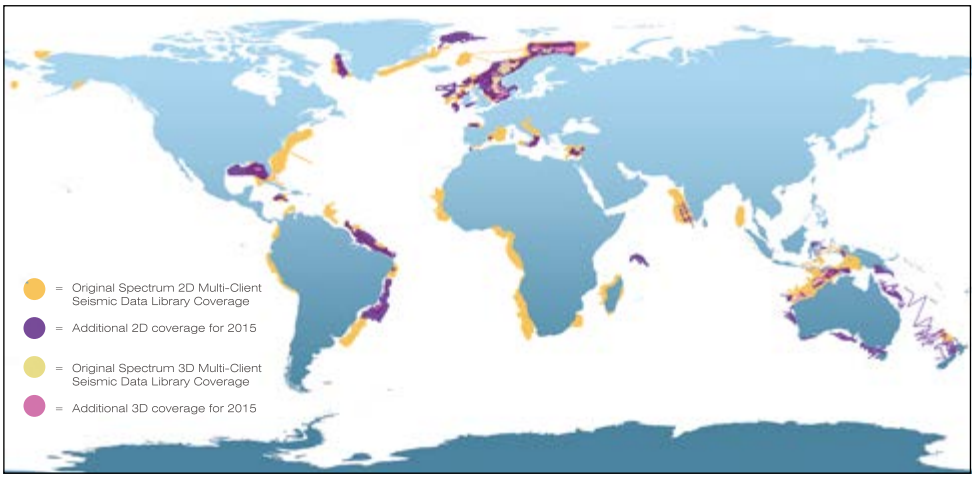
The new study covers the whole Caribbean area.

Going Greener

The public debate on environmental matters is becoming increasingly vocal across the globe, with a corresponding demand for greater transparency from companies of all types. In the oil and gas industry we are witnessing an expansion into new frontiers and environmentally sensitive areas as the search for future global energy continues. This is already driving calls for higher levels of environmental compliance from all participating stakeholders in the value chain, including seismic companies.

Seismic company **Polarcus** aims to be "a pioneer in an industry where the frontiers of seismic exploration are responsibly expanded without harm to our world". To further this vision, the company recently completed a comprehensive verification process in collaboration with specialists from DNV GL, the international certification body and classification society, to review and audit the procedures, methodology, data and calculations, software architecture, and technical documentation related to Polarcus' emissions monitoring and reporting systems. As a result Polarcus has been accredited with **five new DNV GL qualifications** for calculation methodology, covering all greenhouse gas emissions, seascape noise, support vessel emissions data, multi-survey models, and modeled, live and actual emission profiles. The company believes that it can now accurately calculate its **emissions footprint**, key to implementing appropriate mitigations for sustainable operations. ■

Size Matters!



Despite all the gloom and doom in the industry, it is good to hear of a company with some positive momentum. In June **Spectrum**, one of the seismic industry's fastest growing companies, purchased **Fugro's** entire multi-client library, meaning it now holds the **world's largest 2D seismic data library**. As a result of the transaction, Spectrum has more than doubled its library to over 3.3 million km of 2D multi-client seismic data. Spectrum was keen to highlight the fact that there is surprisingly little overlap between the two libraries, which results in the company now holding stronger positions in Brazil and Norway, with 2D data covering all major sedimentary basins worldwide. The purchase has also augmented Spectrum's 3D multi-client data, which now stands at 161,000 km^2 of data, primarily focused on Australia, Norway, UK, Netherlands and US Gulf of Mexico. Spectrum estimates that its data covers more than 40% of the world's known offshore hydrocarbon reserves.

This is not the first time Spectrum has seen its seismic library double in size through adventurous inorganic growth. In 2011 it acquired the multi-client data of CGGVeritas, adding more than 500,000 km 2D data to the library at the time. In the four years that have followed, Spectrum has managed to double the return on its initial investment.

Rune Eng, CEO of Spectrum, explained the thinking behind this development: "Why did we buy Fugro's seismic library? Quite simply because size matters! The combined library gives Spectrum the number one position in the 2D multi-client seismic market in terms of line kilometers. We can now achieve a bigger footprint of data coverage and a larger interface with oil companies. We can offer volume deals, attract global exploration supermajors and provide unique opportunities to national oil companies seeking investments abroad. It significantly strengthens our position in key offshore oil and gas basins.

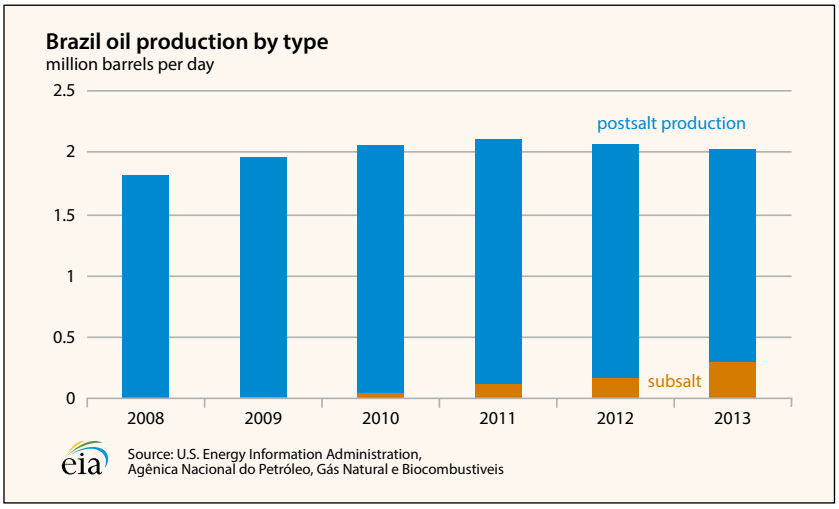
"Our 3D multi-client coverage now includes a substantial focus on prime areas for seismic spending. Oil companies are seeking a rare combination of political stability, high hydrocarbon prospectivity and regular license rounds, all of which can be found in areas covered by Spectrum's expanded seismic coverage. Crucially, this seismic data is a springboard to new projects. Our geoscience teams can use this expansive data library to develop a better understanding of existing and new basins and help identify new play types." ■

Brazil: New Sub-Salt Estimates

A new study undertaken at the National Institute of Oil and Gas at Rio de Janeiro State University suggests that there remain at least **176 Bboe** yet to be discovered in **Brazil's** sub-salt fields. This is about 50% more than previous estimates for the area, which were not supported by technical data, which prompted the researchers, Professor Cleveland Jones and Dr Hernane Chaves, to undertake the study. Brazil's government and petroleum regulator ANP does not publish estimates of the potential of the country's offshore resources.

The first major discoveries in the sub-salt were announced by Petrobras in 2006, since when some of the largest finds in the world of the last ten years have been made in the area. In total between 30–40 Bboe have already been discovered in the Brazilian sub-salt, 64% in the Santos Basin and 36% in the Campos Basin.

In related news, Petrobras announced in April that oil production in the fields it operates in the sub-salt province of the Santos and Campos basins reached the milestone of **800,000 bpd**, constituting a new daily production record. It took the company eight years and 39 production wells to achieve this record – by comparison, Petrobras took 40 years and 6,374 wells to reach oil production of 800,000 bpd onshore Brazil. ■



GeoConvention Success

On the heels of a very successful 2015 program, the **GeoConvention** Partnership Board would like to thank all of the sponsors, exhibitors, presenters, session chairs and volunteers who helped the conference to exceed expectations, delivering a best-in-class technical program with amazing exhibitors, networking and luncheon events.

GeoConvention 2016 is taking place on March 7–11, 2016. The technical program and exhibition floor will be held at the Telus Convention Center in Calgary, Canada, on March 7–9, with additional activities and events planned for March 10 and 11. With low commodity prices and an ever-changing economic and business environment, it is imperative that the industry optimizes the way in which it operates. Whether enhancing recovery methods, or finding the optimal path for a horizontal well or maximizing the return of capital employed,

Optimizing Resources, the theme for GeoConvention 2016, is key to success. Please come along and contribute as speaker, exhibitor or sponsor. ■

Integrated Interpretation Project

RSI, an independent geoscience consulting firm offering quantitative reservoir characterization with the goal of reducing exploration drilling risk and optimizing reservoir appraisal and development plans, recently commenced an important research program with Spanish oil and gas company **Repsol**. The project will develop a state-of-the-art platform for the integrated interpretation and joint inversion of seismic and Controlled Source Electro-Magnetic data within a rock physics modeling framework, using RSI's existing technology and experience in these fields. Repsol, which is the world's 13th-largest publicly-listed hydrocarbons producer and has a presence in more than 40 countries, will contribute its geophysical knowledge and exploration expertise. The program will develop sophisticated, robust and efficient interpretation tools and both Repsol and RSI will own the resulting innovative technology. ■

North Korea

Hydrocarbon Exploration and Potential

Despite a challenging political situation, the Democratic People's Republic of Korea offers relatively low cost, low risk exploration opportunities, with nearby energy-hungry markets.

MIKE REGO

The Democratic People's Republic of Korea (DPRK), commonly referred to in the western media as North Korea, remains one of the world's most secretive and closed societies. The communist politics are headed by a family dynasty, founded in 1948 by the Great Leader, Kim Il-sung (Grandfather of the current leader, Kim Jong-un), whose politics and legacy still determine many of the country's policies.

Despite the armistice of 1953 which ended the Korean War in terms of armed conflict, the two Koreas are technically still at war, and whilst the South's 'Sunshine Policy' of rapprochement with the eventual goal of re-unification has periodically acted to bring the two Koreas closer together, it has also been exploited as a bargaining chip by both sides to achieve various concessions, political stand-offs and aid support when needed. Due to the DPRK's political isolation, the command economy is no longer as strong as in the days when it enjoyed Soviet support, and as a result has been highly exposed to the effects of natural disasters, economic sanctions, and a lack of easy access to modern technologies.

Cheap energy is vital to the lifeblood of any industrial nation, and this is the key area in which the DPRK has suffered in recent years, as aside from coal, there is no known indigenous fossil fuel production, leaving the Koreans heavily dependent on supplies of imported oil by rail and sea which can be easily interrupted in times of political tension. There are no import pipelines for oil or gas.

The lack of indigenous commercial oil and gas production is perhaps surprising, given the abundant evidence for the presence of working hydrocarbon systems both onshore and offshore, and past exploration efforts dating back to the 1970s. Unfortunately much of the early exploration data in digital format was lost due to fire in a data storage archive in the 1990s, but surviving analog data has been digitized to provide more-or-less complete sets of early data.

Offshore Exploration: The West Sea

The West Korea Bay Basin (Figure 1) has seen the most foreign involvement, intermittently in the 1980s and 1990s. It is relatively shallow with water depths generally between 30 and 70m, surrounded by extensive coastal mudflats with a complex tidal system, and is considered to be analogous to the adjacent and highly prolific Chinese Bohai Basin. Exploration began in the 1960s with the Chinese, followed by a joint Korean-Russian study, then 2D seismic prior to the first exploration well in 1977. Major 2D marine seismic surveys were undertaken by GECO A/S in 1980–81.

At least ten exploration wells are thought to have been drilled in the West Sea, the majority in the central Tertiary

The modern city of Pyongyang viewed from the south across the Taedong River.

depocenter, but only seven are known to have reached their planned TD due to numerous mechanical failures. Most wells had fair to poor oil and gas shows, but two of them, #602 and #606, encountered good oil shows, the latter testing up to 450 bopd on DST. Despite more recent seismic in the 1990s being acquired by Taurus Petroleum, and in the early 2000s by Petronas, no further drilling is known, although it is believed that the Chinese may have shot a 3D marine survey in the central Tertiary depocenter area in recent years.

Based on penetrated section and recovered oils, three potential sources have been identified, corresponding to the Lower Tertiary, Lower Cretaceous and Upper Jurassic. To date, most prospectivity has been associated with structural traps, including anticlinal and fault seal, unconformity subcrop, and 'buried hill' type traps. Potential reservoirs have been encountered in Upper Jurassic, Lower Cretaceous and Paleogene sandstones, and Proterozoic and Paleozoic carbonates in 'buried hill' traps. Seismic imaging of the pre-Tertiary is not good on much of the older 2D data.

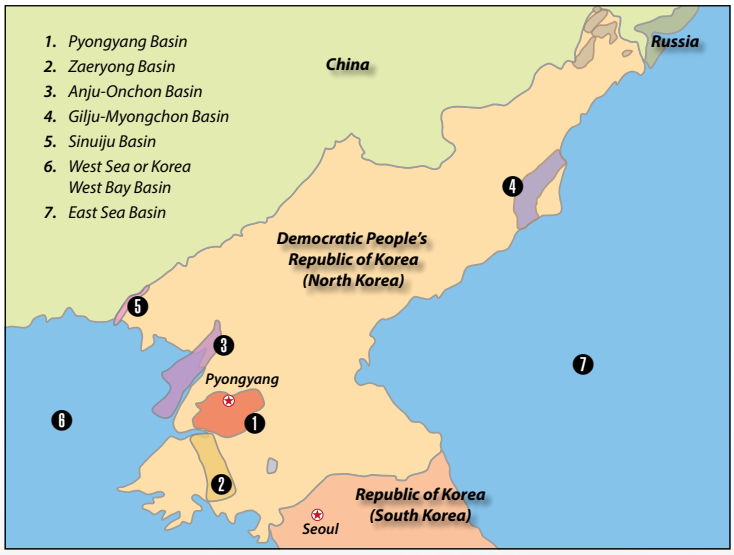


Figure 1: Approximate outline of the main sedimentary basins of the DPRK.

Five Underexplored Onshore Basins

Onshore DPRK has only been lightly explored to date, by the Korean Oil Exploration Corporation (KOEC) with minimal foreign involvement, although HBOil JSC of Mongolia have recently been granted an option to do so via a possible forthcoming licensing round in conjunction with KOEC.

There are five main onshore sedimentary basins in the DPRK (Figure 1), in which a total of 22 wells have been drilled, many encountering shows of oil and/or gas, with one well reporting 75 bopd of light sweet crude oil/condensate. There have been unconfirmed reports of a 1 Tcf gas discovery in 2002, but little supporting evidence is available. Several smaller basins of limited extent are located in the extreme north-east adjacent to the Chinese and Russian borders, but these are relatively inaccessible to foreigners, and whilst it is known that several have coal production, little is known about their oil and gas potential.

Of the five larger basins, all but one have had seismic acquired over all or part, at least one deep well drilled, and oil or gas seeps and shows recorded (seen at first-hand by the author).

The **Pyongyang Basin** is the largest, lying in the central Pyongyang synclinorium with Mesozoic at outcrop, and over 7,000m of Proterozoic and Paleozoic present. Only two deep wells have been drilled, in 1974 and 2009, the latter located on seismic data, whilst surface geochemical work from the last 40 years and several surface oil seepages reveal several major anomalies often associated with fault zones. One such seepage encountered at 6m depth whilst drilling a water well was found to be of Mesozoic age, from a saline marine environment. Deeper subsurface shows found in the two exploration wells were from alternating Lower Ordovician grey-white limestones, and Upper Cambrian dolomites.

The **Zaeryong Rift Basin** to the south-west of Pyongyang has some 3,000m of Mesozoic and Cenozoic sediments present, with up to a further 3,000m of Paleozoic, and potentially a further 4,000m of Proterozoic. Prolific oil and

Mike Rego

gas shows are recorded at the surface, particularly on the Taedong River, where slicks have been sampled and typed to Jurassic lacustrine to marine source rocks, similar to those present in the West Sea. The basin also has pre-Cambrian source potential. The only well drilled, a deep stratigraphic well prior to seismic data acquired 1994–95 and 2007–08, encountered Jurassic-sourced oil shows in a pre-Cambrian tilted fault block. Several large structural features have been defined from the more recent seismic and gravity-magnetic surveys in 2010, but despite good evidence for the presence of a working hydrocarbon system, no further wells have been drilled.

Figure 2: The rice harvest is still gathered largely by hand in rural areas, and many workers assist in the fields at harvest time.

The **Anju-Onchon Basin** lies in the north-east corner of the West Sea area, partly onshore, but separate to the main West Sea basinal area, and contains up to 3,000m of Mesozoic sediments underlying up to 3,000m of Cenozoic sediments. The shallow marine (transition zone) nature of the basin has prevented any significant offshore activity, but oil and gas shows have been encountered whilst drilling onshore, prior to the acquisition of onshore 2D seismic in 2002 and 2007, supplemented by gravity and magnetic surveys between 1961 and 2008. In 1970 well 3203 encountered approximately 70 barrels seepage of water and oil from the Eocene, whilst well 3208 in 1978 found about 35 barrels from the Oligocene. Additionally, well An-401 (drilled 1992, re-drilled 1998) encountered shows of C1-C3 and flowed some 40,000 cmpd of CO_2 from Middle Proterozoic Calcareous dolomites. Despite this encouragement, there has been no further exploration drilling since 1998.

The **Gilju-Myongchon Basin** is on the east coast of DPRK, with some 1,500–3,000m of Cenozoic sediments overlying lower Proterozoic sediments and Mesozoic granites (Figure 3). Exploration has been limited to gravity and magnetic surveys in the late 1960s, and several deep stratigraphic wells drilled primarily as stratigraphic coal wells. Gas has been recorded from several of these, with well 2229 recording a minor influx of gas, oil and water leading to a 40m blowout. Oil saturation was reported at 36%, with shows of C1-C4. Geochemical surveys have indicated several anomalies, and gas seeps provide the heating at a commercial mushroom farm and a local bathhouse.

The **Sinuiju Basin** lies onshore on the north-west coast abutting the Chinese border. Exploration has been limited to gravity, magnetic, and surface geochemistry, but estimates suggest up to 2,500m of Mesozoic sediments may be present, overlain by up to 1,000m of Cenozoic. No wells are known to have been drilled.

Offshore Exploration: The East Sea

The East Sea of Korea extends from a broad shallow shelf of less than 50m water depth in the easternmost part to a central

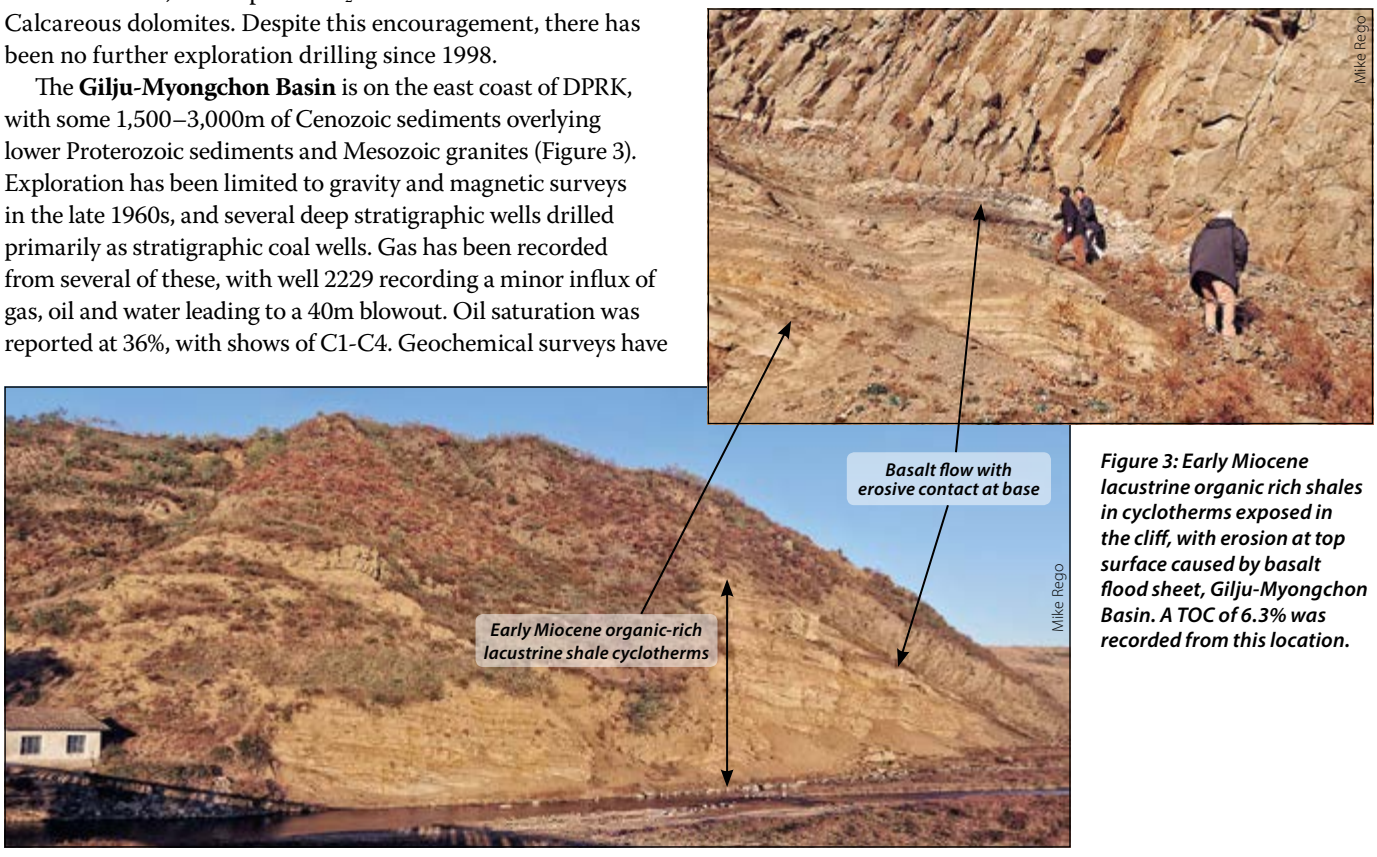
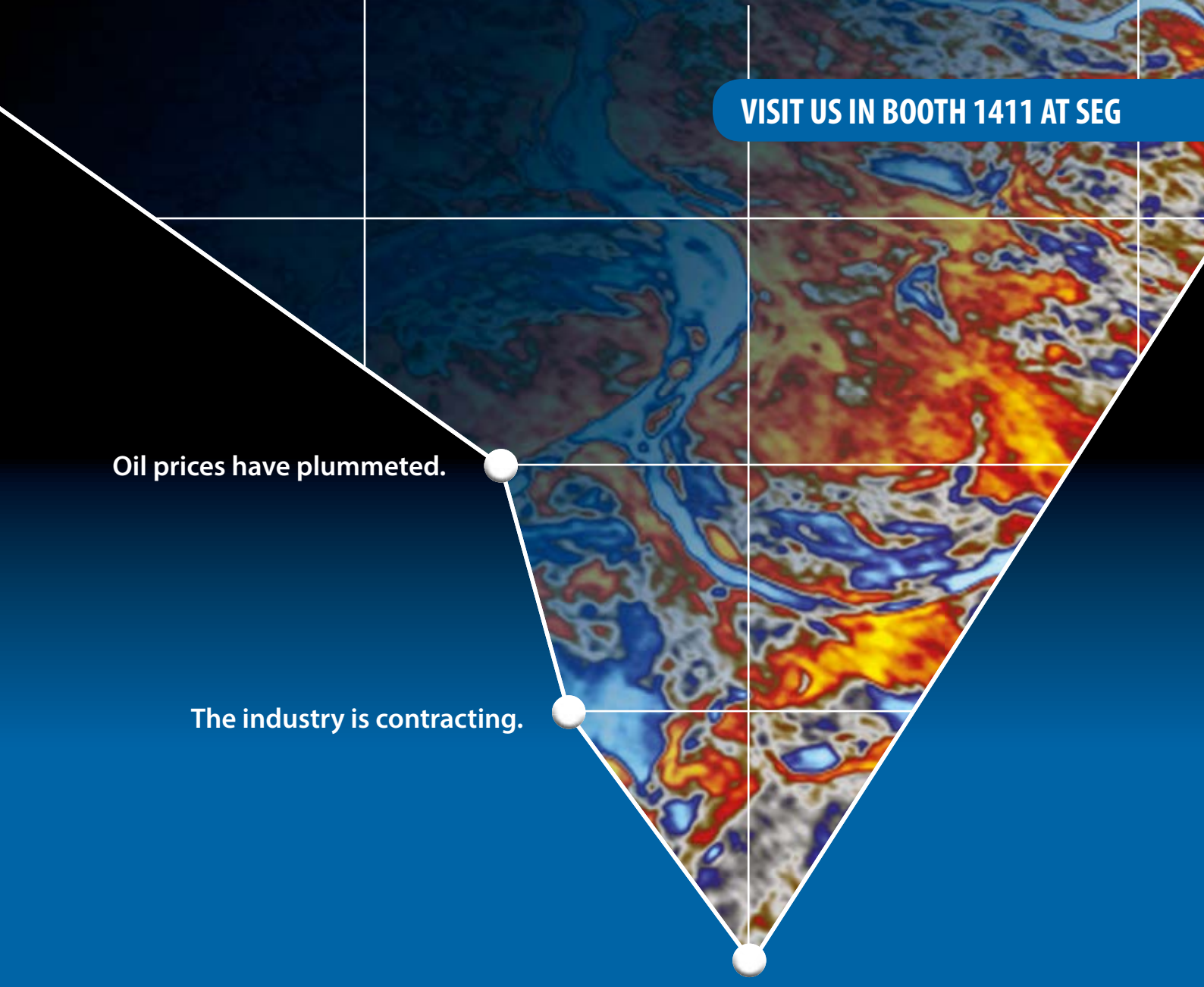


Figure 3: Early Miocene lacustrine organic rich shales in cyclotherms exposed in the cliff, with erosion at top surface caused by basalt flood sheet, Gilju-Myongchon Basin. A TOC of 6.3% was recorded from this location.



We're Rock Solid.

In the face of industry uncertainty, RSI is opening new facilities in Sheffield, and hiring. Good timing? Absolutely. Year after year through market ups and downs, our experts have helped clients reliably predict reservoir geometries and properties by combining advanced rock physics and sophisticated geologic models. We lead the industry in the interpretation and integration of seismic data with well log, CSEM and MT data.

And now RSI has even more resources to help you succeed – in any market.

While others look to the future with apprehension, we're seizing opportunities. And we can help you do the same. Take your exploration, appraisal and development plans in a positive direction. Go with RSI.

RSI

rocksolidimages.com

HOUSTON | LONDON | VILLAHERMOSA | SHEFFIELD

deepwater region in excess of 2,500m. The surrounding shelf is cut by several major canyons corresponding to broad braided river systems onshore (Figure 4), providing perfect sedimentary entry points for the deposition of extensive submarine fan systems in the deepwater.

Exploration started in the 1970s with Russian geophysical studies, prior to the first 2D marine surveys by the Russians in 1986 and 1989. These led to the drilling of two stratigraphic wells, E-601 and E-602, between 1989 and 1991 in relatively shallow waters to the west of Tongjoson Bay (Figure 5), both of which encountered encouraging shows of oil and gas. In 1997 Beach Petroleum shot approximately 1,000 km of 2D marine seismic in the shallower western region around the two wells, and found that both had been drilled on structures that lacked structural closure along strike. However, they did identify a large number of trap types, most associated with basement structural highs. Unfortunately Beach were unable to continue their exploration program and withdrew, and no new data was acquired until 2012, when Korex Ltd reprocessed the surviving digital seismic data prior to acquiring a new 5,000 km long-offset 2D seismic programme.

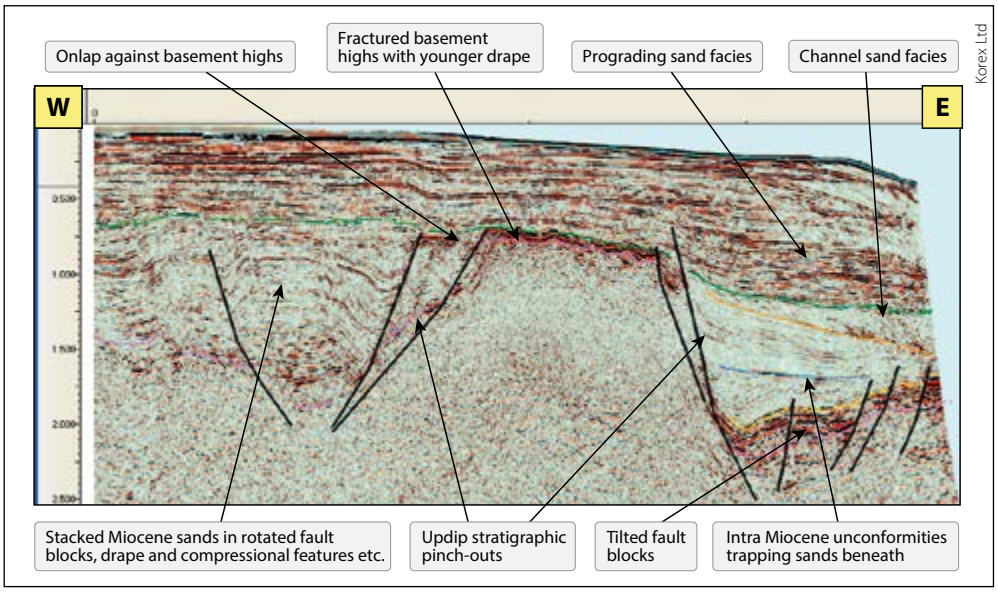


Figure 5: Illustrative east-west seismic profile from Tongjoson Bay in the western part of the East Sea Basin, showing some potential play types.

Reprocessing of the 1997 2D seismic was highly significant in that it led to the recognition of several potential stratigraphic trap types, previously unrecognized on the older seismic data, including beach bars at a shelf edge break zone (in present day shallow water depths) and prograding seismic facies supportive of the presence of submarine fan/basin floor fan deposition eastwards into basinal lows beyond the shelf-edge via the deep submarine canyons that bisect the shelf region. There is also a good possibility for a shallow basement/'buried hill' play, dependent upon the degree of fracturing present.

Analysis of cuttings and oil shows from the two wells drilled to date indicates Lower Miocene dark shales to be the most likely source rock, with TOC values of up to 9.3% recorded by Beach Petroleum in E-602. Tar balls collected from the shoreline at Kimchaek are considered to have originated from naturally occurring seafloor oil seeps related to source rocks not unlike those that yielded the E-601 and E-602 GCMS extracts, matching the depositional setting of the sediments, namely Tertiary paralic, with a lower oleanane content possibly indicating a more marine setting. There is a risk of lower maturity source rocks in the deeper water environment, where their quality could be similar to those of the associated diatomaceous cherts (Type I hydrocarbon sources) of the Honshu region of Japan, and similar to the Monterey Cherts of California.

The present is the key to the past: the current East Sea Basin is fed by large rivers, with beach bars, hills and mountains slowly being buried offshore and point-sourced inputs of major sediment supply, all comparable to what is seen offshore on the 2D seismic. With only two offshore wells, located on the basis of limited 2D seismic, the East Sea Basin clearly has much potential to offer.

Figure 4: Broad, braided river systems flow into the East Sea providing major sedimentary input.

Excellent Exploration Potential

Undoubtedly the DPRK does have good hydrocarbon potential, both on and offshore, and for those who are prepared to take 'first mover advantage', the rewards are there to be had. Sadly, the current politics are a deterrent to many, but despite the DPRK's reputation in some of the western media, it does offer relatively low cost and low risk exploration opportunities in a low competition environment, with nearby energy-hungry markets. ■

Divided Peninsula

Japan annexed the whole Korean peninsula in 1910, and it remained under Japanese rule until the end of the Second World War, when Soviet troops occupied the part of Korea north of the 38th parallel while US forces held the southern half. After many years in exile in China and the Soviet Union, Kim Il-sung returned to North Korea to become, in 1948, the first premier of the newly established Democratic People's Republic of Korea, with a political system partly styled on the Soviet system, with political power held by the Worker's Party of Korea. In the same year UN-sanctioned elections in the south had resulted in the creation of the Republic of Korea, with Seoul as the capital.

In 1950 war between the two Koreas broke out, and after a series of offenses and retreats by both sides and major loss of life, the war ended in July 1953, with the two countries still separated by 4 km of no man's land – the Korean Demilitarized Zone – centered on the 38th parallel.

Figure 6: The Juche Tower, 170m tall, built to commemorate Kim Il-sung's 70th birthday, completed in 1982. The tower is named after the Korean state principle of Juche, a blend of self-reliance, Korean traditionalism, and socialism, which still guides all aspects of present-day life in DPRK. Associated with the tower is a 30m high statue of three figures: a worker holding a hammer, a peasant holding a sickle, and an intellectual holding a writing brush.

Smart Fields: People, Processes and Technology

The implementation of Smart Fields solutions has enabled Shell to increase production, reduce deferment, and improve ultimate recovery while reducing costs and HSSE exposure.

C.F. CHAI, F.G. VAN DEN BERG, P. ENGBERS;
Shell Global Solutions International B.V.

Intelligent digital oil or gas fields – known as 'Smart Fields' to Shell employees – are asset or groups of assets that can be optimized continuously. This is achieved via integrated models and workflows which can manage both surface and subsurface aspects of the field to maximize lifecycle value, while honoring existing operational constraints. For more than a decade, Shell's Smart Fields program has built intelligent capabilities into key field developments by introducing new technologies and ways of working to ensure that there are appropriate technical solutions for each asset to become technology-enabled from the earliest phase in its development: in essence, the innovative integration of people, processes and technology.

The main areas in which Smart Field workflows and technologies are applied are production surveillance and optimization, smart wells, real time monitoring and optimization, and time lapse reservoir surveillance. Assets which are part of the Smart Fields program have shown increased production, timely delivery, faster and superior decision-making, improved cooperation and increased ultimate recovery, while reducing costs and HSSE exposure.

Integration and Collaboration

Shell's focus is on integrated solution generation through Appropriate Level of Smartness (ALoS) methodology, ensuring that the project is 'Born Smart'. Firstly, ALoS screening identifies which solutions to include in order to maximize the project value and help reduce its key business uncertainties, looking at the whole lifecycle. Secondly, ALoS deployment focuses on having the ALoS Recommended Solutions at start-up, and then using them in a sustainable way going forward, tracking progress and mobilizing support to provide a consolidated overview and to help set focus and targeting actions in a meaningful way.

There are many Smart Fields solutions and they may be applicable for

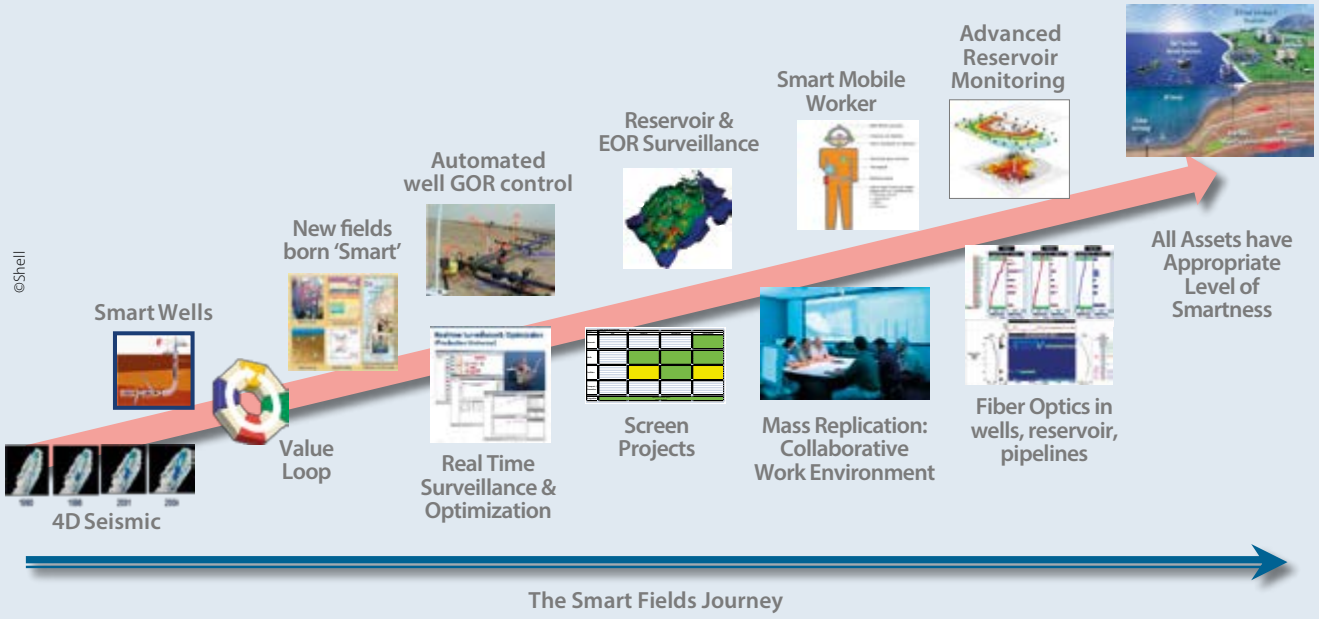
©Shell

The Real Time Operations Center in Shell's office in New Orleans.

The Smart Fields Journey

Smart Field technology started with 4D seismic, smart wells and real time surveillance, combined with collaborative working environments. For more complex field development, 'stacking' of different solutions became common; so with EOR, for example, a combination of smart wells and reservoir surveillance solutions are deployed. During the first decade of Smart Fields activities in Shell, the delivery model was built around a central team in the Shell Projects and Technology Upstream Development organization in collaboration with regional coordinators. Regular global meetings between the collaborators ensured the identification and delivery of different integrated solutions to improve the performance of the regional assets. The knowledge sharing within this framework equipped both the central team and the regional coordinators with a consistent set of information and technology data to develop an appreciation of Smart Field technologies.

A decade later additional solutions, such as advanced reservoir surveillance and fiber optic monitoring, have been incorporated, while the main focus of the Smart Fields program has shifted from 'selling' individual solutions to the efficient identification and deployment of the right mix and balance of ideas in a way that sustains lifecycle value generation – appropriate Smart Field capabilities, or ALoS.



many types of fields – but not every solution works everywhere.

For example, the implementation of Collaborative Work Environments (CWEs), which bring together petroleum engineers, well services and offshore operations staff in virtual real-time decision-making, has proved key to the success of the Smart Fields initiative. The concept of CWEs has evolved, gradually expanding from real time monitoring centers to the development of standard solutions and designs for the various processes and disciplines involved.

CWEs have become standard practice and have been implemented on a large scale, most focusing on the production and field surveillance area and on real time monitoring, improving cooperation across disciplines and between office and field locations, thus enabling enhanced decision-making. Strong focus has been placed on embedding these new ways of working in the organization, based on the philosophy of how a field should be managed, so each operation is based on one data set, one plan and one common set of priorities. It is a flexible and multilateral instrument that integrates people, processes and technology so that, for each asset, an assessment identifies the key aspects relevant to the asset and formulates the best collaborative solution for it.

Shell estimates that CWEs contribute to production gains of between 1% and 5%, creating considerable value to the assets. In addition, they result in reduced travel, lower HSSE exposure and higher staff morale, better common understanding of the field, faster response to observed and predicted events in wells and facilities and improved activity planning.

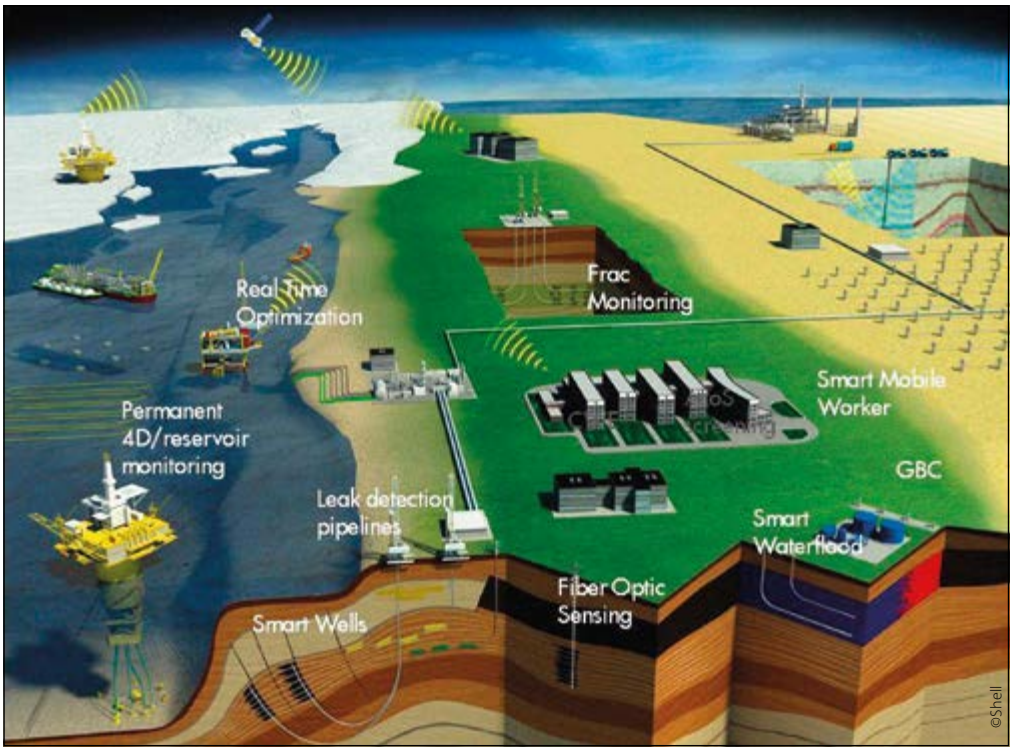
Benefits of Smart Fields

A decade of experience in applying Smart Fields applications around the globe has shown that significant value can be derived if we gather more information from reservoirs, wells and facilities. In fact, Shell has demonstrated that over a five-year period the value of Smart Fields implementation to the company was in the region of US$5 billion (Van den Berg et al., 2010).

About 200 smart wells have already been deployed by Shell, resulting in

significant impact to the business; the estimated value of these alone is more than US$3 billion. In Siberia, the use of Smart Field technology has resulted in the ESP start-up time after trips being reduced by more than 50%, which has also avoided additional travel in sub -40°C temperatures. Similarly, using 4D seismic in Europe has led to the drilling of wells in previously by-passed oil-bearing areas and avoided drilling in watered-out zones, while in the US the use of land microseismic gave rise to a modified injection strategy, adding significantly more reserves.

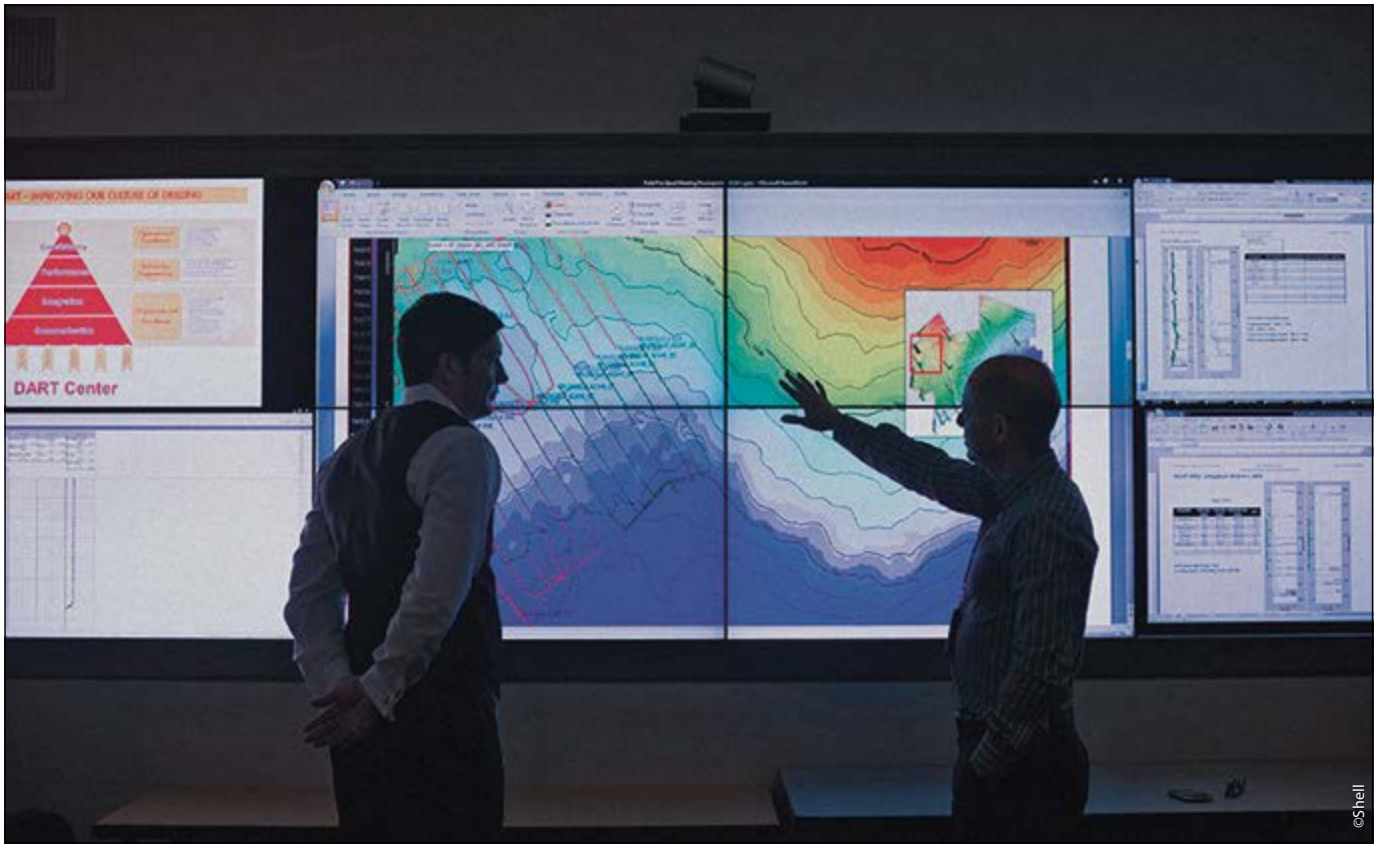
Installing Smart Fields remote monitoring and operation capabilities in a Middle East asset resulted in 20% less travel time to and from wells and to the mothballing of some gas compressors due to higher production and less flaring, while smart wells helped unlock several hundred million barrels of oil in the Asian offshore environment.



The Smart Field.

Sustaining Solutions and Benefits

Having proved the effectiveness of Smart Fields solutions, it is important to show they can be sustained, and continue to be used, after the implementation project has finished. This has sometimes been difficult to achieve, particularly if, for example, the original sponsor is moved to a new job after the initial project team has left, and all relevant project staff in the asset team are replaced. To achieve



the desired sustainability of the solutions and benefits, specific elements need to be in place during the design and implementation phases.

The existing implementations of Smart Fields technologies have provided a wealth of information to suggest which elements were likely to result in a successful roll-out and what was required for sustainability.
To understand the key drivers and pitfalls in global implementation, a 'sustain' methodology was developed which provided insight into where these areas were, and which has led to a significant change in Shell's approach to the preparation for deployment of smart technologies.

Since integration is usually a critical proponent of smart technologies, more emphasis was placed on designing capability, creating a 'value loop' (measure – model – decide – execute) with defined workflows and staff roles. It was realized that a number of requirements need to be in place during integration.

Critical success factors for sustainability of the solutions were identified as:

- Implementation of technology wrapped as integrated capability, with the focus on people and organizational elements;
- Fitting the technologies in a closed loop results in solutions that fit in the asset setup;
- Business ownership of the full solution, including after the implementation;
- Alignment of the solutions with business needs;
- Quality of the project team leaders during implementation;
- Clear accountability for data quality assurance;
- A support structure to help staff, covering processes software, instruments, infrastructure and data;
- Local and global learning and sharing of the practitioners;
- Key performance indicators to ensure workflow and people elements are maintained and in place.

Transformational Leaders Needed

There are five important elements in the successful deployment of Smart Fields: leadership, organizational structure, people, behavior, and process and technology. Smart Fields implementation in particular requires tailored talent management: the right number of people, with the right knowledge and skills, in the right location. People with problem-solving skills and the ability to grasp new ideas make competent Smart Fields professionals, preferably also with resilience, good communication abilities in a multidisciplinary environment, multidisciplinary business knowledge, marketing skills to help 'sell' the vision or solution, and transformational leadership to inspire people with a shared vision of the future with clear goal setting. A tall order!

Learning from successes and failures in the implementation of Smart Fields has given, and continues to give, deep insights in optimizing the approach for technology deployment. In future, today's 'nice-to-have' technology will increasing become a standard to enhance an asset's value. ■

Walking an Arctic Tightrope

Relying heavily on the petroleum industry for revenue, yet on the pure waters of the Arctic Ocean for subsistence, native Alaskans struggle to find a delicate balance.

HEATHER SAUCIER

Before the historical discovery of oil at Prudhoe Bay in 1968, the Inupiat Eskimos living on the North Slope of Alaska lived a lifestyle unlike most others in the United States. They bathed in galvanized tubs, thawed drinking water from ice, and relieved themselves in 5-gallon cans. Power, infrastructure, and the safe disposal of human waste? None were part of their existence in temperatures that often dipped – and still do – below zero.

The oil and gas industry's major discoveries north of the Brooks Range changed all of that.

The North Slope Borough, a local governing body established by the Inupiat in 1972, taxes the industry's above-ground infrastructure, including pipelines, buildings and roads. The flow of funds – more than $100 million annually, in fact – practically modernized the Inupiat community overnight with clinics, fire protection, schools, and flush toilets.

Yet, ironically, as the industry moves into the Arctic Ocean, some say it could threaten the existence of thousands of Inupiat Eskimos. One oil spill or any loss of well control could jeopardize the food sources on which practically every Inupiat depends. This concern has become the talk on the North Slope these days, especially since Shell announced plans to resume its exploration program in the Chukchi Sea this year.

Perhaps no one understands the precarious walk down the tightrope better than Richard Glenn.

The son of an Inupiat mother and Caucasian father, Glenn moved to Alaska as an adult to work as a geologist. It didn't take long, however, for him to accept a corporate position overseeing millions of acres of Inupiat land and resources, striving to find a way to simultaneously welcome the industry and protect the beloved environment.

Unlikely Groups

Although Glenn grew up in San Jose, Calif., he spent many summers in his mother's native village of Barrow, Alaska, the northernmost community in the United States – 340 miles north of the Arctic Circle – knowing in his heart he would later move there. He left San Jose State University with a bachelor's degree in geology in 1985 and headed to Fairbanks, Alaska for his master's, which he earned in 1991.

While his professional experience includes petroleum geologic studies, field mapping, structural geologic and seismic interpretation, and permafrost, among other subjects, it was the study of sea ice

Richard Glenn, wearing a white hat and navigating his way through the Chukchi Sea near Barrow, Alaska, is co-captain of his family's subsistence whaling crew.

R. Glenn

that played a pivotal role in his career.

Studying sea ice in a classroom gave him an academic perspective on the science. Learning about sea ice from the Inupiat, who have observed its patterns for hundreds of years, rounded out his education in ways that few students experience. It also opened his mind to the whole picture that can be achieved by combining unlikely groups.

"When you get experts together from both sides, the cultural differences disappear. Everyone simply becomes colleagues," he says.

Richard Glenn smiles after a successful whaling expedition off the coast of Barrow, Alaska in the Chukchi Sea in 2003.

Politics on the North Slope

Glenn is not a historian, but like many Inupiat – a word that means 'the real people' – he knows well the plight of his predecessors' long struggle to retain rights to their land, especially after the major discoveries of Prudhoe Bay and the Kuparuk River oilfields in the late 1960s.

The US government passed the Alaska Native Claims Settlement Act of 1971 that gave approximately 75,000 native Alaskans 44 million acres (178,000 km^2) of land and nearly $1 billion with which to establish businesses to generate revenue. These were mandated to operate under the auspices of 12 regional corporations created by the settlement act that are owned and managed by native Alaskans. One of them, the Arctic Slope Regional Corporation (ASRC), where Glenn serves as executive vice president of Lands and Natural Resources and as a board director, oversees 5 million acres (20,250 km^2) rich in minerals on the North Slope. The ASRC is owned by 11,000 Inupiat, many of whom support the petroleum industry with businesses that provide engineering, operations and maintenance services. In fact, Glenn ran a business in the 1990s that provided information about ice strength to various researchers.

However, it is the tax revenue generated from the industry that keeps the Inupiat Eskimos in the modern world. "There is no other revenue that can support the level of public services we are providing to the people. Oil and gas have become very important to our livelihood," says John Hopson, mayor of Wainwright, one of eight villages represented by the ASRC.

The tax revenue also enables the Inupiat to continue their subsistence lifestyle, which grows more costly by the day. Skin boats and dog teams have been replaced by snow machines and motorboats – all of which rely on fuel, which typically costs $8 a gallon in this corner of the world. "Hunting is our main diet," Hopson continues. "Whaling is very important to the people of the North Slope."

As a co-captain of his family's subsistence whaling crew, Glenn understands the importance of both subsistence living and oil and gas revenue firsthand.

Finding That Delicate Balance

With the US federal government's announcements earlier this year of new areas off limits to exploration in the Chukchi and Beaufort seas in addition to stricter drilling regulations, industry advocates such as Glenn have their work cut out for them.

Aware of the perceived dichotomy

Taken by Richard Glenn, this photo shows the Atigun Gorge in the east-central part of the Brooks Range.

between the industry and the environment, Glenn is working to bring together another set of unlikely groups: the offshore industry and those who oppose it. As a member of the US Arctic Research Commission, board president of the Barrow Arctic Science Consortium, and board member of the Arctic Research Consortium of the United States, Glenn's credentials carry weight.

Several years ago, he spoke before the House Energy and Commerce Subcommittee on Energy and Power to try and win the federal government's support for offshore Arctic exploration. Citing the steep decline in the quantity of oil that creeps through the Trans-Alaska Pipeline (less than one-third of its peak throughput), he explained that offshore exploration will pave the way for future generations to attend school and power their villages.

"This issue boils down to community survival," he said. "Safe and responsible oil and gas development is the only industry that has remained in our region long enough to foster village improvements. The people of the North Slope have a heightened concern for the environmental effects of oil and gas exploration and development. No one has more at stake than we do regarding environmental risks."

After making a plea to the government, Glenn and his colleagues at the ASRC are now turning to those in their own community who have trepidations about offshore exploration. Hunting whales, fish, seals and walruses is woven into the DNA of the Inupiat. Especially for the community's elders, continuing such activities is of primary concern, explains Teresa Imm, senior vice president of Resource Development for the ASRC. The thought of oil and gas companies drilling in the Chukchi and Beaufort seas has unleashed outspoken critics, she says, attributing many of their fears to erroneous messages swarming on social media platforms and concern over the 2010 Macondo incident repeating itself.

In response, an educational campaign has begun in order to inform the Inupiat that public safety, schools, search and rescue capabilities, water and sewer services, planning and zoning, and health and social service programs only exist through North Slope Borough revenues generated by the petroleum industry – a fact that many don't realize.

"In the 1970s, a large segment of the population believed that when Prudhoe Bay was discovered, subsistence would be lost as a result of the impacts of oil industry infrastructure – that it would have a major impact on the caribou," Imm says. "But that hasn't played out as it relates to subsistence. Subsistence is still strong on the North Slope."

Co-Existence

Having studied the oil spill prevention and response plans of Shell and other operators in the Arctic Ocean, Glenn believes that a robust system – complete with dispersants, in-situ burning techniques and mechanical recovery – is in place for safe exploration. "We were favorably impressed by the timing, technology and safeguards introduced by the Alaska Outer Continental Shelf explorers," he says. He noted that offshore drilling in the past has taken place more than 80 km from the coast and never disrupted the subsistence activities of the Inupiat.

Working to demonstrate that the offshore industry and the Inupiat can co-exist, Glenn and his team have achieved some degree of unity.

Some Inupiat Eskimos in the coastal villages have teamed with Shell to train for oil spill response efforts, if ever needed. And six of the ASRC villages have created a business partnership with Shell so they might reap the financial benefits of a discovery to balance any potential risks.

"Some people are not ever going to support offshore exploration and development, which we recognize," Imm says. "But for the most part, we have received positive responses from the shareholders on this venture."

"The key to our success is to be able to sit around the table so that industry and government and the people have a say in what happens with our future," Hopson said.

As Glenn reminds us, offshore Arctic drilling is taking place in multiple countries. In his eyes, to make lucrative areas off-limits or economically unfeasible to drill essentially transfers an unlikely threat to the environment to a looming threat for the Inupiat.

Yet, both can be protected, insists Glenn, from his rare vantage point. The environment and the Inupiat are not unlikely groups. Rather, each is part of the other and must remain so. ■

The Oooguruk offshore oil field is located on Oooguruk Island, which is eight kilometers offshore from Harrison Bay in the Beaufort Sea.

Teresa Imm

KNOWLEDGE FOR DECISIONS.

DAKS™ is a knowledge platform that enables you to apply lessons learned and best practices from over 1,400 rigorously documented reservoirs. Benchmarking and analytical tools, along with the ability to capture knowledge about your own assets for comparison against proven analogs, empowers you to make better E&P decisions.

- **Validate your project assumptions against facts from proven reservoirs to help reduce subsurface uncertainty**
- **Capture your asset knowledge and benchmark against global analogs to identify potential areas for improvement**
- **Identify reserve growth potential and candidates for acquisition or divestiture to help optimize recovery**
- **Generate and test new ideas for exploration and production**

CCRESERVOIRS.COM
For more information, contact info@ccreservoirs.com

C&C Reservoirs
ANALYZE. EVALUATE. OPTIMIZE.

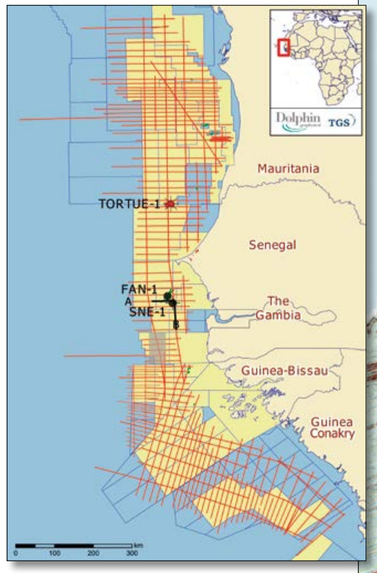
Offshore Mauritania and Senegal

Revisiting a 2D regional seismic dataset and integrating information from recent significant discoveries.

The North West Africa Atlantic Margin (NWAAM) region was underexplored for many years, but since the discovery in 2007 of the Jubilee Field by Kosmos Energy in Ghana, industry has refocused efforts to explore similar plays around the entire West and North West Africa coast. On October 7th, 2014, Cairn Energy announced an important and potentially commercial oil discovery in the Sangomar Deep block offshore Senegal. The FAN-1 exploration well recovered light oil from a series of stacked Cretaceous sandstones, with APIs ranging from 28° up to 41°. Cairn Energy drilled a second well, SNE-1, offshore Senegal in 1,100m of water and announced, on November 10th, 2014, that they had made an additional discovery. Initial analysis of the well, as reported by Cairn Energy, showed a 95m gross oil-bearing column with a gas cap, excellent reservoir sands with net pay of 36m of 32° API oil and a P50 contingent resource of 330 MMbo.

Kosmos drilled their first well offshore Mauritania in block C8 in early 2015. The Tortue-1 exploration well made a significant and play-opening discovery and, based on preliminary analysis of drilling results, encountered 117m of net hydrocarbon pay. The Tortue discovery area has been renamed Ahmeyim. The Cretaceous slope/channel complexes are imaged throughout the NWAAM seismic survey.

Location of main foldout line.



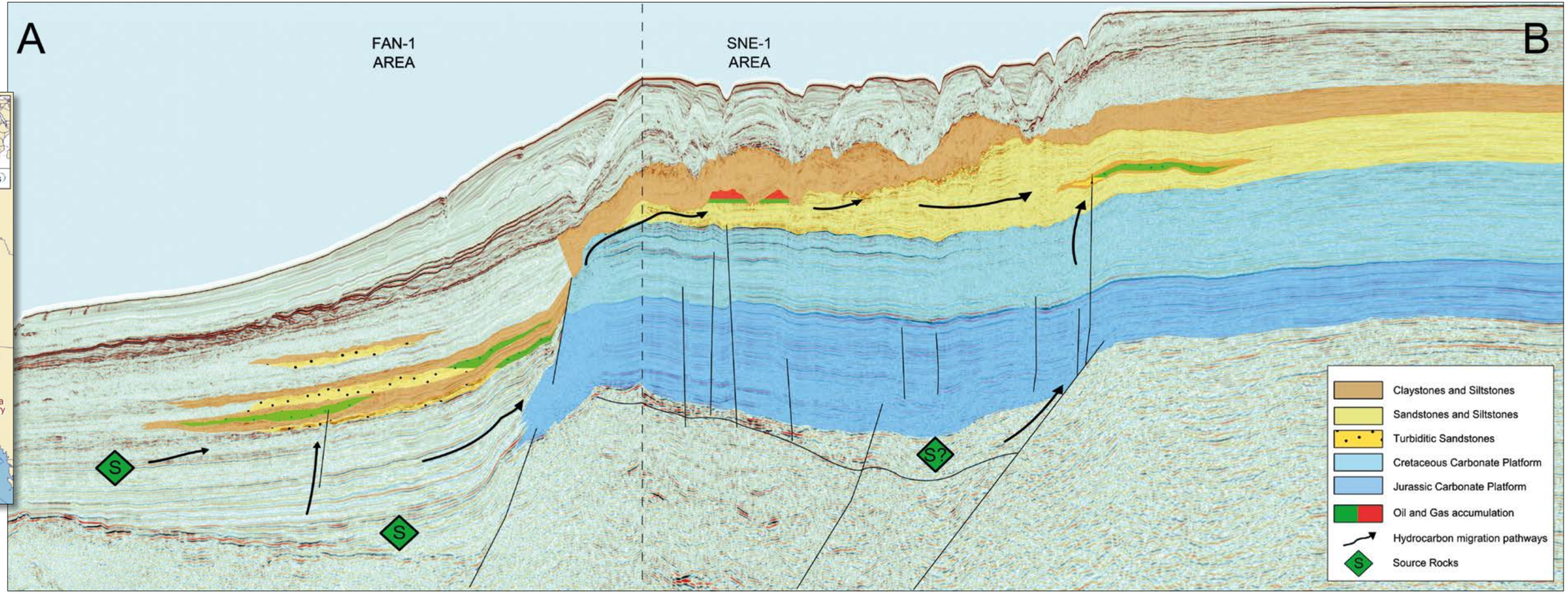


Figure 1 – Seismic traverse A-B extending through the FAN-1 and SNE-1 Areas.

Slope/Channel Complexes Offshore North West Africa

Newly acquired and reprocessed seismic reveals potential masked by complex geometries.

NICOLAS HAND, AZZURRA CILLARI, IAN EDWARDS and DAVID JACKSON
Dolphin Geophysical Multi-Client New Ventures

In 2011 TGS and Dolphin Geophysical acquired a regional seismic dataset (NWAAM) consisting of 17,764 km of 2D seismic with a record length of 9 seconds and which covered the margin of four countries – Senegal, The Gambia, Guinea Bissau and Guinea Conakry. This survey was followed by the acquisition of NWAAM Phase 2, which again was jointly acquired by TGS and Dolphin Geophysical in 2012. The Phase 2 survey consists of some 11,212 km of 2D seismic data with a record length of 14 seconds and covers the entire offshore margin of Mauritania. The location of the combined NWAAM datasets, and associated recent discoveries, are shown on the location map on the preceding page.

Geological Overview

The offshore geology of the NWAAM has been shaped by the evolution of the rift system that started with the Late Permian breakup of the African, North American and South American Plates. The area underwent three main tectonic phases: pre-rift, syn-rift, and post-rift. The pre-rift phase occurred in the Proterozoic-Paleozoic, the syn-rift phase in the Permo-Triassic, and a post-rift/drift phase occurred up to the present day (Brownfield and Charpentier, 2003).

All the elements of active petroleum systems have been confirmed by drilling, with source rocks proven in the Barremian, Cenomanian, and Turonian by deep sea drilling (DSDP-367). Exploration wells to date have proved a range of sandstone reservoirs ranging from Early Cretaceous (Loup de Mar-1), through Late Cretaceous (Faucon-1), to Late Tertiary (Chinguetti Field).

Ahmeyim Discovery

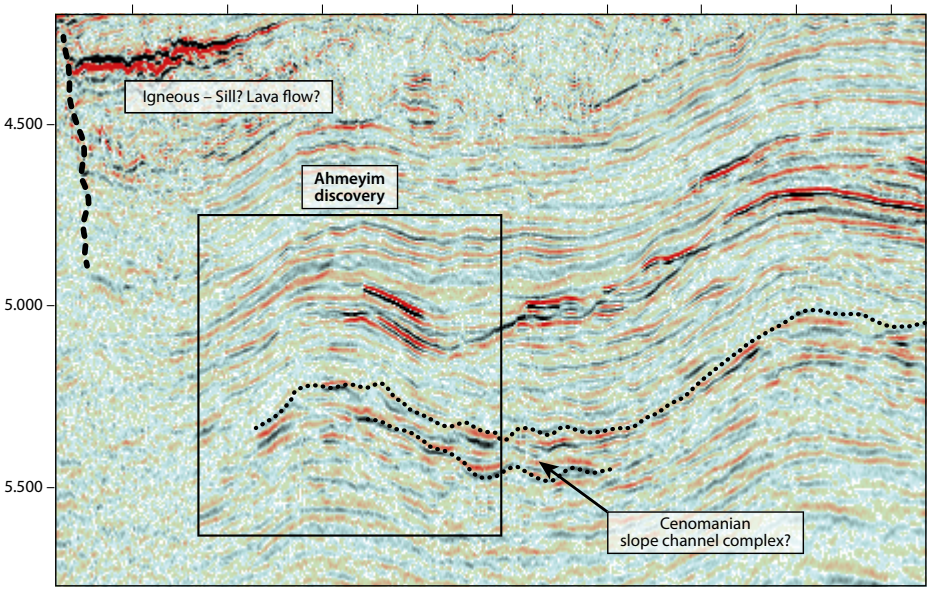
Kosmos's Ahmeyim discovery was made by the Tortue-1 well, which found 107m of net pay in the primary Cenomanian objective, and another 10m of pay in a lower Albian section. The Tortue-1 well was designed to test the western closure of a series of Upper Cretaceous slope/channel reservoir systems in combination structural/stratigraphic traps. The seismic line from the NWAAM dataset (Figure 2) lies seven kilometers to the south of the Tortue-1 well but covers the southern end of the Ahmeyim discovery. The preliminary estimate of the gas volumes for Ahmeyim are of the order of 5-8-12 Tcfg (Kosmos, Mauritania Exploration Update, 2015).

Architecture of Slope/Channel Complexes

The Tortue-1 well proved the very high potential of the Cretaceous slope/channel corridor that extends along the Mauritania and Senegal margins. Following the discovery we revisited the regional scale interpretation to see what we could deduce from the 2D seismic in the light of this new information. Figure 3 outlines what we believe to be the internal architecture of a line perpendicular to the channel axis of a complex lying to the north of the Tortue-1 well. Essentially, two basic seismic characters can be seen – mounded structureless areas (showing compactional drape above), surrounded by variable dipping reflectors. The complex geometries are a result of the interplay between migratory channels and their associated overbank/levee deposits. On the left-hand side of the section a smaller migratory channel system has been interpreted.

The spacing of the regional dataset is of the order of 10 km between lines shot perpendicular to the margin, but by using seismic character to distinguish between areas dominated by migratory channel complexes and their associated overbank/levee deposits, it has been possible to

Figure 2 – NWAAM 2D seismic across the Ahmeyim discovery.



highlight channel-rich corridors. Figure 4 shows a composite line extending from the salt-structured eastern edge of a channel complex sequence, into the channel complex, and then back onto the eastern edge of the channel complex sequence. By simply mapping the thinning edge of the overall channel complex sequence, along with the internal 'mounded/structureless migratory channel complex' and the 'layered/reflective overbank/levee' seismic facies, a series of complex channel corridors can be mapped for various stratigraphic levels.

Figure 5 shows a stacked series of Cretaceous slope/channel complexes interpreted from the north of the Ahmeyim discovery, where the upper two complexes have possible DHIs (flatspots) conformable with structure.

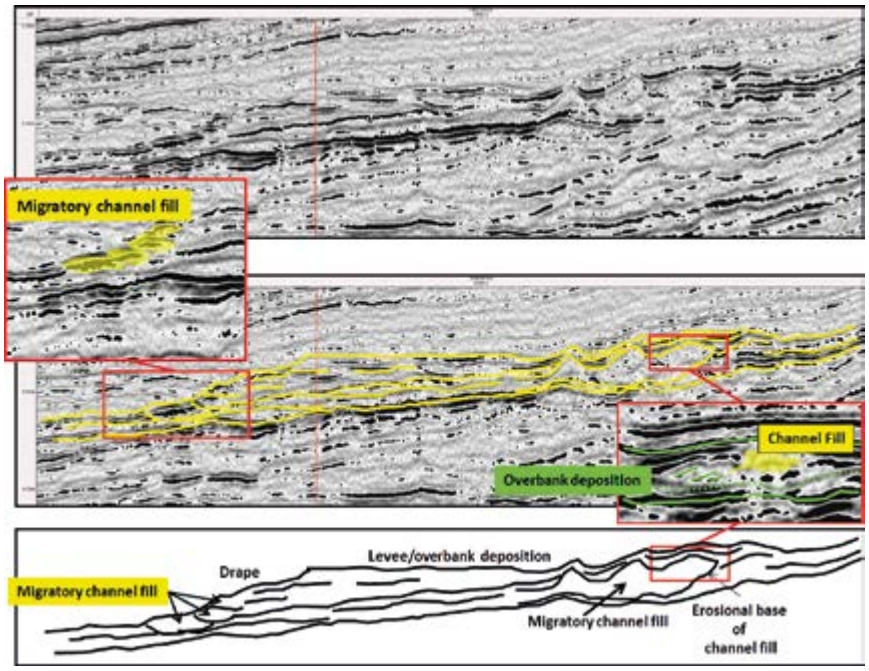


Figure 3 – Cretaceous slope/channel complexes to the north of the Tortue-1 well - architectural interpretation of NWAAM 2D seismic.

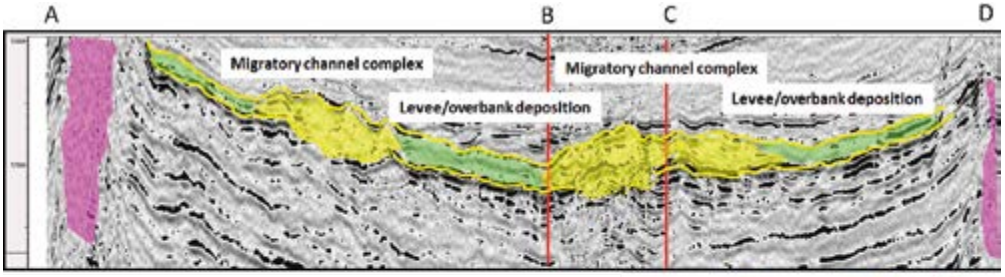
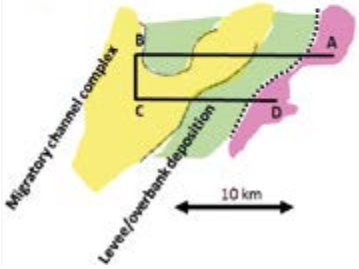


Figure 4 – Cretaceous slope/channel complexes to the north of the Tortue-1 well – architectural interpretation of NWAAM 2D seismic.



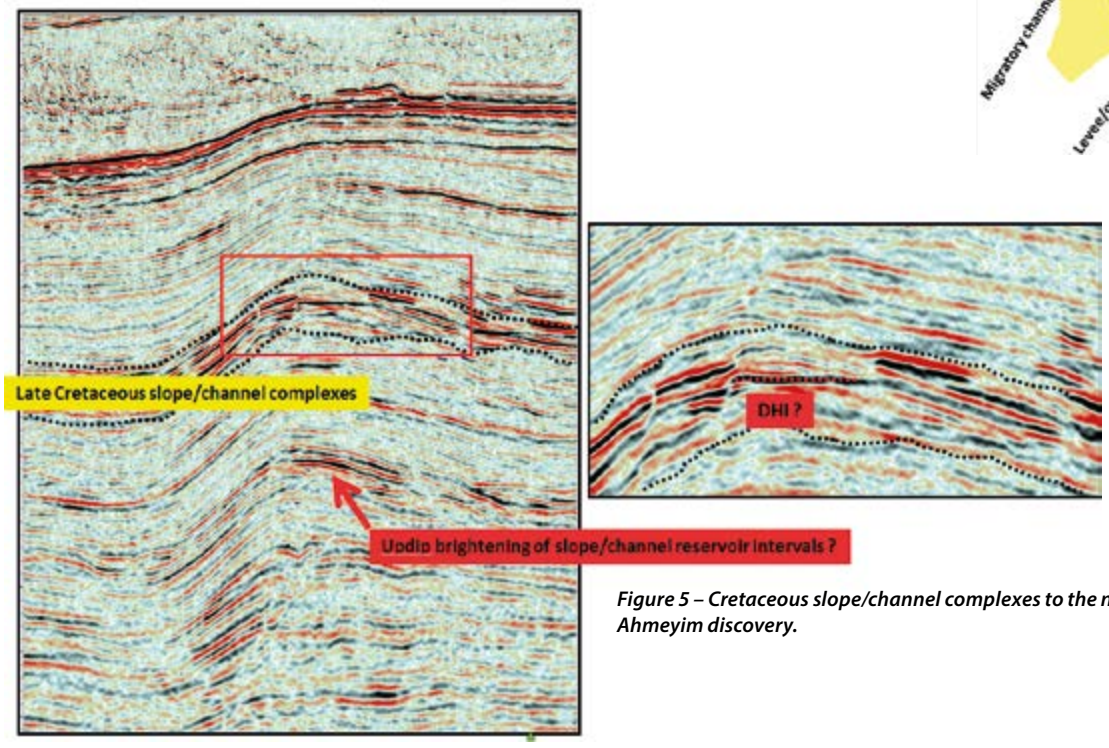
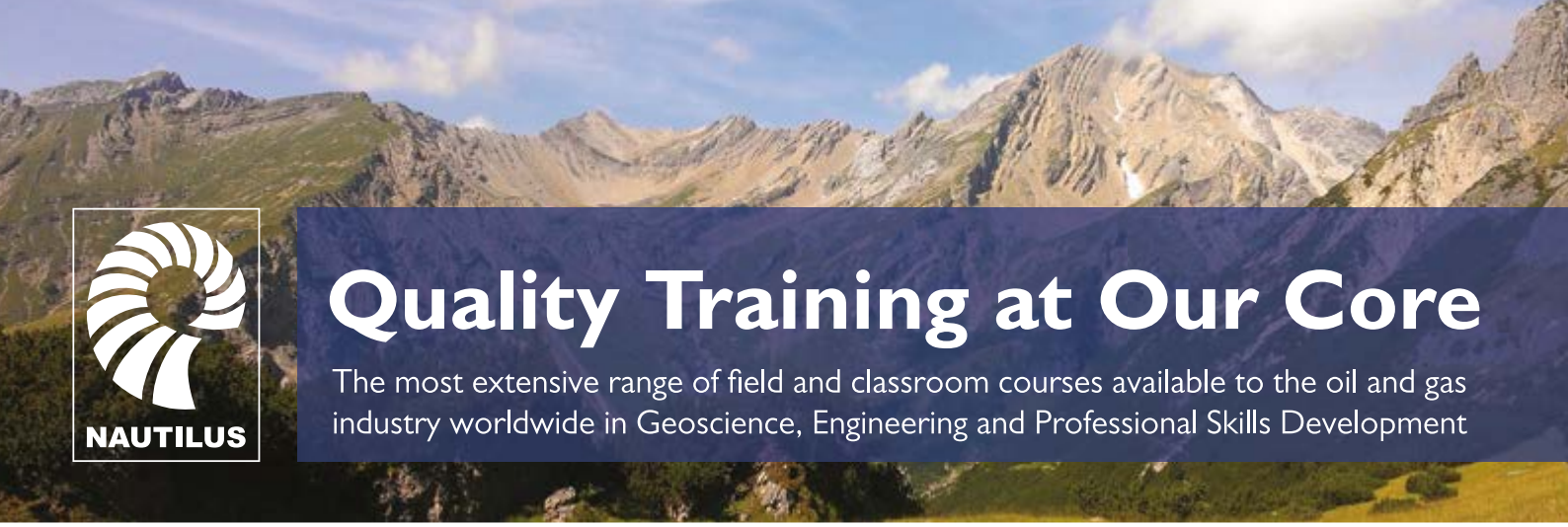


Figure 5 – Cretaceous slope/channel complexes to the north of the Ahmeyim discovery.

References :

Brownfield, Michael E., and Ronald R. Charpentier. Assessment of the Undiscovered Oil and Gas of the Senegal Province, Mauritania, Senegal, The Gambia, and Guinea-Bissau, Northwest Africa. U.S. Geological Survey Bulletin 2207–A, 2003: 1-29.

Mauritania Exploration Update, May 2015. Kosmos Energy. ■



NAUTILUS

Quality Training at Our Core

The most extensive range of field and classroom courses available to the oil and gas industry worldwide in Geoscience, Engineering and Professional Skills Development

Subject Areas:

- Basin Analysis
- Carbonates
- Clastics
- Geophysics
- Introductory Courses
- Petrophysics
- Production Engineering
- Professional Skills Development
- Reservoir Development
- Reservoir Engineering
- Seismic Interpretation
- Stratigraphy
- Structure and Tectonics
- Unconventional Resources

Course locations include:

Aberdeen, Edinburgh, Houston, Kuala Lumpur, London, Perth and Stavanger.

Upcoming Courses for 2015:

N245: Sedimentology and Stratigraphy of Lacustrine Systems: Reservoir and Source Rocks, Great Salt Lake and Green River Formation
Dates: 13 Sep 2015 - 18 Sep 2015 (field class)
Location: Utah and Colorado, USA

N356: Production Geoscience
Dates: 14 Sep 2015 - 18 Sep 2015 (field class)
Location: Pembrokeshire, UK

N984: Introduction to Reservoir Engineering
Dates: 14 Sep 2015 - 18 Sep 2015
Location: Houston, USA

N934: PVT
Dates: 14 Sep 2015 - 18 Sep 2015
Location: Edinburgh, UK

N217: Seismic Imaging and Velocity Model-Building Techniques: Concepts, Examples and Pitfalls
Dates: 21 Sep 2015 - 24 Sep 2015
Location: Houston, USA

N143: Advanced Concepts in Carbonate Exploration and Reservoir Characterisation
Dates: 24 Sep 2015 - 29 Sep 2015 (field class)
Location: Northern Spain

N319: Sedimentary Basin Evolution and Petroleum Systems
Dates: 28 Sep 2015 - 02 Oct 2015
Location: Kuala Lumpur, Malaysia

N975: Integrating Geomechanics and Reservoir Management
Dates: 28 Sep 2015 - 30 Sep 2015
Location: London, UK

N840: The Fundamentals of Creativity and Innovation with Applications to E&P Organizations
Dates: 05 Oct 2015 - 06 Oct 2015
Location: Houston, USA

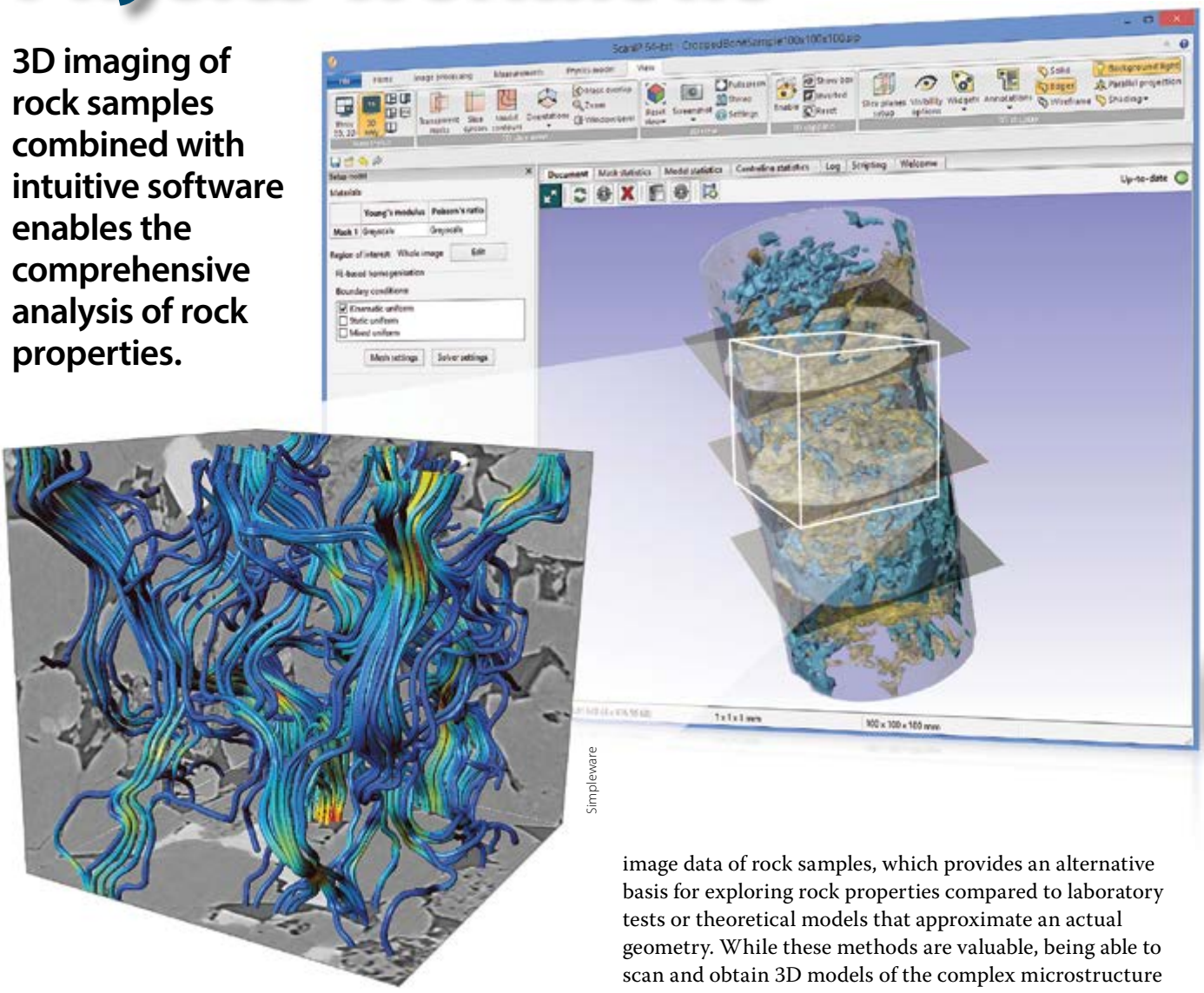
RPS® Training

For more information please visit: **www.nautilusworld.com**
or email: **info@nautilusworld.com**

Simplifying Digital Rock Physics Workflows

GARETH A. JAMES PhD
Simpleware Ltd.

3D imaging of rock samples combined with intuitive software enables the comprehensive analysis of rock properties.



Simpleware

Oil and gas researchers have a range of options available to them when analyzing rock samples, from more traditional experimental methods to techniques that use computational simulation. Virtual special core analysis and digital rock physics allow specific features of cores and geological samples to be analyzed from 3D scans, including porosity and transport properties. This type of analysis has the potential to cut down on laboratory waiting times in areas such as reservoir characterization, hydrocarbon production, and many others. However, getting to grips with software solutions for digital rock physics can be difficult for non-experts, creating the need for integrated techniques.

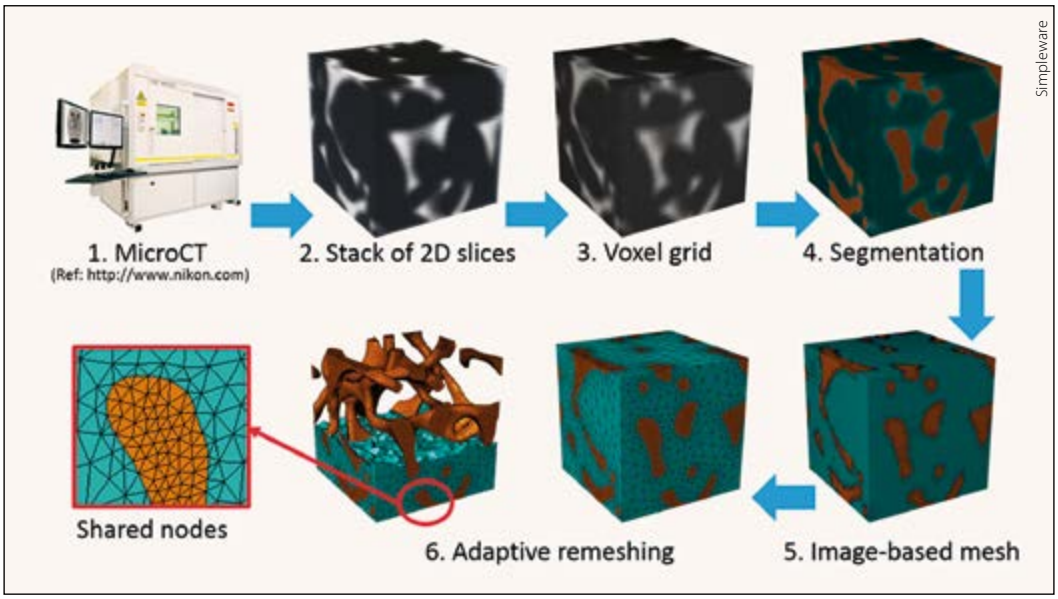
From Scan to Simulation

Digital rock physics involves obtaining high-resolution image data of rock samples, which provides an alternative basis for exploring rock properties compared to laboratory tests or theoretical models that approximate an actual geometry. While these methods are valuable, being able to scan and obtain 3D models of the complex microstructure of a rock sample can provide a deeper understanding of pore geometries and other features such as elastic and electrical properties.

3D images of rock samples can be obtained by using scanner types like computed tomography (CT), micro-computed tomography (micro-CT), and FIB-SEM (Focused Ion Beam-Scanning Electron Microscopy). These volume imaging techniques produce data that can be explored using image processing and simulation software to understand material phases, grain structure and porous networks without having to carry out destructive tests.

In a standard digital rock physics workflow, a sample object is scanned, with micro-CT typically producing the highest-quality images. Scanners reconstruct image projections to create a stack of images that can be exported in different formats, such as BMP, TIF, or PNG, which then somehow

need to be transformed so that the properties of the core can be modeled and analyzed. Simpleware Ltd, a UK-based company, has developed software solutions that make it fast and easy to convert rock sample scans into simulation-ready models.



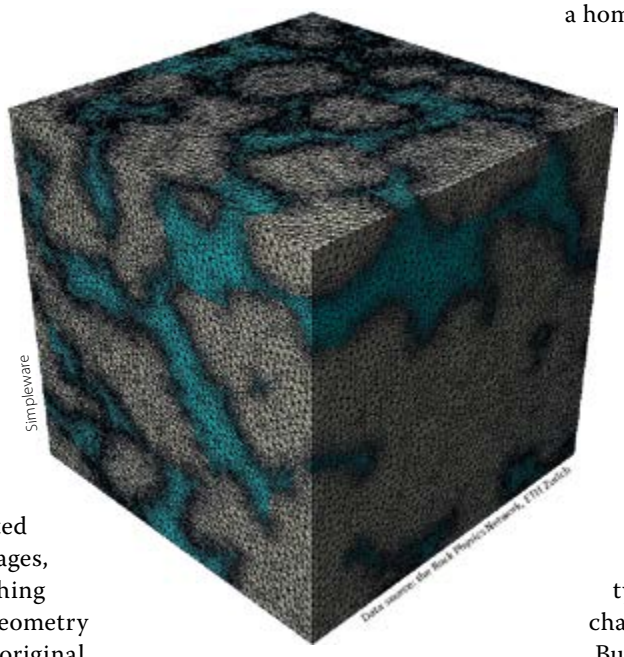
A digital rock physics workflow.

Image-based Meshing

A stack of images is imported into the software, and each image slice extruded to convert 2D pixels into 3D pixels, or voxels. To identify different materials phases, it is possible to distinguish between brighter voxels which have a higher density representing solid domains, and darker voxels representing surrounding air or fluid. Image segmentation techniques are used to label voxels that belong to specific regions of interest, such as different materials, and are supported by image processing tools. At this stage in a digital rock physics workflow, image noise created during scanning can be removed to enhance image contrast, while segmentation techniques such as thresholding can identify pores. Other software tools can remove unwanted features and segment particles, while initial measurements and statistics can be obtained on surfaces, volume areas and porosity.

Once image segmentation and processing is complete, models can be exported as a mesh, or grid, for numerical simulation. Finite element and computational fluid dynamics simulation approaches work here to predict the response of the sample to physical stimuli, for example an applied pressure gradient, generating valuable data. However, researchers and analysts who work with these types of data often have to carry out more work on meshes in simulation software before they can be used.

Simpleware's solution, by comparison, creates numerical models that can be directly exported and used in these simulation packages, and uses a novel image-based meshing method to maintain the original geometry of a scan. This involves taking the original scan data's voxel-grid and converting the voxels into mesh elements that accurately represent the original scan; this approach is distinct in the field of digital rock physics for being able to handle multiple material parts, where the accuracy of a model only depends on the quality of the original image and how the user chooses to segment regions of interest.



Meshed sample of Berea sandstone.

Understanding Material Behavior

The company has also developed software modules (the Physics Modules) for calculating effective material properties of scanned rock samples; individual modules can be used to retrieve properties such as the stiffness tensor, porosity, absolute permeability, electrical conductivity, among others. Homogenization, the method underpinning the calculations, is based on the idea that a complex heterogeneous material can be approximated by a homogeneous material with effective physical properties chosen so that it responds to different inputs in a manner very similar to the original material. Replacement of a microstructured medium by a uniform material vastly simplifies its analysis and reduces the computational resources required for the study of its behavior in macroscopic settings – for example, when the scanned rock is analyzed as part of a large reservoir. This approach can be useful, for example, when analyzing scans of different rock types obtained during reservoir characterization.

Built-in finite element analysis capabilities can be used to calculate the fields induced in a sample subjected to a

series of stimuli, represented mathematically with specific physics-dependent boundary conditions. For example, when the absolute permeability of a porous material is sought, the fluid velocity fields generated by pressure differences applied between the three pairs of opposite faces of a cubic sample of that material would be calculated. By post-processing these fields, the algorithm obtains the values of the effective physical properties of the sample. The software is designed to make it easier to quickly run simulations and get results. The use of image-based meshing and decimation of surfaces is particularly useful here as the size of meshes can be reduced without compromising their fidelity to the original geometry derived from the image.

The Simpleware Physics Modules contain tools that can be used by non-specialists working in oil and gas exploration to interpret results; these include convergence graphs that indicate whether the obtained results are accurate, and in particular whether the sample size is large enough to provide meaningful results. The software is able to calculate full tensorial effective properties as well as their best approximations matching specific assumptions about the material symmetry, for example isotropy, where the properties of the sample are identical in all directions. The fields induced by each set of boundary conditions used in the homogenization process can also be visualized or animated within the software suite.

Intuitive Software Needed

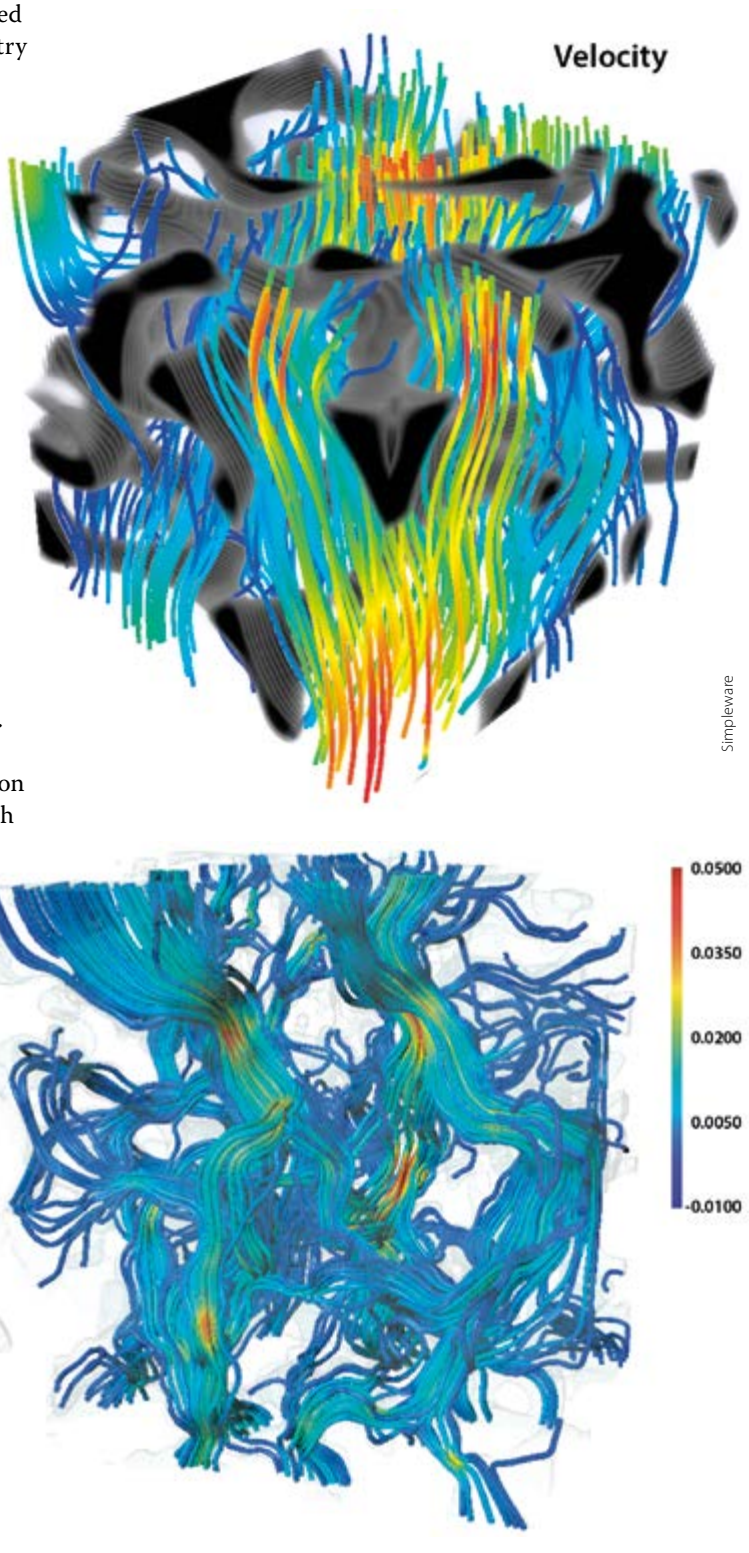
Making these results easy to obtain, and ensuring that safeguards like convergence graphs and other tools for deciding on the quality of generated meshes and results are available, is a key goal for digital rock physics software. In the same way, the use of scripting to automate or part-automate typical workflows has the potential to cut down on time-consuming tasks in the laboratory when working with multiple datasets.

The effectiveness of these software approaches has been tested by Simpleware using digital rock physics data from ETH Zurich, as well as data from published literature. For example, micro-CT data of a dry Berea sandstone sample was segmented in order to identify quartz and mineral inclusions and air occupying pores. Different meshes were tested, and effective properties calculated for elastostatics, viscous fluid flow and electrical conductivity. The results showed good agreement with published techniques and experimental data.

Future applications for digital rock physics involve adapting to changing computational resources, as well as working with samples where pores are filled with substances like clay or oil. Being able to accurately represent these fine features has significant potential for increasing the effectiveness of digital rock physics.

To make simulation technologies more accessible to geologists, technical software needs to become more intuitive and offer a simple and flexible workflow to handle complex tasks. The software solutions provided by Simpleware are focused on reducing the learning curve associated with digital rock physics and integrating multiple tools into the same interface. Continuing to add detail and customization options to analysis of porosity and permeability is another goal for the technology, particularly when studying unconventional reservoirs and tight rocks encountered during fracking operations and other forms of exploration. ■

Visualization of fluid velocity streamlines found in the process of calculating the permeability of a sample using Simpleware software.



Are you ready to explore Asia Pacific?

Leading Technology for Frontier Exploration

With leading edge Ramform vessels, GeoStreamer® and Imaging technology, PGS provides invaluable insight into both mature hydrocarbon basins and frontier exploration areas in Asia Pacific.

In a challenging market, we provide the highest quality data, which together with associated interpretation products helps de-risk and support your exploration success.

To locate and evaluate prospects, visit the PGS MultiClient Data Library

PGS

Waking up to Papua New Guinea

Perched on the edge of a subduction zone, Papua New Guinea bears little resemblance to most of the world's petroleum terranes. But the small Pacific nation is suddenly on the radar of the global petroleum industry and major players are racing to secure a position.

DAVID UPTON

The shift in attitude towards Papua New Guinea (commonly known as PNG) is largely thanks to ExxonMobil, which changed many long-held perceptions about exploration and development in the country when it brought PNG LNG on stream last year.

The US$19 billion project, which is based on more than 9 Tcfg in the Hides and Angore fields in the remote Highlands, shipped its first cargoes in April 2014, ahead of schedule and on budget. The two-train development was completed at around three-quarters of the cost of many new projects in neighboring Australia, debunking all notions that PNG was not just politically difficult, but carried a cost penalty because of its extreme and jungled terrain.

EnergyQuest chief executive officer, Dr Graeme Bethune, said the cost per tonne of capacity per year of the 6.9 million tonne per annum project was US$2,750, which was significantly lower than the US$3,000 to US$3,500 range of recent Australian projects.

"Interestingly, PNG LNG has been delivered at a cost close to the original budgets of the Australian projects. Gorgon was initially a US$37 billion project to deliver 15MMtpa, or US$2,460/tpa. Some of the reasons advanced for PNG being cheaper are that it is stick-build with 50% cheap local labour and no unions. It's an impressive achievement given the logistical nightmare of working in the Highlands, where they had to build an airport with a three kilometer-long runway."

Bethune added that PNG was also attractive relative to the newly emerged LNG project destinations of Mozambique and Tanzania. "It doesn't have as much gas, but PNG has now established a good track record in LNG development," he said.

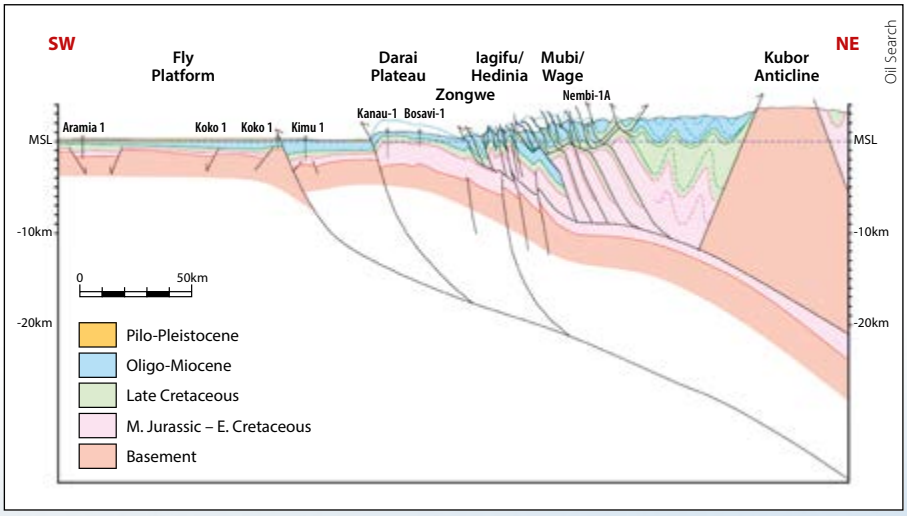
A development well in the Moran field in the Southern Highlands, 570 km north-west of the capital, Port Moresby. The field was discovered in 1996 and started producing two years later.

Oil Search

Key Factors All Present

Attention has now turned back to PNG's prospectivity, which is just as dramatic as the country's mountainous landscapes. Someone who understands the country's oil potential better than most is Julian Fowles, executive general manager of the PNG business unit for the PNG independent oil company Oil Search, which is a 29% partner in PNG LNG and has been actively exploring in the country for decades.

Fowles said PNG brought together a number of factors that all petroleum explorers looked for. "One of the key features is having a good regional source rock that will produce hydrocarbons. It has to be mature, and part of a system that allows hydrocarbons to migrate into good reservoir rocks, and sealed with a good shale or seal horizon that is thick enough and continuous enough to hold significant oil or gas columns. In the main areas we focus on, which is the broader Papuan Basin running all the way from the Highlands into the Gulf of Papua, all of these things come together very well. It has an additional level of petroleum geological interest because parts of the basin have been folded through regional plate tectonic action into very large structures. The fundamental forces shaping the geology have formed these big traps, which is where the hydrocarbons are now found. Hides, Kutubu and Moran are all



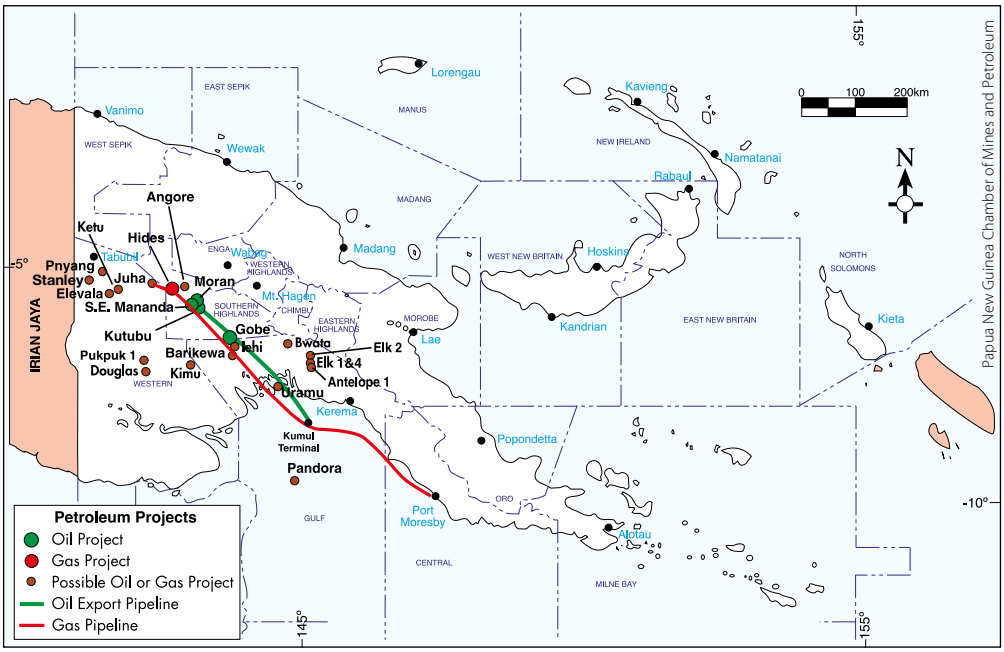
Regional cross-section across Papua New Guinea.

examples of very large, elongate anticlines formed in this way."

He added that even though parts of the Papuan Basin are quite deformed, the regional seal has sufficient continuity to create very large traps.

The main source rocks range from about 140 million to 200 million years old, while the major reservoir is the 125-million-year-old Toro sandstone – a widespread unit with very good porosity and permeability. The excellent quality of the reservoir, together with the large hydrocarbon columns, produced high flow rates of more than 200 MMcfgpd from the Hides field.

East of the central Highlands, the geology changes and the main reservoir units are altered limestones, aged just 10 million years or younger, also sitting beneath a thick shale seal. This petroleum play is seen in PRL15, which hosts the Elk and Antelope fields, the largest undeveloped gas resource in PNG and potentially containing over 7 Tcfg.



New Entrants

French supermajor Total is the biggest of the new players to be attracted to PNG's rich petroleum potential. Total last year bought a 40.1% interest in the Elk/Antelope fields from InterOil for up to US$3.5 billion. This followed Oil Search's acquisition of a 22.835% interest in the same project from Pac LNG for US$900 million.

Total is not the only oil major to have recently arrived in PNG. Repsol has taken a large position in Foreland licenses in the western provinces through its recent acquisition of Calgary-based Talisman. Among Talisman's key assets in PNG are a 40% interest in the Stanley gas-condensate project, which is now operated by Repsol, and a 32.5% interest in nearby Elevala/Tingu/Ketu fields, operated by Australian

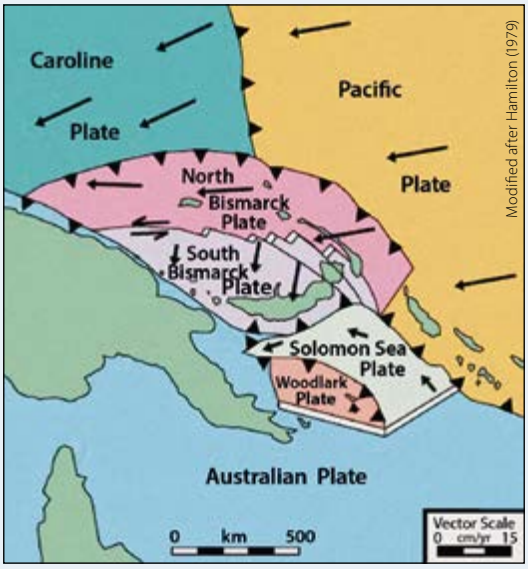
Land of Great Diversity

Papua New Guinea comprises the eastern half of the island of Guinea in the western Pacific Ocean (the western half being part of Indonesia), together with New Ireland, New Britain and Bougainville and a number of smaller islands. It has a mountainous spine, rising to over 4,500m in the Eastern Highlands, while the coastal area in the south is dominated by the lowland swamps of the 650 km Fly River, and in the north by those of the 700 km Sepik River. The climate is very changeable, with high humidity and up to 9,000 mm of rain a year in places, and although average temperatures are 23–32°C, snow is not unknown in the Highlands.

The country is one of the most tectonically active places in the world, as the huge Australian plate to the south pushes northwards, the Pacific plate pushes westwards and micro-plates to the north and to the east of the islands move in a number of directions. There are also several active volcanos such as Mt. Tavurvur on New Britain. More than 20 earthquakes registering over 7.5 M have been recorded in PNG since 1900.

About 65% of the land area of the whole island of Guinea is rainforest, which is home to a unique and very diverse flora and fauna. Unfortunately, however, the forest is subject to clearance because of the worldwide commercial demand for tropical timber, especially in coastal areas. According to research undertaken by the University of Papua New Guinea, if the present rate of deforestation continues, more than half the forest that existed when Papua New Guinea became independent from Australia in 1975 will be gone by 2021.

Tectonic plates activity in the PNG area.



independent Horizon Oil. Repsol's move follows the acquisition of interests in the projects last year by Osaka Gas.

Repsol, Horizon Oil and their partners are building flexibility into their development concepts so they have the option of capitalising on a number of potential options. Positions in the industry are fluid, and exploration success is changing the stakes on a regular basis. For example, Elevala/Tingu/Ketu could be developed as a mid-sized floating LNG project, or as a supply of gas for new trains at PNG LNG or other proposed LNG projects.

Exploration and appraisal activity is on the upswing on a number of fronts, with about US$500 million expected to be spent on drilling in 2016 in and around the P'nyang field and surrounding licenses, lying some 100 km west of Hides.

Working onshore PNG presents many logistical challenges, not least being the terrain, as this photo of Oil Search's Central Processing Facility in the Southern Highlands demonstrates.

Australian independent, Santos, is one of the most active companies in lifting its exploration and investment in PNG, where it has been operating since the late 1980s. The company is a 13.5% stakeholder in PNG LNG and is keen to increase its position. It has farmed into three permits now operated by Repsol, and has acquired a 50% interest in PPL 269 from Kirkland for an initial payment of US$32 million.

Logistical Issues

As an experienced PNG explorer, Fowles knows that new entrants face additional challenges compared to typical petroleum basins. He said that exploration in PNG could be difficult because of the impact on logistics and operations of its remoteness, 'horrendous' climatic conditions at certain times of the year and very rugged terrain. Established in 1929 in PNG, Oil Search has built a logistical backbone that helps to minimize many of these challenges. "We have a well-established base in Moro in the Highlands that allows us to access very remote areas. The logistics can be challenging, but we have that under control. From a geological perspective, the complexity is a factor, and combined with the very rugged surface conditions it can be difficult to get the sort of seismic quality that you would typically gather offshore." The company routinely uses palynologists on its well sites to provide real-time checks of actual versus expected stratigraphy. They are particularly valuable in dramatically folded Highland terrains, where it is not unusual for formations to be overturned.

PNG is immensely rich in biodiversity, with many species unknown elsewhere.

Oil Search's exploration activity was traditionally focused near existing fields and infrastructure, where new reserves can be brought into production at lowest cost. The Hides Deep play was a good example of this strategy, although it failed to locate a deeper economic reservoir. Following the start-up of PNG LNG, Oil Search has adopted a more aggressive approach, reflecting the need to replace the accelerated reserve drawdown, as well as growing confidence in the petroleum potential of the country. Oil Search is on the record as saying it believes that only half of the nation's estimated resource potential of 10 Bboe has been discovered to date.

The company is also stepping out along strike from the Elk-Antelope discoveries. It recently acquired a 70% operated interest in PPL 339 and is planning to drill in 2016, chasing the reefal play on trend with the Elk-Antelope gas field.

PNG Economy

A highly supportive national government is another key factor behind the accelerating growth of PNG's petroleum industry. The government of Prime Minister Peter O'Neill has long understood the economic boost that can flow from major resource projects thanks to mines such as Bougainville copper and Porgera gold mine. But petroleum wealth is taking the country's economic development to another level, as shown by a World Bank forecast of 15% growth in GDP in 2015, thanks largely to the start-up of PNG LNG.

The government is doing everything it can to promote the further expansion of its petroleum industry. PNG's low costs for constructing LNG facilities mean there has been no slowdown in development plans, despite last year's oil market collapse and the subsequent decline in oil-linked LNG prices.

The first item on the government's agenda is the addition of a third train at PNG LNG, boosting capacity to more than 10 million tonnes per annum. In January, 2015, the PNG LNG partners reached agreement with government to supply electricity and gas for the domestic market. As part of the deal, government is clearing a path for the development of the P'nyang field in the Western Highlands as a supply source for a third train. A final investment decision is to be taken by the end of 2017 at the latest.

Planning for the P'nyang-4 appraisal well is underway, with drilling targeted for early 2016. The PRL3 partners are confident of potential for a material increase in proven contingent resources, which already stand at over 1 Tcfg. The P'nyang field is also believed to have big upside, with a number of leads and prospects with potential for the discovery of several trillion cubic feet of gas.

The original inhabitants of PNG were Papuan, Melanesian, and Negrito tribes, all with their own distinct customs and cultures. Due to the very difficult terrain, vertiginous mountain sides and deep rainforest, there was little mixing between areas, and as a result about 750 different languages are spoken by the four million inhabitants.

The country is also racing ahead with its second LNG development, based on the Elk-Antelope fields in PRL15. The new partners in PRL15 – Total, Oil Search and Interoil – announced in July 2015 that Elk-Antelope would be the basis for Papua LNG, adjacent to the ExxonMobil-operated PNG LNG facilities near the capital, Port Moresby. The partners are appraising the field by drilling up to three new wells in 2015, with a view to selecting the development concept by early 2016, with first LNG cargoes expected in 2021.

The government is also spring cleaning its inventory of petroleum exploration licenses and expects to re-issue up to 20 permits that have not been kept in good standing by permit holders. The country's minister of petroleum and energy, Nixon Duban, has reportedly said that major companies, including ExxonMobil, are lining up for the reissued permits, which would inject significant new exploration spending in the country.

PNG governments have also worked hard to ensure a globally competitive fiscal regime for petroleum investment. Wood Mackenzie rated the PNG regime as 'favorable' in its latest global benchmarking assessment, and on par with the likes of Australia, the UK and the Philippines. With all this going for it and a substantial natural endowment of hydrocarbons, PNG can be expected to continue its rapid rise as a petroleum country of real standing.

For more information on the geology of Papua New Guinea, see *GEO ExPro,* Vol. 4, No. 2. ■

LNG loading off Papua New Guinea

'Strata' Smith Enters the Digital Age

A new website celebrates the bicentenary of the first geological map of England and Wales in 1815.

PETER WIGLEY

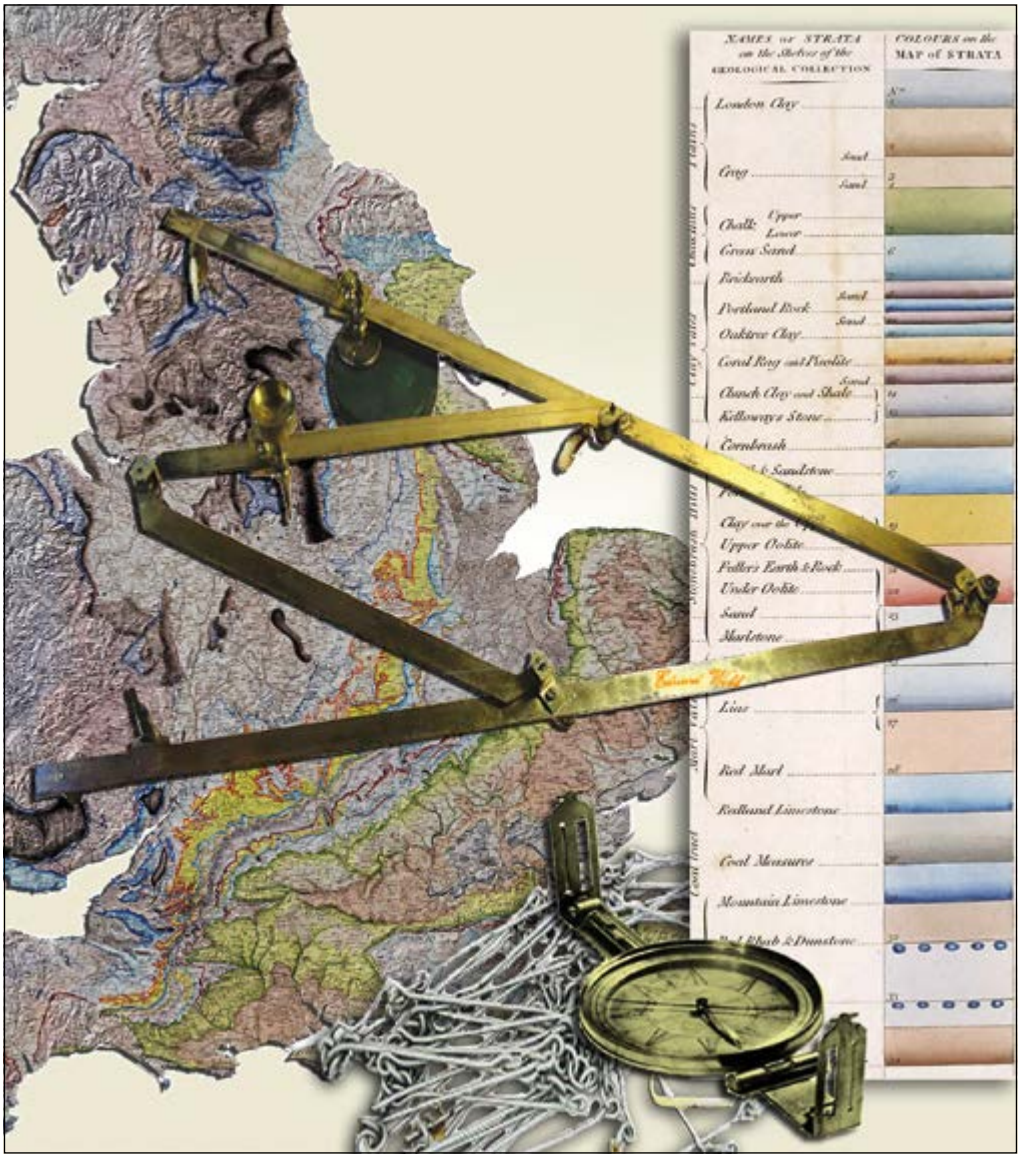
August 1st, 2015 marks the bicentenary of the publication of a map which was to prove to be of extraordinary significance to the science of geology. The map, entitled: *A delineation of the Strata of England and Wales, with part of Scotland* was made by William 'Strata' Smith. Not only did Smith publish the first ever nationwide geological map, but he also laid the basis of what is now known as stratigraphy. As part of the bicentennial celebrations, a new website WILLIAM SMITH'S MAPS – *Interactive* (http://www.strata-smith.com) has been established.

Humble Beginnings

William Smith was born on March 23, 1769 at The Forge, Churchill, Oxfordshire, the son of John Smith, the village blacksmith and his wife, Ann. From humble beginnings he went on to train as a land surveyor. Shown in the illustration are some of the instruments which would have been familiar to Smith, including measuring chains, a surveying compass and a pantograph (used for tracing or copying).

Early in his career, Smith was employed as a land surveyor on an estate in the Somerset coal field and it was here that he encountered the work of another geological pioneer, John Strachey, who more than 70 years previously had made the first real geological cross-section of the coal field. Smith's work impressed local landowners and as a result he was asked to survey routes for the Somerset coal canal which was intended to take land-locked coal to the sea and ultimately, via other canals, to London.

The Somerset Coal Canal played an important role during Smith's formative years, as he surveyed routes for the canal in 1794 and would have been involved with excavations which started in 1795. In an era before motorway and railway cuttings, canal excavations were an ideal way to see vertical sections through strata. In Smith's case he also had the advantage of seeing comparable sections in the two branches of the canal and he also knew, by measurement, the precise level of the canal cuttings. By the end of 1795 he had deciphered the local order of strata from the Great Oolite down to the Triassic 'Red Ground' and soon afterwards noted his critical observation: some of the strata contained fossils and those that did could be identified by them. Today it is easy to underestimate what an achievement this was; Smith had managed to separate several repetitious clay formations and also to separate the Upper and Lower Oolite in this manner. By August 1797, Smith had made his



first attempt at a more general order of strata, starting with Number 1 'Chalk Strata' and descending to Number 28 'Limestone' below the Coal Measures. During the course of several iterations this 'Order of Strata' evolved into the geological table, part of which is shown in the illustration. Many of his stratigraphic names remain in use today.

After losing his position as a surveyor for the Somerset canal in 1799, Smith travelled the country seeking work as a land drainer, sea-defence builder and mineral prospector. It was during this time that he visited the site of an intended colliery at Cooks Farm near Bruton in Somerset and using his knowledge of stratigraphy advised that the boring was far too high in the geological succession to ever find coal. The advice was ignored and many of the shareholders in the mine went bankrupt.

First Maps

Smith's first attempt at a geological map was an odd circular map around the city of Bath; later he made a geological map using John Cary's General Index Map of England and Wales. Smith had some financial support from Sir Joseph Banks and others but largely financed his map-making from his own resources. John Cary was ultimately persuaded to prepare an elegant new base-map of England and Wales at a scale of approximately 5 miles to the inch. Smith then reduced his observations from more detailed maps, probably using a pantograph, on to the new map, which was published by Cary in 1815. Each map was hand-colored and because of Smith's innovative use of graduated color, individual strata appear to levitate from the two-dimensional plane of the map. A part of his map is shown in the illustration and here the three-dimensional aspect has been further reinforced by use of a modern hill shade.

In the early 19th century Smith was a jobbing geologist in a highly stratified and class-ridden English society. The Geological Society of London was founded in 1807, initially as a dining club for gentlemen interested in geology; the first president was one George Bellas Greenough, who was to prove to be Smith's nemesis. Smith's humble position as a tradesman precluded his admission to the Society. Greenough, through his inability to understand stratigraphy, completely disregarded the value of Smith's work yet he liberally plagiarized his map. Sales of Greenough's later 1819 geological map of England and Wales inadvertently added to Smith's financial woes, which ultimately led to his imprisonment for debt. Incidentally, Greenough himself was no aristocrat; he was nouveau riche, his fortune based on his grandfather's business which purveyed tinctures and lozenges for toothache and other ailments. It was not until 1831 that Smith was to be honored by a new generation of Fellows of the Society as the first recipient of its Wollaston Medal.

William Smith, the blacksmith's son who became the 'Father of English Stratigraphy'.

William Smith had undoubted genius, yet he was not a theoretician. He was a practical man with little interest in the grand idea or the unifying theory. He was, however, a keen observer with an eye for landscape and an extraordinary ability to think three-dimensionally. His map is a masterpiece and his understanding of the order of strata remains an enduring geological legacy.

Interactive Website

The WILLIAM SMITH'S MAPS – *Interactive* website has been generously funded by a grant from the UK Onshore Geophysical Library (UKOGL). It is a free-to-all educational resource designed for teachers and students as well as academicians and anyone with an interest in the life and work of William Smith.

A number of fine examples of Smith's 1815 map are available on the website, together with all of Smith's published county geological maps and a number of unpublished county maps. The principal feature of the website is an interactive map viewer, which enables users not only to view the maps but also to overlay one against another and compare them with modern geology, wells, seismic and current topographic maps. Users can also display Smith's magnificent geological sections and view 3D animations of his maps. The website also has information on the map sources, Smith's biography, stratigraphy, coordinates and maps in 3D.

There is also a section concerning the 'Map That Might Have Been'. Using a mosaic of images from Smith's county maps (published and manuscript), and other Cary county maps enhanced by Smith's 1815 geology, a composite geological map has been made. This map might resemble a more detailed edition of his great map, which Smith could have made were it not for his dire financial situation at the time.

The digital images of maps used in this website have been provided by The Geological Society, Oxford University Museum of Natural History, National Museum of Wales, Stanford University and Nottingham University.

The William Smith's Maps – Interactive website online team consists of Peter Wigley (Editor), Peter Dolan, Tom Sharpe, Hugh Torrens, Dave Williams, Neil Anderton and Christoph Schramm. ■

Reg Nelson
A True Explorer

Although recently retired, Reg Nelson is still aiming for more in petroleum, minerals and public life.

DAVID UPTON

Reg Nelson retired from Beach Energy after a remarkable 23 years in the top job that took the company from near-bankruptcy to being Australia's biggest onshore oil producer. At its peak last year before the oil price collapse, Beach had a market capitalization of more than US$1.5 billion, and today still ranks just outside the top 100 companies on the Australian sharemarket.

While the statistics are impressive, they don't convey the impact Beach made on the oil and gas scene in Australia over the past two decades. Under Nelson, Beach was a trailblazer that consistently spotted opportunities ahead of the pack. Other explorers often took their cues from the company, and its heady growth in production volumes and revenues generated just a little bit of awe among competitors.

Tough Legal Battle

The Nelson years of Beach Energy are all the more remarkable because of a six-year slog at the very beginning to extract the company from one of the most notorious episodes of fraud in Australian corporate history. In 1987, Beach fell to a hostile takeover from Independent Resources and was drawn into a labyrinth of fraudulent deals, including a transaction to sell a US$3 million oil field in Oklahoma to Beach for US$27 million.

After the collapse of Independent, a new board took control and hired Nelson in 1992 to help in the legal battle to reclaim many of its assets. A geophysicist by training, Nelson had already had a long career exploring for minerals and energy. He had also served as Director of Mineral Development at South Australia's Department of Mines, overseeing a major leap forward in the quality of pre-competitive surveys and the digitization of data.

Nelson told *GEO ExPro* that the legal battle was 'do or die' for the company, and its chances of surviving were only 50/50. "We won, but the toughest times came after that because there was no money to claw back, despite the fact we had won on all fronts." In 1995, Nelson accepted the board's invitation to become managing director on a full-time basis. At the time, Beach had just six staff, a small income from its interests in the Kenmore and Bodalla oil fields in south-west Queensland, and was still mired in a web of deals left behind by Independent Resources.

"Mopping up that mess was six years of flat out work from 1993 to 1999. We owned gold companies and finance companies, and we had to untangle all these cross shareholdings and intercompany debts to claw back whatever money we could. That consumed most of our efforts, and it was frustrating because we were not able to move on any other opportunities."

Early Mover in Cooper Basin

But there was enough time to set in motion a bid for acreage in the gas-rich Cooper Basin, Australia's most prolific onshore petroleum basin with

Retirement from Beach Energy means Reg has more time to tend his broadacre farm of 600 hectares at Kapunda, a historical copper mining town on the edge of South Australia's famous Barossa Valley wine region.

a production history dating back to the late 1960s. It had been locked up for decades in the hands of the major independent Santos and its ExxonMobil-owned partner, Delhi Petroleum. With production in decline, the South Australian government took the bold step of forcing the joint venturers to relinquish large parts of their acreage to revitalize exploration activity.

Nelson convinced his board to make a concerted effort to win acreage in the re-release of the Cooper Basin. "I said that if we are going to build this company, we should go to the Cooper Basin because it has the potential to deliver," he explains. "The board eventually backed me on that, and in '96 and '97 we got some great people on board, including Neil Gibbins. He had been heading up Santos' accelerated oil exploration program in that part of the world."

The re-released acreage eventually went to competitive tender in 1999, with Beach successfully securing what would become a core asset, Petroleum Exploration License 92. Beach also farmed into adjacent permits won by Stuart Petroleum, subsequently acquired by Senex Energy.

Lengthy negotiations with traditional landowners meant another two years passed before Beach could drill its first well in PEL 92, but the wait was worth it. They quickly established that the western flank of the Cooper Basin was dotted with oil reservoirs that could be reliably discovered with 3D seismic. This play proved to be a remarkable cash generator, and led to a scramble for adjacent acreage by local and international competitors. In the next few years, the western flank exceeded all expectations and by 2014 was producing as much oil as the giant offshore fields of the Gippsland Basin. Nelson believes that Beach's biggest discovery on the western flank, the Bauer field, may yet prove to hold 20 MMb of high margin recoverable oil when appraisal drilling continues.

Creating the Right Culture

Nelson quickly turned success with the drill bit into the company-making acquisition of Delhi for $574 million in 2006, giving it a 21% interest in the core infrastructure and gas acreage of the Cooper Basin. The deal stunned Santos, outmaneuvered by a far more wily and nimble competitor just a fraction of its size.

Photographing landscapes and wildlife in the remote Cooper Basin.

On the exploration side, Beach branched out and invested in numerous new plays in Australia and abroad. It was an early entrant to coal seam gas, selling for a profit of more than US$300 million to the big players that would soon invest billions of dollars in building LNG projects at Gladstone. One of its most important moves was into unconventional oil and gas in the Cooper and Otway Basins as early as 2009, well before the US shale boom started to reverberate around the world. A project based on the Nappamerri Trough in the Cooper Basin is the most advanced and ambitious shale plan in Australia, and in 2012 attracted Chevron as a joint venture partner. The plunge in oil prices last year was a blow for unconventionals everywhere, and Chevron recently withdrew as part of a global cutback in capital spending, but Nelson is convinced that unconventional gas from the Cooper Basin is essential for meeting the energy needs of the eastern states. Domestic gas supplies are forecast to swing into critical shortages next year as gas is diverted to higher-priced export markets.

While Beach's successes over the past 20 years have been many, Nelson says the highlight for him has been building a company with the right culture. "I would like to look back on that as an achievement," he says. "Not many people get that opportunity. Basically, we started with next to nothing, but key was the ability to recruit people like Hector Gordon, Neil Gibbins, and on the financial side Kathryn Presser, and my ever-faithful personal assistant, Marilyn Falahey. They were tough times, and we all had the right attitude and supported each other and it grew from there. I think like begets like, so when you recruit someone else you tend to look for people with the same sets of values."

He says that Beach today is a much larger company and more driven by policy and procedure, but the ethos that served it from the beginning is still there. "I hope it will always retain that core, and I see Beach as being at almost an adolescent phase. We still have to build on long-term legacy

Reg Nelson.

projects, amongst other things a long-term dividend policy, but you still need that spark of creativity."

Innovation Stifled

Nelson believes that the oil and gas industry always need "ratbag thinkers" driven by curiosity and smart geoscience to find opportunities outside the mainstream.

"Looking at what is happening with shale oil and gas in the US, I think it somewhat unfortunate for the industry that the activist shareholders are driving all those North American companies back to the US because it has become almost an industrial factory. Granted, there are innovations in technology and thinking, but I think it is likely to kill off that creativity that you get from broad-based exploration. I think it needs to be balanced in some way."

Nelson says there was no question that huge innovation and thinking had gone into creating the shale revolution. "There is certainly a lot of technical development to emerge from it and that can be applied elsewhere. On the geophysics side alone, some of the microseismic work, the seismic attribute inversion, all those sorts of things that are emerging from this can be applied elsewhere. But there is a danger that things could be lost in a big industrial-factory approach. It is up to senior management and board level to see that original thinking is not stifled."

He added that regulation and corporate governance was also stifling innovation and diverting a lot of effort from the business of discovering petroleum. "There are so many layers of governance and all these cottage industries that feed off it – proxy advisers, corporate governance advisers; it all costs money and absorbs so much of directors' time. Listed companies are actually becoming a very risk-averse society. I think ultimately that will open up the opportunities for private equity investors who see the potential for value creation. Of course, we need prudent management and governance, but explorers should not be subject to the whims of advisers who frankly don't have much experience in the business world."

Return to Minerals

Nelson, now aged 70, can look back on an exceptional career and numerous industry accolades, including Honorary Life Membership of The Society of Exploration Geophysicists. But farewelling shareholders at last year's annual general meeting, he quipped that his career was merely at the halfway point. A quiet retirement is clearly not on the agenda. Nelson has already joined the board of junior petroleum explorer, FAR, which last year announced two world-class oil discoveries offshore Senegal and has developed big plays in west and east Africa, attracting Cairn Energy and ConocoPhillip as exploration partners. Nelson said FAR was run by people he knew and greatly respected. "The company has the same ethos as Beach in terms of its love of exploration and empathy with communities."

Nelson is also working on a return to minerals exploration, which has been interwoven with his career in petroleum for decades. His experience goes right back to the start of his days as a geophysicist, exploring for paleochannels that could host roll-front uranium deposits in South Australia. More recently, Nelson was the driving force behind successful gold producer Ramelius Resources, which he spun out from Beach with many of the gold assets inherited from Independent Resources.

At Cooper's Creek during the floods of 2009. The desert environment of the Cooper Basin was transformed by a once-in-40-year flood event that shut down exploration and production in many areas.

"Oil and gas remains a big focus, but you accumulate many ideas over 50 years in the industry and I want to go back and pursue some of those, whether copper or uranium or a host of other things. Now is not necessarily the time to launch these projects because of the state of the market, but it is the right time to be thinking about them and assembling a portfolio with an eye on the future."

Nelson also plans to spend more time educating the public about geology and how society depends on minerals, oil and gas. "Years ago, driving in Colorado I used to carry a book called the Roadside Geology of Colorado, and I thought 'that's what we need here'." He wants to produce a similar book that serves as a tour guide to the many geological highlights on the 500 km stretch in South Australia from Adelaide to the northern Flinders Ranges, including the famous fossils of Ediacara. Collaboration with an ex-colleague (and former Beach director), Dr Neville Alley, has brought the idea close to fruition, but Nelson acknowledges that Alley has done most of the hard work. "However, now that I have a bit more time I can assist with doing the next leg, wherever that might be."

Abundant Opportunities

As for the petroleum industry, Nelson says there remain abundant opportunities in Australia, despite lower oil prices. "The western flank is still a great place to make money, but gas also has a very good outlook. Anyone who can supply volumes of gas in eastern Australia in excess of what is already contracted is in a pretty good position. Demand is healthy, whether for export or domestic use."

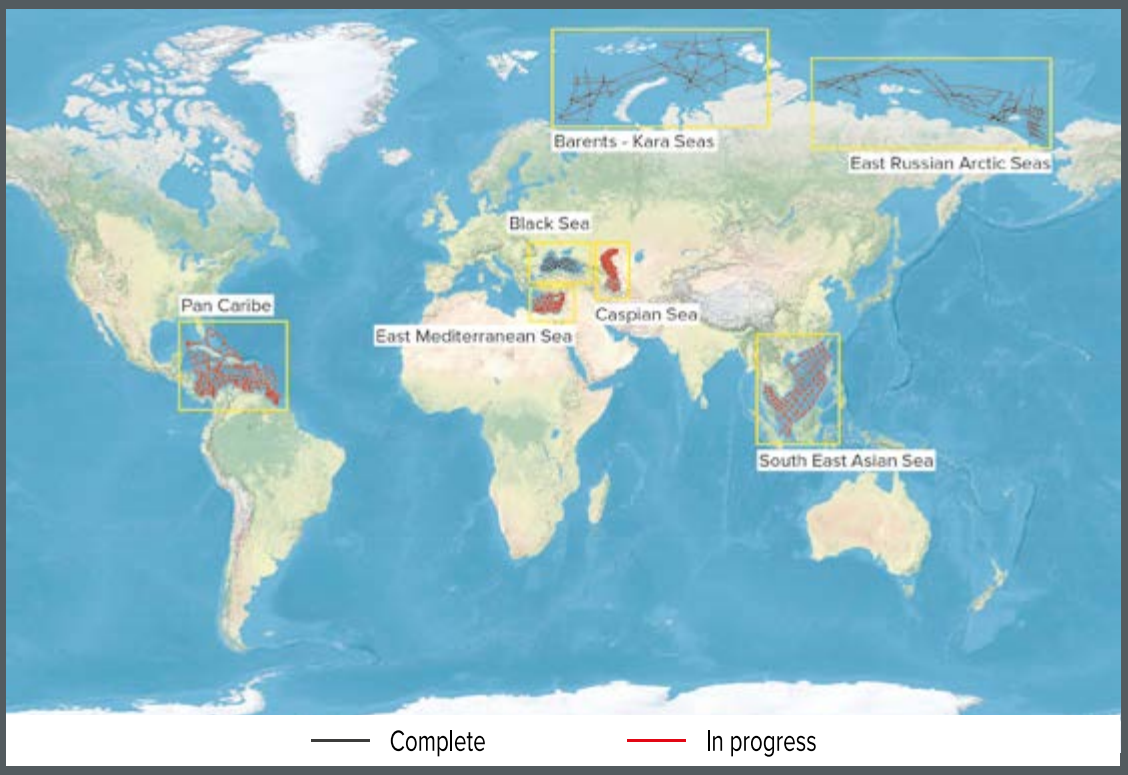
He believes the Cooper Basin will be a key source of new gas supply, despite now being in its fifth decade as a producer. "If you look at eastern Australia, the only real potential sources of gas for the domestic market are the Cooper Basin and the onshore Otway Basin. Certainly there is more gas to be found offshore in the Gippsland and Otway Basins, but assuming discoveries are made, you are talking five to ten years before you get it to market. That is not going to solve the real shortages that we are facing in the short term." ■

GEOLOGY
WITHOUT LIMITS

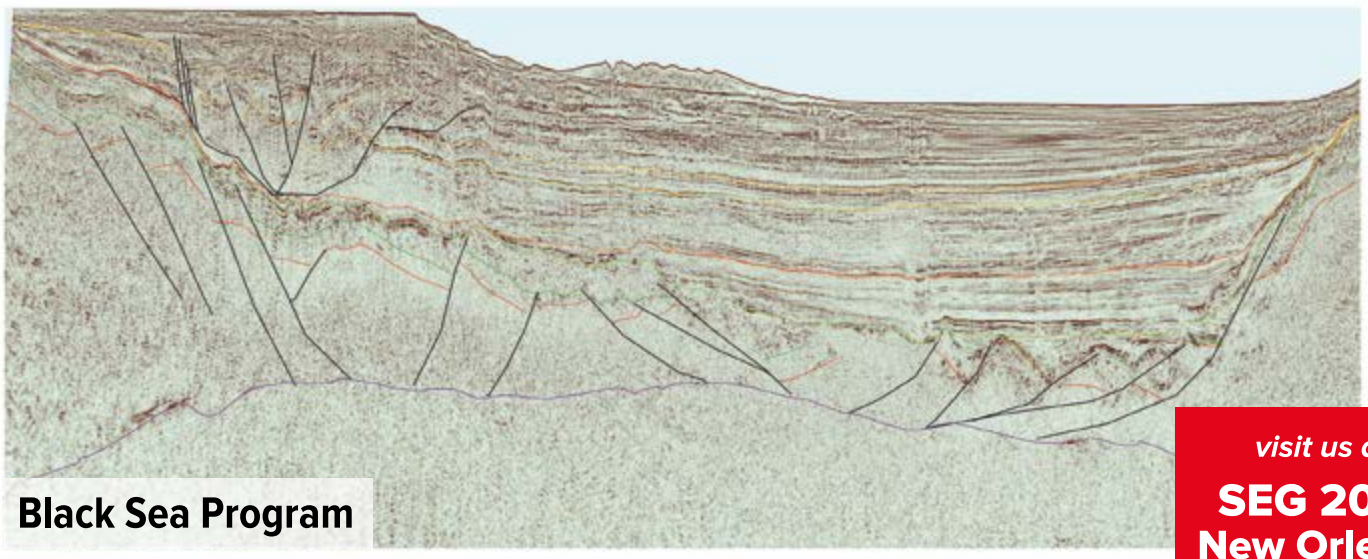
GWL's Basin-Wide surveys -
deep insight into
exploration understanding

Would you like to extract more from seismic data?

GWL reveal more geology per line kilometers.



Geology Without Limits has a new approach - carrying out surveys over entire marine basins. It accounts for all known geology at the design stage. Proprietary technology includes ultra-long offset via combination of seismic streamer and free-floating Seismobuoys®.



Black Sea Program

company@gwl-geo.com
www.gwl-geo.com

visit us at
SEG 2015
New Orleans
Booth #2207

Driven to Success on the Seismic Superhighway

Whilst the first oil wells in a marine environment were drilled when Queen Victoria sat on her coal-powered throne, the state of Earth imaging at that time would have left most modern explorers unamused. These were the oil exploration dark ages, which lasted until the sub-surface illumination reformation delivered by the development of the seismic method in the 1950s. This new super-power, with the profundity of being able to image into the profound, indeed to see the beating hydrocarbon heart of Mother Earth, has brought the world the oil that has supported our civilization and indeed ensured our species survival ever since.

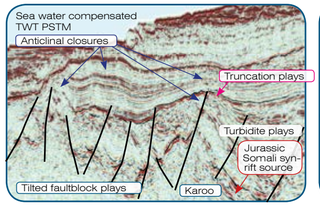
Explorers today have had a lifetime of experience developing intuition and skills to crack ever harder subsurface puzzles in the hunt for mobile carbon. Yet, post the sequence stratigraphy orogeny, the only new tool in the box for explorers has come from new innovations in seismic acquisition and processing technologies, and the integration of this super-vision with new, improved resolution remote sensing tools.

Modern seismic has now evolved into a forensic clue machine, solving issues from idea sublima tion to license application. Here, four of Spectrum's geoscientists working in these fields capture the state of practical seismic in applications through the exploration value chain.

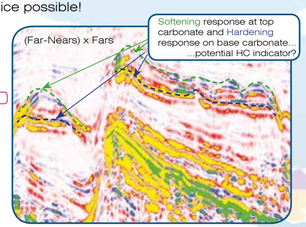
Spectrum

Hi-Tech Seismic…
… in a Frontier Basin

If you could choose where to work where would it be? Obviously some sun-kissed shores rather than in yet another rain-drenched English summer at best. Recent good quality seismic surveys and targeted reprocessing have opened up the potential in areas such as Barbados and the Seychelles, making the choice possible!



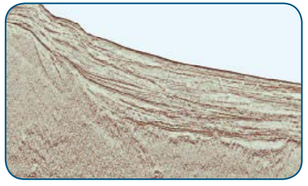
Seychelles: Thick synrift package below thick sediment maturing source rocks



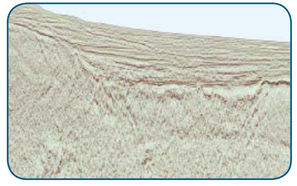
Seychelles: Far offsets dimming on carbonate reef crests suggestive of hydrocarbons

New Play Systems…
…across the Final New Frontier

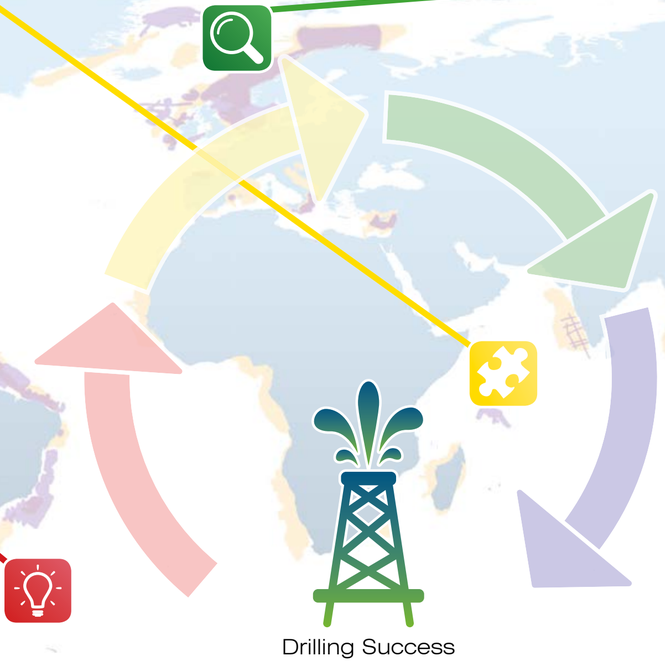
Dreams of avarice have driven the industry over the past 20 years to drill in up to 3,000m of water on the Atlantic passive margins, chasing the great successes of the shallow water into the abyss. However, the journey isn't over…



Pre-STM data from Uruguay. Reflectors dip seaward, suggesting hydrocarbons can migrate from SE up onto the NW shelf

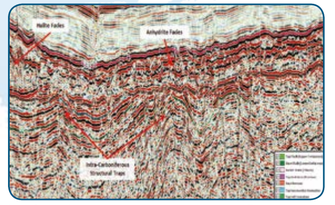


Depth Migrated (Pre-STM): Landward-dipping reflectors create outward trapping geometries for basin floor sands.

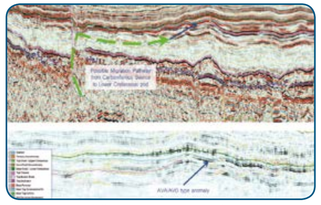


Seismically Driven New Plays…
…in a Mature Basin

In some areas mature regions are surprising seasoned explorers as they reveal hidden secrets and open up new possibilities. Latest images of the Triassic, Permian and intra-Carboniferous sections in UKCS Southern North Sea have given great clarity…



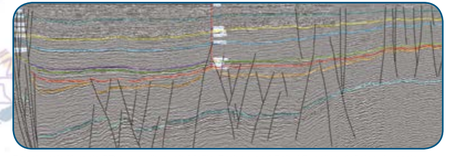
Intra-Carboniferous well-imaged structural traps and Zechstein seal seismic facies



Lower cretaceous AVA type anomalies up dip of a possible hydrocarbon migration window

3D Seismic Risk Reduction…
…for a License Round

Headlines in the Caswell basin (Browse), Western Australia are dominated by Shell's Prelude discovery and associated infrastructure investments. But a hat trick of discoveries made over the last few years are stealing the show, proving that significant gains can indeed be made in "mature" basins.



Spectrum's Kyranis 3D survey through Melita Graben and Sahul Syncline defining Jurassic- and Cretaceous-age hydrocarbon traps

Key to world map:
= Existing Spectrum seismic library
= New data added to library in 2015

The State of the Art in Seismic

3D Seismic Risk Reduction for License Round

PHILLIP HARGREAVES

On Australia's North West Shelf, acreage in shallow water multi-TCF neighborhoods is highly prized and competitively sought. To assess the value of acreage for optimum license round bidding requires investment in detail, to reduce risk and support confident, intelligent action.

The North West Shelf is characterized by frequent licensing rounds, and very rapid development of play ideas by explorers who need to outcompete. Rapid adoption of new imaging technologies supported the exploration for deeper, older reservoirs such as the Lower Jurassic of the Crown, Bassett West and Lasseter (2014) discoveries. The key to imaging and chasing this play is the availability of modern 3D data, and extrapolation from offset well success into unlicensed acreage.

In the Browse Basin to the west of the Ichthys and Prelude LNG projects, 3D data acquired in 2013 covers both the Lasseter discovery and open acreage in the current license round. This 3D images both extensional fault block plays and associated drape structures in which Jurassic and Cretaceous-aged sediments form the primary reservoirs.

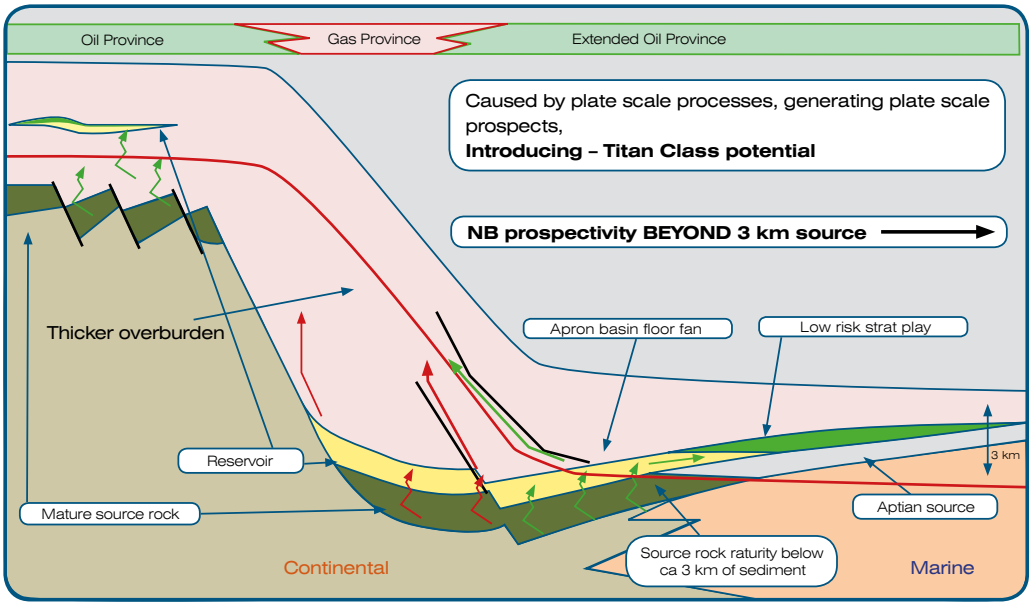
When combined with additional 3D coverage over the wider Browse Basin, this dataset presents an essential evaluation tool to support a confident bidding strategy for acreage and subsequent exploration and development activities. Significant remaining prospectivity in the area is present, only fully realized with modern seismic data. ■

The Final New Frontier

NEIL HODGSON

One of the main deepwater plays targeted by exploration companies in the past decade has been to chase sands deposited in canyons running down into passive margin basins. Inherently risky, with the potential for up-dip leakage below the resolution constraints of seismic to image, and often small in volume, such exploration in deepwater has brought mixed success and a degree of indifference from the industry.

However, the journey into deepwater isn't over; yet in the new frontier beyond 3,000m water depth lies the real prize: the basin floor fans that provide prospects ten times bigger and at a third of the risk of the constrained canyon plays. Here, 'new' seismic steps up to the plate: long streamer 2D data, processed in the time (PSTM) and depth (PSDM) domains with new techniques to eliminate multiples (SRME) yield a secret big enough to kick 'Peak Oil' back onto the fiction shelf. In many places along the Atlantic passive margins, plate cooling and loading has depressed the landward margin, so up-dip trapping is guaranteed – outward from the coast (see foldout figures). Structures like these, with zero up-dip risk and oil prone (the source has less burial cover) are present on both Atlantic margins. They form a suite of the biggest as-yet unexplored prospects in the world, affectionately referred to as 'Titan Class prospects'. ■



Schematic illustration from the Sergipe Basin, Brazil showing the Titan Class potential plays seaward of the conventional oil and gas provinces in the shelf and slope domains – a result of reduced overburden and landward dipping structures.

Seismically Driven New Play in Mature Basin

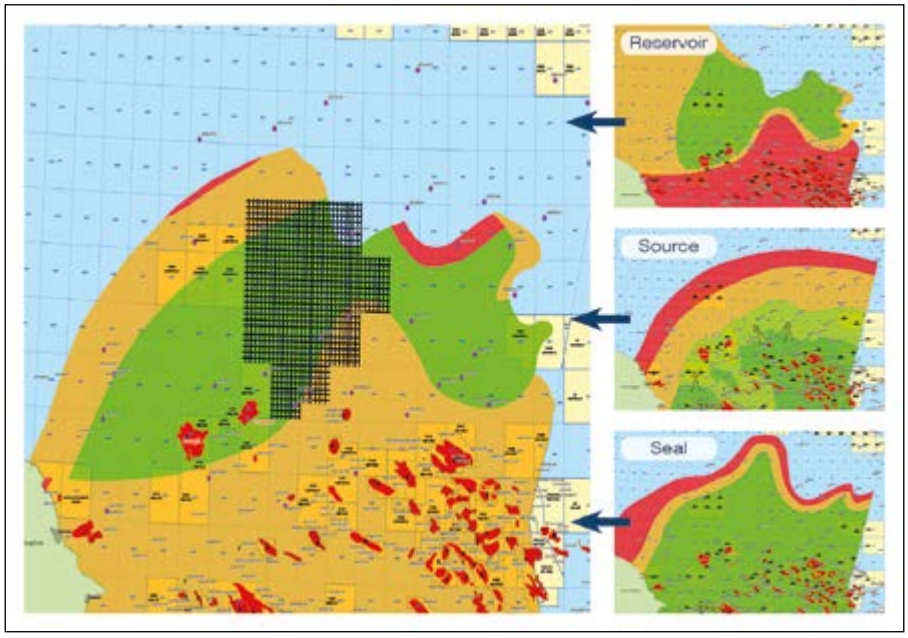
KARYNA RODRIGUEZ

The UKCS Southern North Sea has two major mature plays simply defined by the distribution of Permian and Carboniferous gas fields. North of these, beyond the Rotliegendes pinch-out, exploration of the Carboniferous was hampered by poor seismic data, yet the successful appraisal of the early Carboniferous Breagh Field in recent years indicated that a greater game was afoot.

New seismic acquired in 2013 with long record length has been combined with an innovative processing methodology (delayed-start SRME at Top Chalk level, dual domain Tau-P Decon and high resolution radon), which has re-invigorated the area as for the first time it allows the intra-Carboniferous to be evaluated. An Early Carboniferous Dinantian play fairway analysis evolved from this seismic acquisition, extending the limits of established fairways and developing new untested fairways.

Further north, in areas where the Zechstein top seal thins, hydrocarbons migration from the Carboniferous section up into higher stratigraphic levels can be investigated now via AVO/AVA analysis, illuminating a strong relationship between migration windows and overlying Triassic Bunter Sandstone, Lower Cretaceous Sandstone and Chalk plays. ■

Dinantian play fairway analysis.



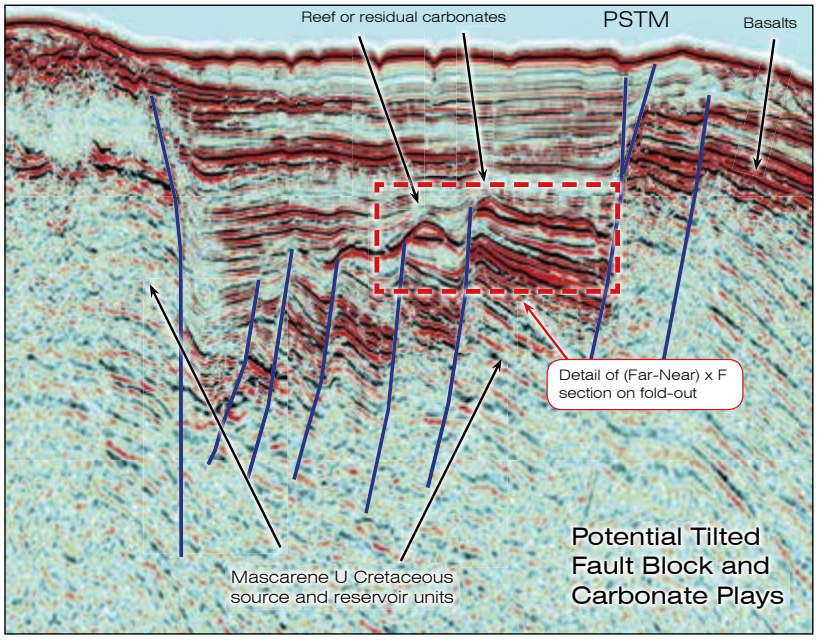
Hi-Tech Seismic in a Frontier Basin

ASHLEIGH HEWITT

In the Seychelles, recent good quality seismic surveys and targeted reprocessing is identifying hydrocarbon traps and accumulations missed in early reconnaissance.

In the '80s and '90s the four wells drilled in the Seychelles proved source and reservoir rocks but only oil shows were encountered. This lack of success was in part a result of inadequate seismic resolution making it difficult to reveal the best place to drill and understand possible trap-breach mechanisms. However, there is no doubt the hydrocarbon system is proven, with tar balls and seeps typing to prolific Jurassic Somali-rift and Cretaceous/Paleocene shales. With longer offset seismic and new processing techniques, oil hunters have returned to better define leads of giant proportions. The use of angle stack data is also proving to be invaluable. For example, evidence of dimming on the far angles at the top of a possible reef and brightening at the base could be indicative of hydrocarbons (see foldout figures). Additionally, initial results from ongoing reprocessing using broadband processing and PSDM suggest even better definition of deeper potential targets in and around the Seychelles Platform and Mascarene Plateau. ■

Potential tilted fault block and carbonate plays.



Under the Patronage of
His Royal Highness Prince Khalifa bin Salman Al Khalifa
Prime Minister of the Kingdom of Bahrain

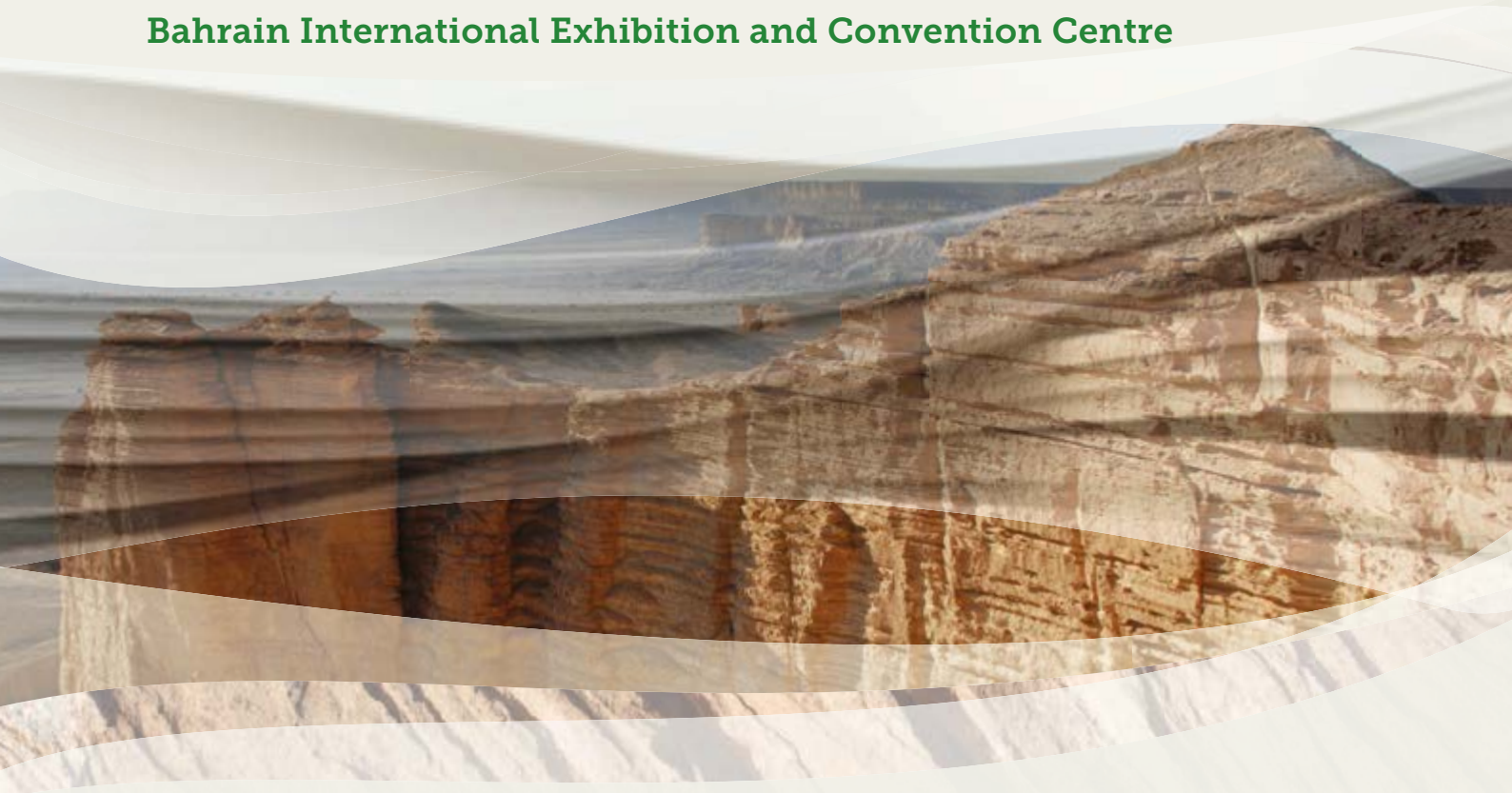
GEO 2016

12th Middle East Geosciences Conference and Exhibition

Conference: 7 – 10 March 2016

Exhibition: 8 – 10 March 2016

Bahrain International Exhibition and Convention Centre



AN ALLWORLD EXHIBITIONS EVENT

AAPG Middle East Region

EAGE EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

SEG

www.GEO2016.com

The Pain and Sorrow of Reservoir Modeling

Back in the late eighties our ambition was to put modeling capabilities on every geoscientist's desk. Now in 2015 that aim has been achieved, but are we actually producing the right models?

STEPHEN TYSON, Ph.D.

It is almost thirty years since I started reservoir characterization and stochastic modeling. Over the last three decades I have had plenty of opportunities to watch how this modeling technology is being used and there are some days when I feel as though Pandora's box has been opened. Before we start let me just define that by model I mean some 3D representation of a reservoir, most typically as a geocellular model.

What surprises me most is the unsuitability of the models that are being made for the questions that are being asked. As static modeling became possible during the nineties, the concept of a 'shared-earth model' was proposed and embraced: a single model that could be viewed by anyone from any discipline, which would ensure that everyone was thinking about the reservoir in the same way. Calculations could be made on this model by any of the geoscientists or engineers, knowing that they would be consistent with the other disciplines. A simple thought experiment may highlight the folly of this approach.

A Shared-View Model?

If we try to imagine a perfect model, this would behave in exactly the same way as the real reservoir. Every interrogation of the model would give the same answer as investigating the real reservoir. This is manifestly improbable even for the simplest reservoirs. How can we get around this difficulty? If we relax our requirement that the model is perfect to just 'good', then we would still be expecting 'good' answers to the same wide range of questions. I think that 'good' means 'close to the real model's response'. The simplest solution is to frame the problem and restrict the range of questions for which our model is valid.

Figure 1: Wing loading test on a Dreamliner. Aeroplane designers and engineers do not use single shared-view models, so should geoscientists?

What happens in other disciplines that use computer models? Let's look at aerospace. Before the Boeing Dreamliner first flew millions of hours of computer simulations were run. But were they run on a single shared-view model? No, different models were built for different questions, from the time it would take to evacuate the passengers, to the strength of the wing joints. Then many of these simulations were tested mechanically and the results were used to recalibrate the model. Figure 1 shows just how far you can bend the wings on a plane, so don't get stressed if you see them wobble a bit in flight!

So, the aerospace engineers build specific models for specific questions. Then, when they have real data, they don't just add this to the model like we add a new well to a reservoir model. They work out the difference between their predictions and their measurements and use this to determine a confidence in their predictions. This, to me, appears quite a different philosophy to reservoir modeling. Geoscientists receive new data from new wells, include them in the model, rebuild the 3D grid, and then their model is 'right'. Wrong! Each time new data is added there is an opportunity to assess the predictive capability of your model. This important step is usually overlooked.

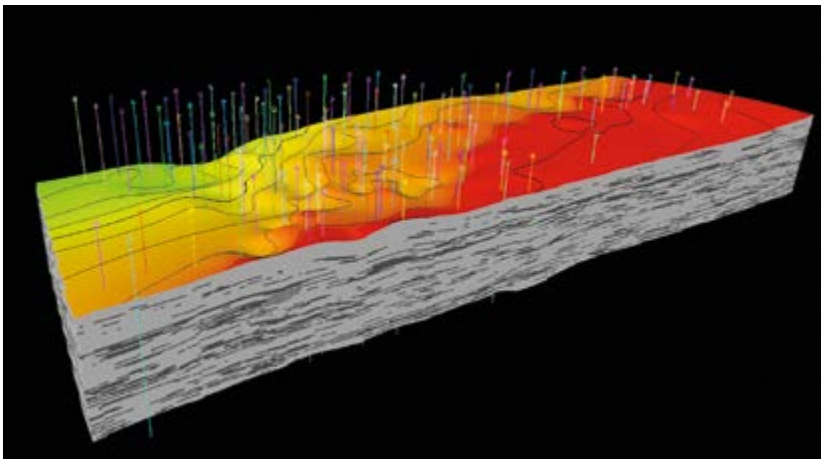


Figure 2: Facies model of a coal bed methane reservoir

Modeling Aims

If we subscribe to the concept that the desire to build a shared-earth model adds to our woes, we now need to think more carefully about the aims of our modeling project, the best way to frame this and how we can ensure that our model is only used within the appropriate frame.

Qualitative: I think the most important contribution that reservoir modeling has had over the last three decades is in communication. Visualization is very powerful and 3D images of reservoirs really help everyone understand many different aspects of the problems that their colleagues in different disciplines face. So building a model with the aim of providing a visualization of the reservoir seems to be a good aim. It helps get investors, both internal and external, onside because they now understand or can picture what you are trying to do. But this model should be tattooed to show that it is for qualitative use only.

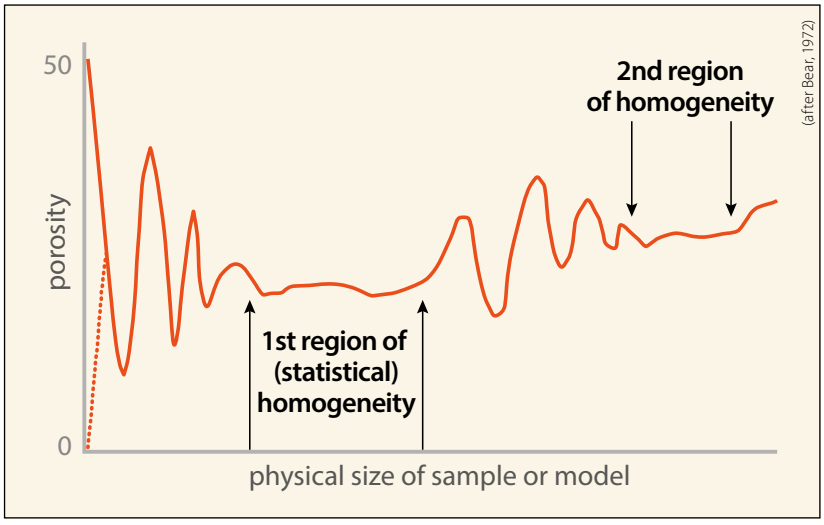
Quantitative: If we want to use the reservoir model for quantitative aims then we have to come back to the concept of predictive capability and rigorously and fastidiously quantify and improve on this. I think that we also need to be much more careful with our framing. Here, I will focus on two main quantitative modeling aims: volumetrics and flow simulation.

Let's look at simulation first, since flow simulation precedes static reservoir modeling by almost 10 years. How can you frame your modeling project to make the predictions more accurate? The general technique would be to make smaller models; single well models and sector models reduce the number of parameters in the solution space and therefore the complexity of the problem. Models over a smaller volume allow you to increase the resolution without blowing out your computer memory. Radial models and 2D models were all the rage in the '80s; I know that computers were much smaller then, but this forced engineers to think about the appropriate scale for modeling and to build up an understanding of the reservoir by looking at individual wells. Sadly, I don't see many single well models and 2D models any more. Perhaps the workflows make it easy to create full field models.

Static reservoir models are most often used to compute reservoir volumes. An important task and an admirable aim, but increasing the resolution of your reservoir model only improves the precision of the calculation, not the accuracy. To make your life easier you have to consider the well-known diagram shown in Figure 3 by Jacob Bear, of homogeneity as it relates to scale. If you consider any 2D or 3D system of sand and shale, then measurements at a certain probably small volume may be either 100% sand or 100% shale. At a different measurement volume you may find 50% sand and 50% shale (or some other fixed proportion) in almost every sample, as shown below.

Figure 4 shows a satellite image of a braided stream.

Figure 3: Homogenous scale ranges.



Looking in each of the red squares, which have been enlarged to the right of the main image, you see predominantly either green or blue pixels, but looking in each of the larger white squares, enlarged to the left, you will see a more consistent mixture of green and blue pixels. If you then model at the white scale your modeling task is massively simplified. I have seen two companies with adjacent acreage with one modeling at a homogenous scale and the other agonizing to create a model at a scale that had a much larger variance. And the impact on the volumetrics calculation of the two approaches? Well, when you look at errors in the velocity model and some of the petrophysical parameters and then run some uncertainty modeling there's almost no difference in most cases – except you've saved about six months' work.

Model Types

Over the years I have been involved in a lot of different modeling activities and this has led me to classify reservoir models according to their purpose. Generally models lose utility if they change purpose. Going back to the shared-earth model, I think there is a very significant value in collecting all the data from a reservoir or field or region in a single location, in being able to cross-reference this data and ensure its domain and referential integrity. This often involves visualizing objects from different disciplines in the same graphical space and is an absolutely vital activity. I would prefer to be a little pedantic and call this a database and as far as possible exclude modeled data from this, i.e. the 3D grid. If you insist on calling this a model, then it would be a 'Museum Model'. Stuff is collected, categorized and stored in the museum. Geoscientists can look at the museum and find out about the exhibits but only the museum's curators can change it. More mature reservoirs have better museum models.

At the other end of the spectrum is what I call the 'Forensic Model'. The data is limited. You have to work quickly to realize an opportunity. The reservoir is like a crime scene and you're looking for clues. You approach the problem with the open mind of a seasoned detective and quickly eliminate the usual suspects. It is very important to focus in on what really matters so your model tends to be light and small. You are trying to understand anomalous behavior to make better decisions. You have fastidiously collected all the data from the crime scene and you need to start testing your theories as to what might be happening. At this point do you create a full-field model?

No, we don't, we try to restrict the scope of the model to answer the simplest question that will confirm or refute our hypothesis. And then build the 'Hypothesis Model'. By choosing to build models to answer simple questions we can build up a more reliable predictive capability, albeit limited in scope. Let's look at a simple point: knowing that sand bodies connect together differently in 2D and 3D systems, the probability of connectivity between wells depends on the net-to-gross, the shape of the sand bodies and the dimensionality of the system. A series of very simple models can be made to determine whether the system is 2D or 3D and test this hypothesis.

Identifying the most important questions about a reservoir's behavior and designing appropriate experiments to test hypotheses sounds like a sensible strategy. It is how science has progressed since the Renaissance. Scientists do not build big complicated models of everything. Engineers do not build big complicated models of rockets and cars and planes. Why do geologists?

The Future

We will certainly see more reservoir models as the industry appears addicted to them. Undoubtedly resolution will get finer and will approach multi-gigacell static models. In the meantime I hope to see some real movement towards verification, validation and acceptance testing of geological models, as well as new ways to quantify the predictive capability of models. We need an industry-wide aim to improve this by fastidiously assessing the overall quality of the model as new information becomes available, rather than blind addition and update workflows. ■

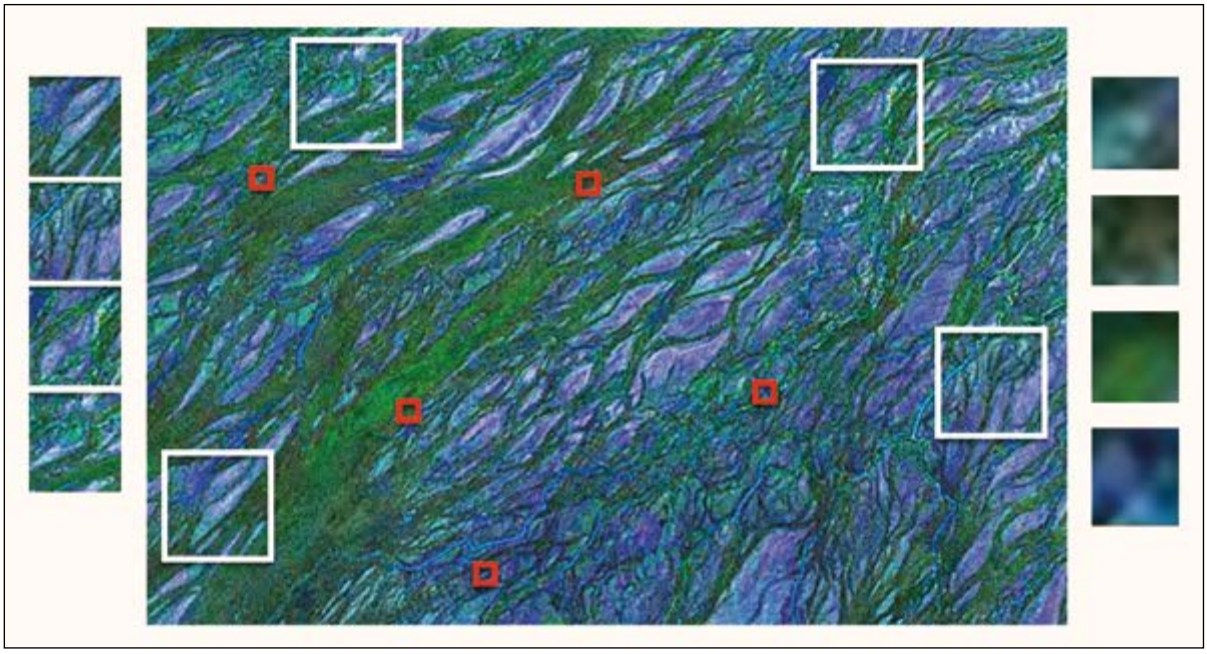
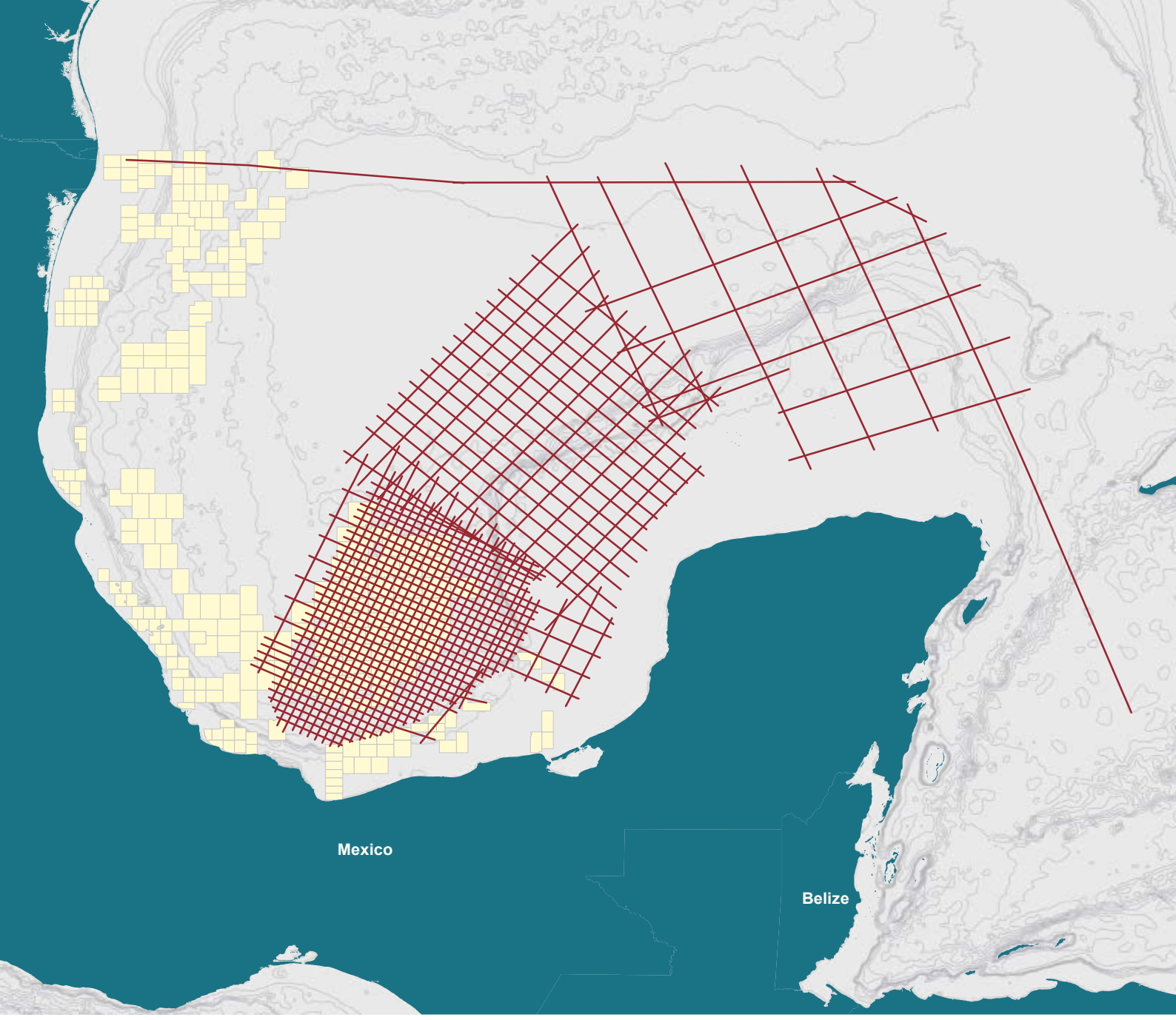


Figure 4: Measurement scales and heterogeneity.



MCG PRESENTS

OFFSHORE MEXICO

MAXIMUS - REGIONAL SURVEY: OFFSHORE MEXICO.

MCG...new ideas...new data...on the forefront of new exploration trends.
Maximus - acquired by MCG, processed by DUG and coming to a workstation near you.

Please contact us for more information

Kenneth Mohn
kenneth.mohn@mcg.no

Tom Wolden
tom.wolden@mcg.no

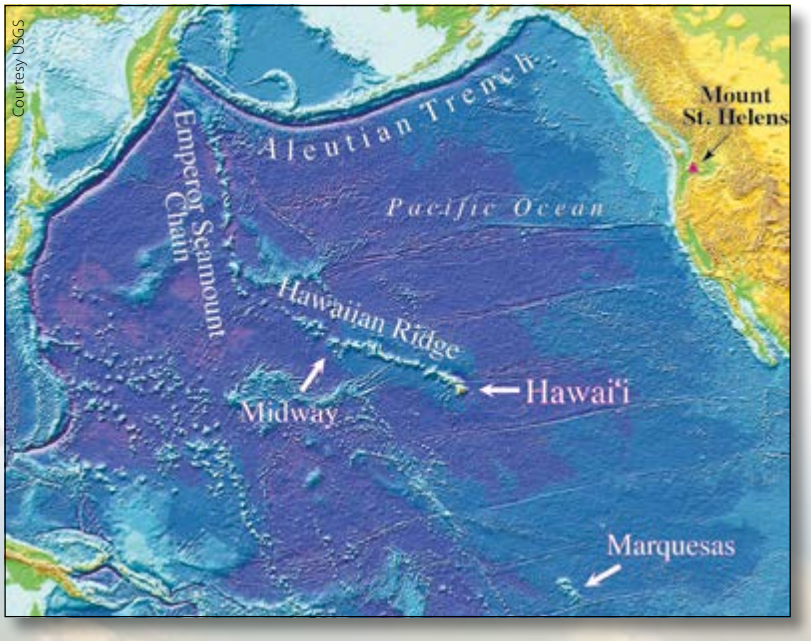
John Whitcomb
john.whitcomb@mcg.no

The Active Volcanoes of Hawai'i

Breathtaking views, surreal landscapes, and the chance to come face to face with an active volcano, the Island of Hawai'i offers the geotourist encounters of a lifetime, and scientists a window into a volcano's inner workings.

THOMAS SMITH

The linear trends of the Hawaiian Ridge and Emperor Seamount Chain in the northern Pacific Ocean.



Before Hawaii became a state, or even a territory of the US, it was the Kingdom of Hawai'i ruled by a native monarchy. Honolulu native Lorrin Thurston, then a Columbia University graduate and member of the Honolulu bar, led a revolution that overthrew Queen Liliuokalani on January 17, 1893. He immediately sailed to Washington, D.C. and in two years there helped pave the way for Hawaii to be annexed to the US in 1898. He developed sugar plantations and railroads for the new territory and became publisher of a Honolulu daily newspaper. A frequent visitor to the active Kīlauea Volcano, he loved exploring the area – a lava tube he discovered in 1913 bears his name. He used his influence through his many business contacts and his newspaper to promote both a volcano observatory and a national park at Kīlauea.

The Hawaiian Volcano Observatory (HVO), established in 1912, was America's first facility of this kind. The site provided scientists with a perfect laboratory for the study of these giant volcanoes that are among the most active in the world. For the first time, scientists could continuously monitor the changes to the volcano caused from the upward and lateral movement of magma before, during and after an eruption occurred and issue warnings of the relative danger level of impending volcanic activity.

Creating a national park at Kīlauea would take some additional effort. Thurston used his newspaper and influence to bring a group of congressmen to Kīlauea in 1907 and again in 1909. He even had meals cooked over the hot volcanic vents to impress his visitors. His newspaper continued the campaign with printed

Looking across Kīlauea Iki Crater at the huge Kīlauea Caldera and the currently active Halema'uma'u Crater gives visitors a sense of scale of this intriguing and unique National Park.

Thomas Smith

endorsements of the park by President Theodore Roosevelt, conservationist John Muir, and the powerful Senator Henry Cabot Lodge. Finally, President Woodrow Wilson formally established the Hawai'i Volcanoes National Park in 1916. It has been enlarged several times and is recognized as a UNESCO International Biosphere Reserve as well as a World Heritage Site.


Thomas Smith

A view across Hilo Bay and the city of Hilo on the Island of Hawai'i. The massive shield volcano in the background is Mauna Kea, at 4,205m above sea level the highest in the Hawaiian chain. To the left and out of the photo is the still active Mauna Loa, only 36m lower but the most massive mountain on earth, rising 17 km above the sea floor.

Origin of the Island Chain

Early explorers, from the first Polynesians who began settling in the Hawaiian Islands over 1,000 years ago to the first European pioneers, noted the island's north-west to south-east alignment. In fact, the Hawaiian Ridge extends 2,600 km from the Island of Hawai'i, where it turns northward, becoming the Emperor Seamount Chain, continuing another 3,400 km to the Aleutian Trench. These two lineal features are made up of tall volcanic sub-sea mountains. The more than 80 large volcanoes in these two chains were formed from countless eruptions of lava, enough to bury the entire State of California over 1,600m deep.

Pioneering American geologist and explorer, James Dana, conducted the first geologic study of the Hawaiian Islands in 1840. He noted that the islands are increasingly younger from north-west to south-east primarily from the degree of erosion increasing in the opposite direction. (Long before, native Hawaiians had noted this: the mythology of Pele, the Hawaiian goddess of the volcano, tells of her travels from island to island until she found a home in the fire pits of Halema'uma'u Crater.) Dana also proposed that the alignment of the islands was caused by volcanic activity along a great fissure that crosses the ocean floor.

It was not until the plate tectonics theory was formulated in the 1960s, and, more relevant to this island chain, the work of Canadian geophysicist J. Tuzo Wilson in 1963, that Dana's fissure theory would be challenged. Wilson proposed that the Pacific Plate's movement over a fixed hot spot created the island chain. To test his hypothesis, he sampled volcanic rock from each of the islands. He found the furthest north-eastern island of Kaua'i was the oldest, as had Dana over 100 years prior, and that the ages became progressively younger the further south-east he went. Additional support for Wilson's theory is occurring today in the form of a new volcano forming south of the Island of Hawai'i called Lō'ihi; as the lava continues to erupt and build to the surface, it too will join the chain of Hawaiian islands.

Observing Volcanic Behavior

Similar to improvements in early oil and gas exploration methods, volcano monitoring at HVO has undergone constant refinements over the past 100 years. When Thomas Jaggar first started

USGS Hawaiian Volcano Observatory, which has been in service over 100 years, currently sits on the western rim of Kīlauea Caldera with great views of the active vent within Halema'uma'u Crater that opened up in 2008.


USGS, Tim Orr

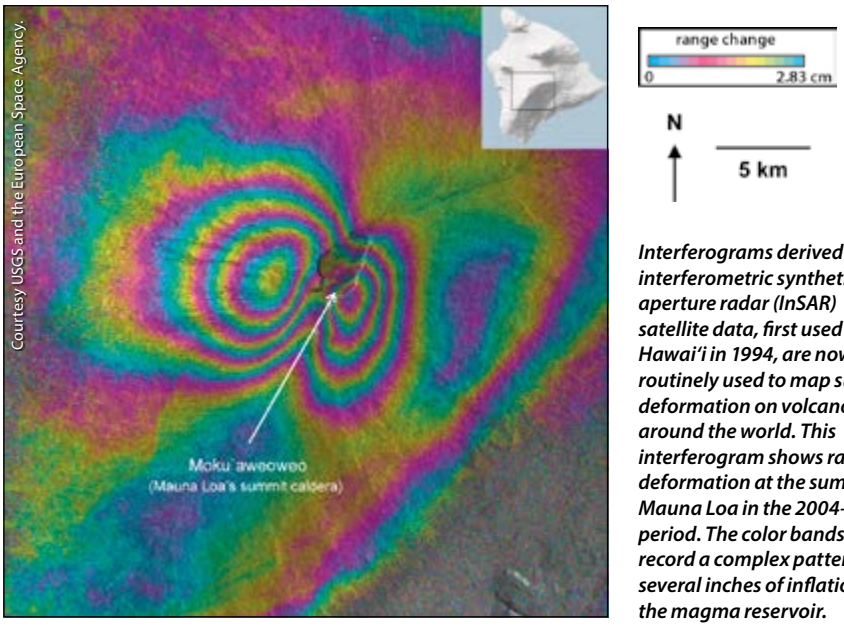
observing the Hawaiian volcanoes in 1909 he had a few elementary seismometers, some meteorological equipment, and a surveyor's transit to monitor seismic activity and the changes in the shape of the volcano. Now, there are over 100 field stations that collect seismic, deformation, volcanic-gas, and geologic data, along with a vast network of other monitoring tools. What Thomas Jaggar did with a camera and a notebook now requires a bank of computers to track of all of the field data.

HVO scientists use many of the same tools that the oil and gas industry use to monitor activity such as strainmeters, tiltmeters, seismic, gravity, GPS receivers, gas sensors, InSAR satellite data, and more – all to increase our understanding of how volcanoes work.

"HVO has served as a proving ground for most of the equipment used today to monitor volcanic and earthquake hazards around the world as well as a training center for volcanologists," says Dr. Michael Poland, USGS research geophysicist. "The first true seismic network was developed here, and lessons learned from that were used to develop networks in places like California to monitor earthquake activity. The same is true for many other monitoring methods including those used before and after the May 18, 1980, major eruption of Mount St. Helens. Many of the scientists working on the St. Helens eruption were also trained at HVO. The training and 'new gizmo' trials that started in Hawai'i over 100 years ago continue today.

"As for the tool to monitor and be able to predict future activity, I do not think there is one 'best' tool, no magic bullet, as it were," Dr. Poland continues. "I tend to think of monitoring as a toolbox. You need a variety of tools in order to be effective at the job site and the same is true at any volcano observatory. Some eruptions have been presaged by certain types of signals, while other times those same signals are not so strong. You need to have a diverse approach to monitoring."

Indeed, like any successful oil and gas company, HVO employs scientists of many disciplines and a wide array of methods to follow volcanic activity, which has enabled scientists to learn much more about the inner workings of the Hawaiian volcanoes. Their findings are published in both scientific papers and on their website, keeping other scientists and the public informed about Hawaii's volcanic activity.



Interferograms derived from interferometric synthetic aperture radar (InSAR) satellite data, first used in Hawai'i in 1994, are now routinely used to map surface deformation on volcanoes around the world. This interferogram shows rapid deformation at the summit of Mauna Loa in the 2004–2005 period. The color bands record a complex pattern of several inches of inflation of the magma reservoir.

Living on an Active Volcano

When I interviewed Dr. Poland at HVO last December, I was very interested in all the various tools he had at his disposal and took away a new respect for both these scientists and the people living in this ever-changing environment.

Visitors come to the Island of Hawai'i to enjoy the tropical fruits, beautiful flowers, stimulating coffees grown from the rich volcanic soils as well as the spectacular mountain and ocean scenery. When eruptions occur, we are a witness to nature's show like no other. Those who call Hawai'i home enjoy the same great qualities that attract visitors but must live day-to-day with the potential hazards such as poor air quality caused from the eruption gasses emitted from Kīlauea, property loss from frequent earthquakes, and dangerous lava flows.

"Standing next to fountaining lava during an eruption is a very overwhelming experience," says Dr. Poland. "You smell, taste, hear, see and feel an event that you have no control over. It is absolutely overwhelming. Then, when the lava flows toward populated areas, it can have a huge impact on the people and society. Most of the scientists at HVO live here and feel the volcano's consequences on the environment and people, both the benefits of what it brings to us as well as its destructive nature."

Special thanks to Janet Babb and Michael Poland of the USGS for their contributions to this article. ■

Dr. Mike Poland, a USGS research geophysicist stationed at the HVO from 2005 to 2015, was responsible for deformation monitoring of the Hawaiian volcanoes.

Organised By: Global Pacific & Partners

ITE GROUP PLC

Lead Sponsor

TULLOW OIL plc

Titanium Sponsor

TOTAL

Rhodium Sponsor

Oando

www.africa-oilweek.com

22nd Africa Oil Week

Africa Upstream

Cape Town, 26th - 30th October 2015

17th Scramble for Africa: Strategy Briefing
26th October 2015

13th Africa Independents Forum
26th October 2015

71st PetroAfricanus Dinner In Africa
26th October 2015

22nd Africa Upstream - Conference & Exhibition
27th-30th October 2015

4th Global Women Petroleum & Energy
Business Luncheon: 29th October 2015

120+ Speakers
160+ Exhibitors
1600+ Attendees in 2014
Senior Executive Networking
African Governments/Ministries

Cocktails & Social Functions
"Big Five" Board Awards
Africa Hydrocarbon Arguments
Award: Africa Oil Legend
Young Professionals Meeting

The longest-established Conference dedicated to Africa's Upstream industry

MANAGEMENT

Duncan Clarke: duncan@glopac.com

Babette van Gessel: babette@glopac.com

Dan Read: daniel.read@ite-exhibitions.com

SPONSOR/EXHIBITION

Amanda Wellbeloved
amanda@glopac-partners.com

Sonika Greyvenstein:
sonika@glopac-partners.com

REGISTRATION

Judith Moore: +27 11 880 7052
judith@glopac-partners.com

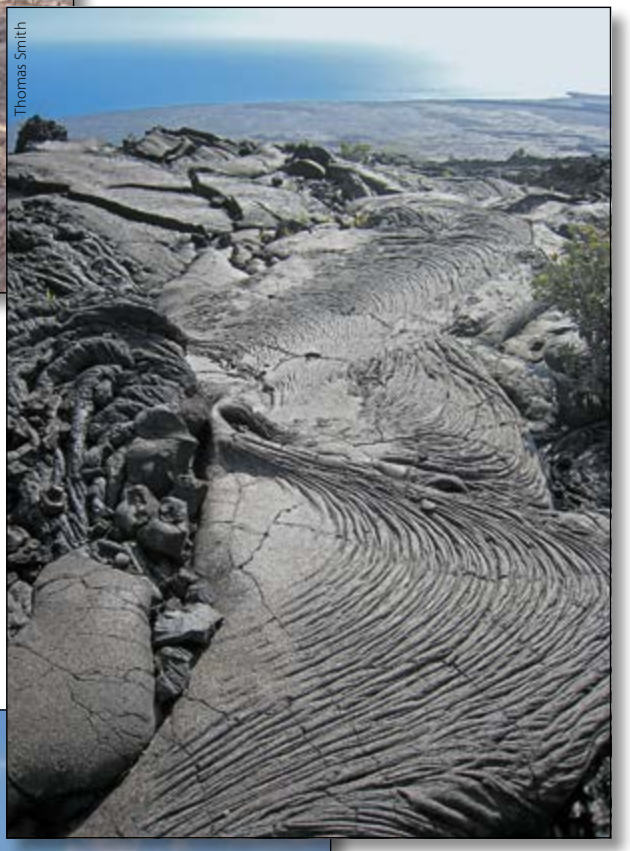
Jodee Lourensz: +31 70 324 6154
jodee@glopac-partners.com

A Photo Essay for the Geotourist

Some of the scenes along and near Hawai'i Volcanoes National Park's access roads and trails.

Pāhoehoe basalt interspersed with 'a'ā basalts (reddish black and blocky) poured over Hōlei Pali (500m bluff in the background) and into the ocean from the 1969 to 1974 Mauna Ulu (Growing Mountain) eruption on Kīlauea's East Rift Zone. These lava flows covered 46 km² and added 93 hectares of new land.

Ropey pāhoehoe basalt viewed along the Chain of Craters Road directly south of Kīlauea Caldera, looking toward the ocean from the top of Hōlei Pali.



As the lava cooled and crusted over, underlying forces buckled what is now the floor of the crater, particularly along the edges.

Hiking across the floor of Kīlauea Iki Crater can be a surreal (and extremely warm) experience. On November 14, 1959, a fissure erupted on the south wall of the crater. Three days before the eruption ended on December 20, 1959, the lava fountain blasted 580m above the vent, the highest ever recorded on the Island of Hawai'i. A lava lake approximately 134m deep was formed over the five weeks of eruptions.

Lava flowing into the sea creates a steam cloud and a brilliant red glow at sunset. This lava has flowed down from the Pu'u'Ō'ō eruption that began on January 3, 1983 and continues today, making it Kīlauea's longest East Rift Zone eruption , although the lava stopped flowing into the ocean in August, 2013. Flows from these ongoing eruptions have been very destructive. In 1990, an entire community, including more than 214 structures, was buried beneath nearly 25m of lava. Recent flows continue to threaten homes and roads in this area.

After a short walk through a lush tree fern forest, the dark confines of the Nāhuku-Thurston Lava Tube come into view. The now lighted cave carried red hot lava several hundred years ago that fed one of the many flows that make up this part of the island.

A Golden Celebration for Silver Seas

'This precious stone set in the silver sea,
Which serves it in the office of a wall
Or as a moat defensive to a house,
Against the envy of less happier lands...'

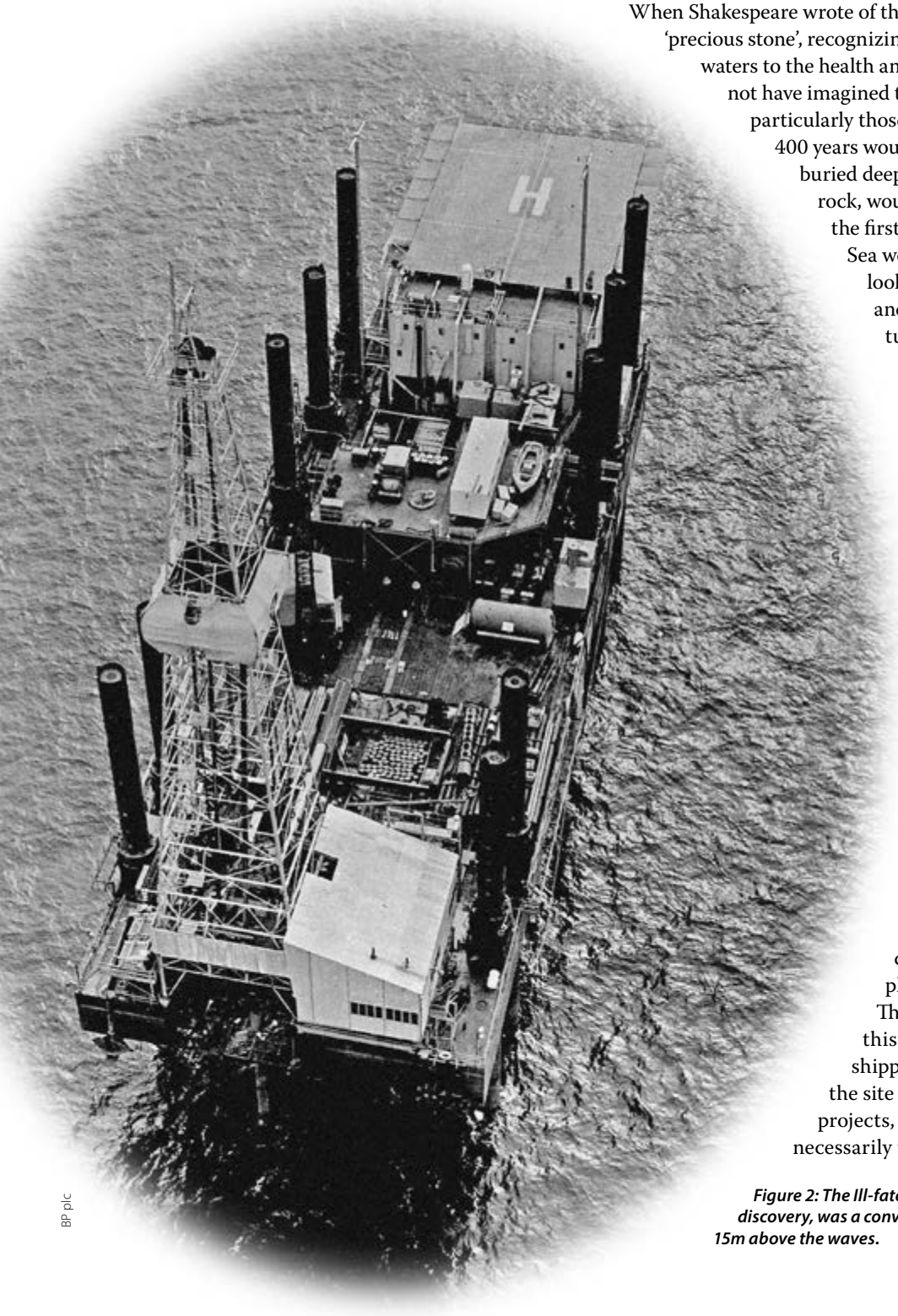
William Shakespeare, 'King Richard II', Act 2 scene 1

WILL THORNTON

When Shakespeare wrote of the 'silver sea' defending England's 'precious stone', recognizing the importance of England's maritime waters to the health and wealth of the 'sceptred isle', he could not have imagined the riches that lay under the waves, particularly those hostile waters of the North Sea. Nearly 400 years would have to pass before those treasures, buried deep beneath thousands of feet of unseen rock, would be revealed. Now, 50 years on from the first oil and gas discoveries in the North Sea we celebrate this golden anniversary by looking back at this important center of oil and gas production, set in silver but often turbulent seas.

A Long and Varied History

The North Sea (Figure 1) is an epicontinental sea located on the north-western European continental shelf and is a diverse maritime province that has provided bountiful riches to the people that inhabit her coastal stretches and far beyond. With a long and varied geological history (see inset box, page 76) the North Sea has undergone multiple changes in shape and extent. Today the rhomb-shaped embayment stretches more than 600 miles (970 km) in length and around 360 miles (580 km) in width, an area of 290,000 square miles (750,000 km^2), with an average water depth of 300ft (90m). For hundreds of years before the discovery of oil the North Sea was plundered for her other treasure – fish. That industry continues and although this busy seaway serves as a major shipping route, tourist destination and as the site for renewable wind and wave energy projects, marine wildlife continues to live, if not necessarily thrive, in and around the region.



BP plc

Figure 2: The Ill-fated Sea Gem, which made the first UKCS discovery, was a converted steel barge, supported on 10 steel legs 15m above the waves.

Hostile and Unknown

During the 1950s and 60s the oil industry had accumulated a wealth of experience developing offshore reserves in places like Venezuela and the Gulf of Mexico, but the relatively small size of fields in and around the North Sea had not attracted companies to this 'hostile and higher-cost' area. However, with the ratification of the 'Continental Shelf Convention' in 1964 and assigning of territorial rights to mineral resources along a median-line, halfway between participating countries, plus recognition of the 'giant' status of the onshore Groningen gas field (The Netherlands), the search for other, analogous fields in the offshore was about to begin.

Geophysical exploration was able to proceed in advance of petroleum legislation but drilling activities in the North Sea would only begin with the 1st Round of UK licensing late in 1964, with The Netherlands, Denmark, Germany and Norway quickly following. Interest in the 1st Round was so great that government departments could not keep up with applications and companies were asked to form consortia to speed things up; there were even tales of bids being decided by the toss of a coin! A total of 53 licenses were awarded – 394 blocks, 22 consortia, 51 companies. In the early days the 'majors' and the US independents led the way, with only 30% of the companies applying for licenses being UK-based.

The first wells were dry but data gained proved invaluable and late in 1965 BP made the first discovery of commercial quantities of gas in a Groningen analog close to the UK, in what was to become the West Sole Gas Field. The drilling rig was the now infamous Sea Gem and the good news quickly turned somber as reports that the rig had collapsed as it was moving out to drill a new well began to make headlines (Figure 2). Two of the legs became detached and the platform plunged upside down to the bottom of the sea. It was two days after Christmas, 1965 and thirteen men were killed.

A short time after the discovery at West Sole, Conoco announced the discovery of the Viking Field (Table 1) and the excitement behind the exploration campaign began to intensify. A 2nd Round was announced in the UK in 1965, this time for 1,000 Blocks – although participation was not as great as for the 1st Round, mostly because the initial work programs were still active and limited human resources were available. News of discoveries from both Rounds followed at regular intervals and the oil rush had begun, with giant fields like those at Ekofisk and Forties convincing geologists that greater rewards could be had in the relatively uncharted Central and Northern provinces.

By the time of the 4th Round 'Scramble' in 1971 the introduction of 'spec surveys' in the North Sea heralded the start of a new phase of development, and within a few years most of the major oil and gas accumulations in both the Northern and Southern North Sea had been discovered and production levels began the rapid incline towards peak production, occurring sometime around 1999/2000 (Figure 3).

(continued on page 78) ▶

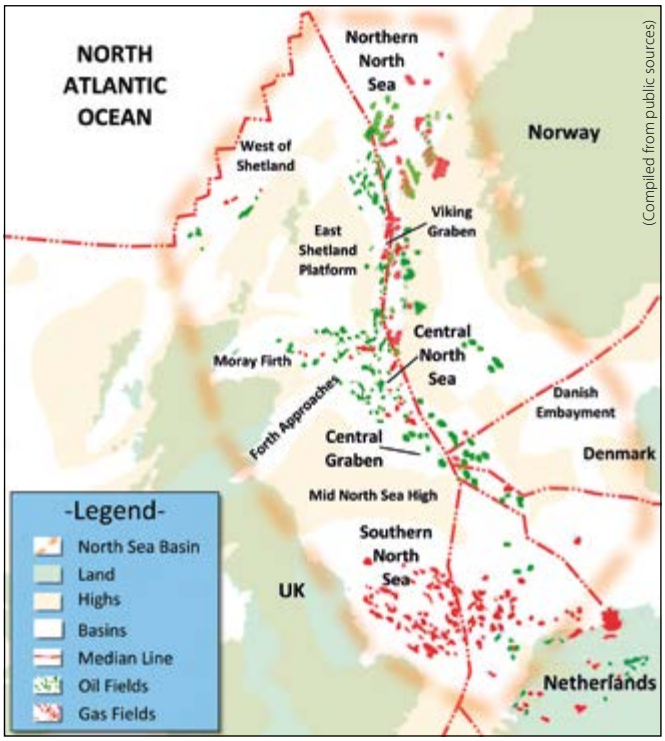


Figure 1: Map showing the location of the North Sea Basin. The major regions discussed in this article are shown along with the main oil and gas provinces.

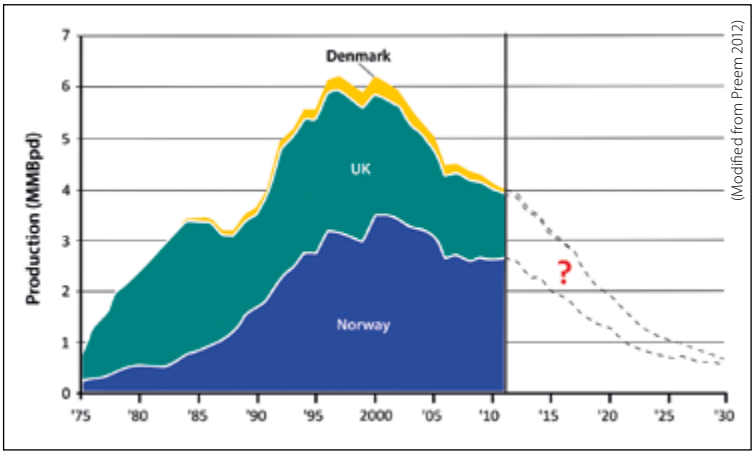
Table 1: Exploration history, showing some of the major discoveries in the Southern and Northern North Sea.

Field	Discovery	Location	Reserves*	Prod*
West Sole Field	BP - Sept., 1965	SNS, UKCS	2 TCF	1967 - Present
Viking Gas Field	Conoco - Dec., 1965	SNS, UKCS	3.3 TCF	1972 - Present
Ekofisk Oil Field	Phillips - 1969	CG, NCS	3.6 Bbo, 5.8 TCF	1971 - Present
Forties Oil Field	BP - Nov., 1970	CNS, UKCS	2.5 Bbo	1975 - Present
Brent Oil Field	Shell - 1971	ESB, NNS, UKCS	2 Bbo and 4.2 TCF	1976 - 2014 (DC)
Piper Oil Field	Occidental - 1973	NNS, UKCS	1.01 Bbo	1976 - Present
Statfjord Oil Field	Mobil - 1974	NNS, UKCS (15%), NCS (85%)	4 Bbo and 4 TCF	1979 - Present
Gullfaks Oil Field	Statoil - 1978	NNS, NCS	2.3 Bbo and 0.9 TCF	1986 - Present
Oseburg Oil Field	Statoil - 1979	VG, NNS, NCS	2.4 Bbo and 3.7 TCF	1988 - Present
Miller Oil Field	BP - 1983	VG, NNS, UKCS	345 MMbo (Prod)	1992 - 2007
Sciehallion Oil Field	BP - 1993	WoS, UKCS	450-600 MMbo	1998 - Present
Buzzard Oil Field	Nexen - 2001	CNS, UKCS	>500 MMbo	2007 - Present
Goldeneagle Oil Field	Nexen - 2007	CNS, UKCS	140 MMboe	2014 - Present
Johan Sverdrup Oil Field	Statoil - 2010	NNS, NCS	2-3 Bbo	FO - 2018

Abbreviations: SNS – Southern North Sea; NNS – Northern North Sea; CNS – Central North Sea; VG – Viking Graben; CG – Central Graben; WoS – West of Shetland; ESB – East Shetland Basin; DC – Currently Decommissioning; FO – First Oil; UKCS – UK Continental Shelf; NCS – Norwegian Continental Shelf.

*Unless otherwise stated all reserves figures are for original recoverable volumes, derived from public sources including DECC and NPD.

Figure 3: North Sea production rates, by year and by country.



A Complex History of Basin Evolution

Prior to the awarding of the first exploration blocks in 1964 there was a limited understanding of the geological history of the region, but seismic exploration and drilling would change that. One thing that characterizes early efforts in the North Sea (and the industry generally during this period) is the rapid rate of adoption and adaptation of existing and new technologies – analog systems gave way to digital, single fold seismic became multi-channel (improving noise reduction by stacking), longer and longer offsets were used (improving migrations, AVO studies, rock physics and depth imaging), 2D to 3D and (perhaps amusingly now, looking back) the advent of color bars for seismic interpretation.

With the increasing data coverage came a greater understanding of the subsurface and a coherent geological story of a major sedimentary province began to evolve. To tell the story we must begin our journey in the Lower Paleozoic, over 400 Ma, prior to the Late Silurian–Early Devonian Caledonian Orogeny, when the North Sea area was made up of widely separated continental fragments, marginal to the Iapetus Ocean. Closure of Iapetus resulted in the creation of the mega-continent of Laurasia, encompassing the region of the present day North Sea.

Devonian–Permian

Rifting in the Devonian period, resulting from adjustments along the margins of the Laurentian and Scandinavian cratons, culminated in the Late Carboniferous Variscan Orogeny, marking the creation of the Pangaea supercontinent. The development of extensive coal basins during this time provided the key source rocks of the Southern North Sea gas belt, with the main period of coal deposition during the Late Carboniferous (Westphalian) when up to 2,500m of strata were deposited.

By Permian times, north-west to south-east transtension in the region led to the formation of the Northern and Southern Permian Basins (separated by the Mid North Sea High), within the northern foreland of the Variscan Highlands. Major rifting with volcanism and deposition of aeolian and fluvial sandstones (Rotliegend) and deposition of thick marine influenced evaporite sequences (Zechstein) followed (Figure 4). Later, buoyancy forces caused the salt to move upwards, generating hydrocarbon traps, in the southern part of the North Sea.

It was recognized early on that there was a strong relationship between the presence of Westphalian coal measures and the accumulations of gas in the overlying Lower Permian Rotliegend sandstone reservoirs in the Southern North Sea, trapped beneath the excellent topseal of the Zechstein.

Mesozoic

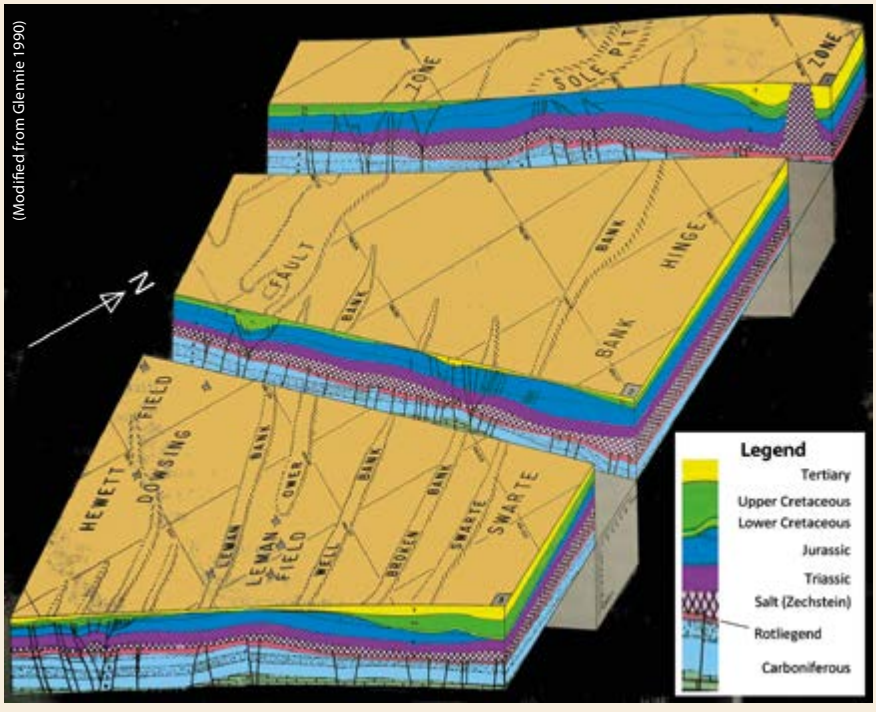
The beginning of the Mesozoic Era saw the end of the marine influences that had produced the evaporite successions of the Permian. Major east-west rifting dominated, with thick coarse fluvial sediments deposited along rift margins, grading into finer-grained river and lake deposits in the center of the basins.

The transition between the Triassic and Jurassic is marked by a widespread marine transgression from north and south, followed by the growth of a volcanic dome positioned over the triple point between the Viking Graben, the Central Graben and the Moray Firth Basin. The doming caused uplift and erosion, followed by rifting. Large deltaic systems containing sand, shale and coal were developed in the Northern North Sea (Brent Group).

An important rifting phase during the Late Jurassic to Early Cretaceous, when major block faulting caused uplift and tilting, created considerable local topography with erosion and sediment supply. In anoxic basins thick sequences of shale accumulated, producing the most important source rock for liquid hydrocarbons in the North Sea – the Kimmeridge Clay (Figure 5).

By the Upper Cretaceous rifting ceased and was

Figure 4: Block diagram of the Sole Pit area of the Southern North Sea, where the first discoveries of gas were made in 1964.



followed by thermal sag. South of 61°N there was widespread deposition of chalk, while to the north carbonates gave way to siliclastic, clay-dominated sediments.

Cenozoic

Paleogene onset of sea floor spreading in the north Atlantic and orogenic events in the Alps and Himalayas all had an influence on the late development of the North Sea basins. Deposition of chalk continued until Early Paleocene when uplift of basin margins, due to inversion, produced a series of submarine fans transported from the Shetland Platform towards the east. In the Miocene a deltaic system had developed from the Shetland Platform towards the Norwegian sector of the North Sea. Due to major uplift and Quaternary glacial erosion of the Norwegian mainland, thick sequences were deposited into the North Sea during the Neogene, leading to burial of the Jurassic source rocks to depths where hydrocarbons could be generated.

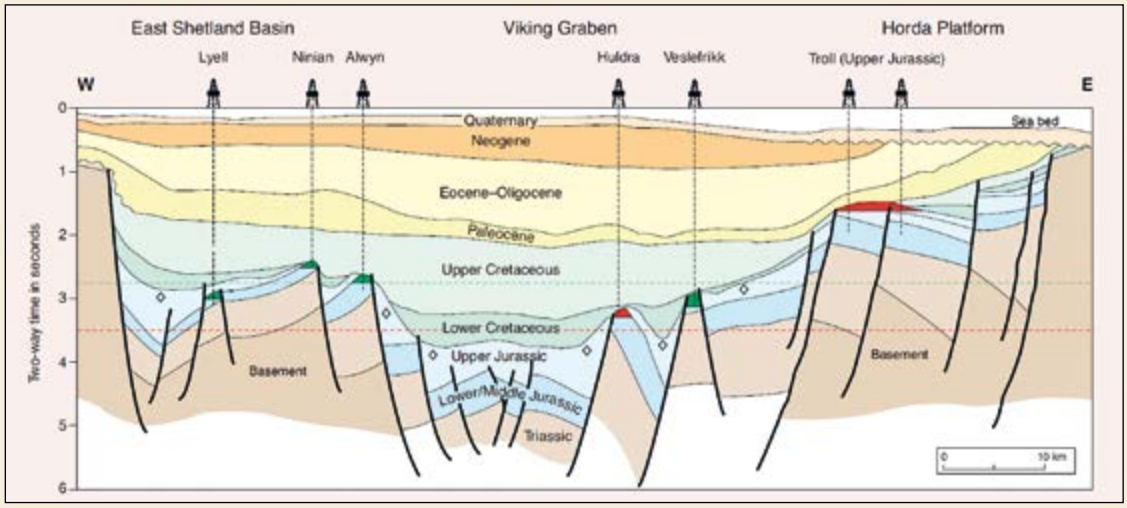


Figure 5: Geoseismic cross section in the Northern North Sea.

(From the Millennium Atlas 2001 – modified from NPD)

Following the early, exciting years of intense exploration activity, the 1980s saw steady but interrupted development and addition to reserves, as the region became subject to the cyclical nature of the industry. By the 1990s the region moved into another phase of exploitation and in 1992 BP discovered Foinaven, the first deepwater oilfield to be developed in the UK and the first development West of Shetland.

In the early part of the 21st century production and reserves additions are in inevitable decline but with imaginative technical and commercial models there are always new opportunities. In 2011, for example, BP sanctioned development of Clair Ridge using 'LoSal' enhanced recovery technology and in 2014 sanctioned a life extension project for the Magnus field. Smaller independents specializing in late field exploitation also have an important role to play and continue to enter the changing business landscape.

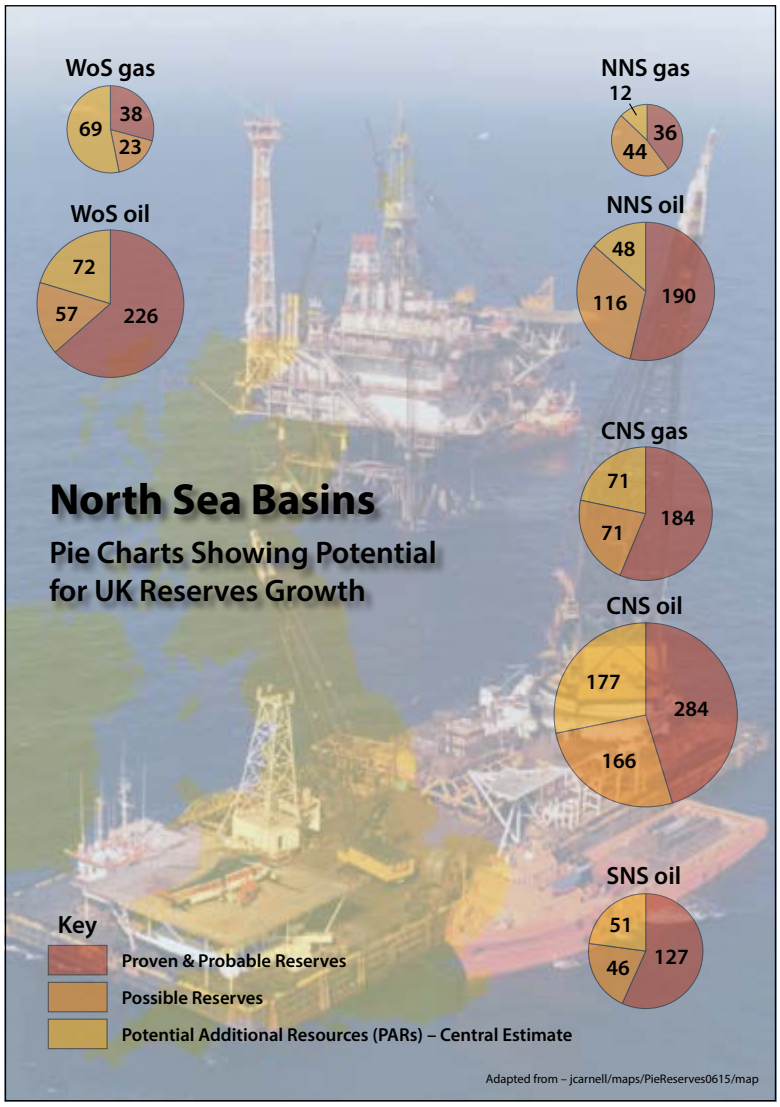


Figure 6: North Sea basins: potential for reserves growth 2015. Key: Gas – billion cubic metres; Oil – million tonnes. Modified from jcarnell www.gov.uk Background image is the Forties Alpha installation (Source: BP).

50 Years and Counting

In 2015 the UK is in the 28th Round, Norway the 23rd and a series of initiatives are being implemented with a view to stimulating exploration and development activities in the region generally and in predefined areas or sectors. Around 40 Bboe have been produced in the UKCS alone and government estimates suggest that there could be another 24 Bboe to recover – another 30–40 years of production (Figure 6). Regionally, production is in a steady decline and, in a climate of diminishing returns and to a backdrop of challenging decarbonization targets, global financial markets will decide the future for North Sea oil and gas; regulators can only do so much.

Initiatives such as the Wood Review are now in the early phase of implementation and the UK is looking to recover the maximum value from North Sea investments. In Norway the sovereign wealth fund – Government Pension Fund Global, valued at $785 billion in September 2013 – will buffer the effects of diminishing North Sea revenues for future generations in Norway. 'One day the oil will run out, but the return on the fund will continue to benefit the Norwegian population' reads the blurb, and informed sources will tell you that 50% of the reserves are still in the ground and 'the era of oil… is not over yet.'

In 1967 BP constructed a terminal in Yorkshire and within 18 months North Sea gas was igniting an energy revolution that changed the face of Britain. Barring any sudden change in commodity prices, or the rapid evolution of some new enabling technologies, the North Sea is unlikely to have the same impact on fortunes in the future. The glory days are gone but the region will continue to provide energy of one sort or another, as long as there is a market for it. The current impact of the industry downturn on North Sea fortunes will make themselves clearer as taxes and royalties dry up and unemployment in the region rises, so the North Sea will feature large in the public conscience for a while longer.

In the immediate future the industry will look to begin to decommission many of the 450+ installations that have been in use for the past 40 years, including 10,000 km of pipelines and around 5,000 wells. Decommissioning expenditure is projected to be £19 billion by 2030, rising to £23–25 billion by 2040.

Final Word

The 'silver sea' has given up her bounty at a cost that is greater than can be measured in dollars alone. An army of men gave their lives in the pursuit of the North Sea's oil and gas, with the tragic events at Piper Alpha and the loss of 167 lives in July 1988 providing the nadir. Their sacrifice has been to our great collective benefit and their memory and legacy must shine bright and long. As we look to the next 50 years of the industry in the North Sea it is imperative that we honor them by ensuring that such tragedies remain a thing of the past.

A full list of references is available online. ■

Enhance Subsurface Prediction

When predicting key play elements in the subsurface, the ability to place quantitative constraints on prospective reservoirs and seals provides major risk reduction.

The Neftex Reservoir and Seal module provides access to a continually growing, global database featuring millions of standardised, temporally and spatially located rock property data. All ready to be seamlessly integrated into your exploration projects.

Augment your exploration strategy.

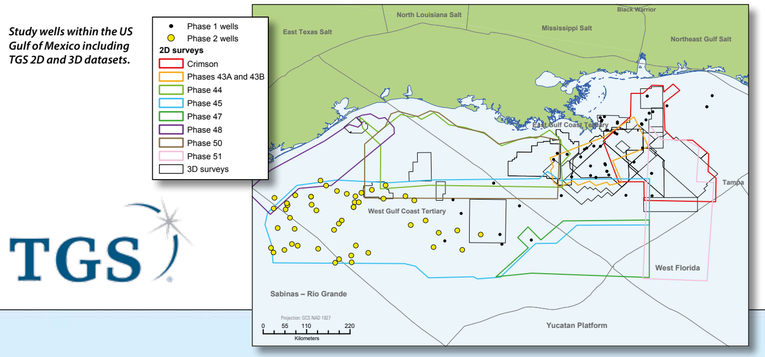
Contact us today:

Website: www.neftex.com
Email: enquiries@neftex.com
Tel: +44 (0)1235 442699
LinkedIn: **linkedin.com/company/neftex**
Neftex • 97 Jubilee Avenue • OX14 4RW • UK

HALLIBURTON
Landmark

neftex

Gulf of Mexico: Post Well Analysis

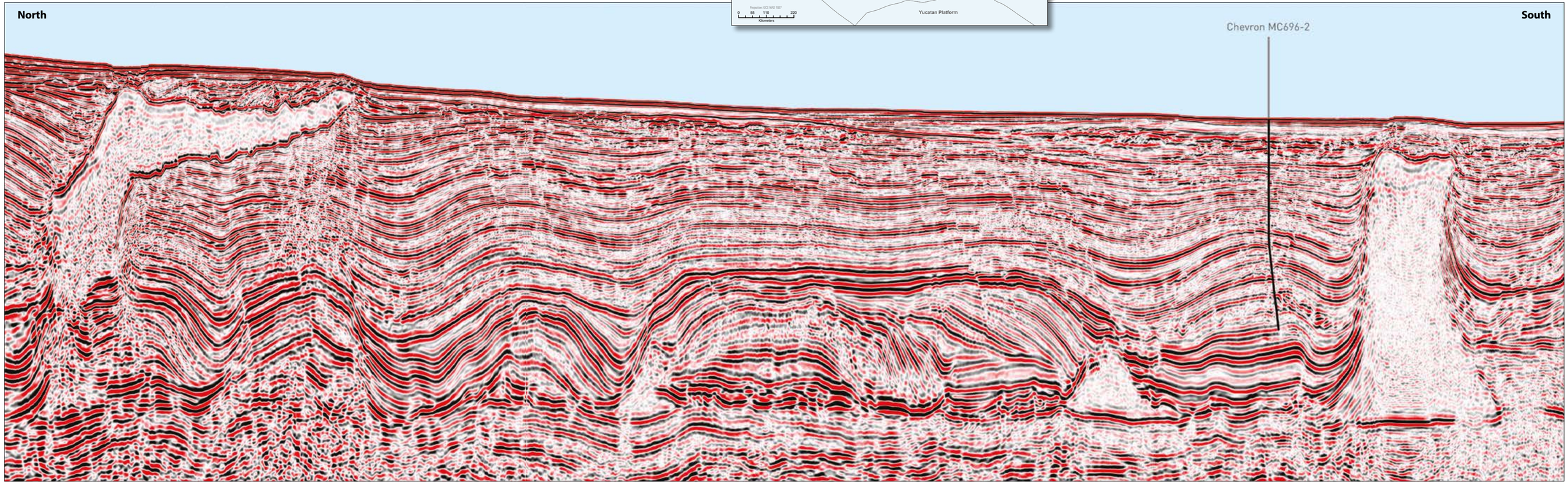


Study wells within the US Gulf of Mexico including TGS 2D and 3D datasets.

In order to assess the four key risk factors for exploration – reservoir, trap, seal, and charge (source and migration) – an interdisciplinary approach is required. Both dry and discovery wells have been analyzed in an attempt to provide an appraisal of the exploration scenarios that characterize this region.

This project requires the integration of well data (geological reports, well logs, biostratigraphic reports and mud logs including cuttings and lithology data), TGS 2D and 3D seismic, petrophysical data, thermal modeling and any other publicly available data, to create a concise assessment of the petroleum systems of the US offshore Gulf of Mexico. Presentation of results as a GIS project provides easy access to data and the possibility of detailed analysis of patterns and trends.

Seismic line from TGS Justice WAZ 3D, demonstrating overall structure and potential trapping mechanism.



Interdisciplinary Approach to Gain Confidence

Using post well analysis in an interdisciplinary approach leads to a more confident understanding of complex petroleum systems.

ALESSIO CHECCONI, PETER CONN, DAVID LITTLE, EDWARD SMITH, JAMES STOCKLEY, ERIKA TIBOCHA; TGS

Due to the complex nature of strata offshore in the Gulf of Mexico, it is difficult to identify formations and sequences across wells based on lithology and wireline data alone. Integration of biostratigraphic data from the US Bureau of Ocean Management unified with the Gulf Basin Depositional Systems stratigraphic framework was, therefore, utilized to characterize differing units. All the data inputs, from a variety of sources, have been collated into a geodatabase which can be scrutinized using ESRI's ArcGIS software and specific query tools developed by TGS.

This interdisciplinary study currently includes 50 wells from the US offshore Gulf of Mexico. A further 50 wells are being included in a second phase (see map on preceding page). The criteria for well selection is based upon location in key areas of exploration, depth, well stratigraphy and availability of data.

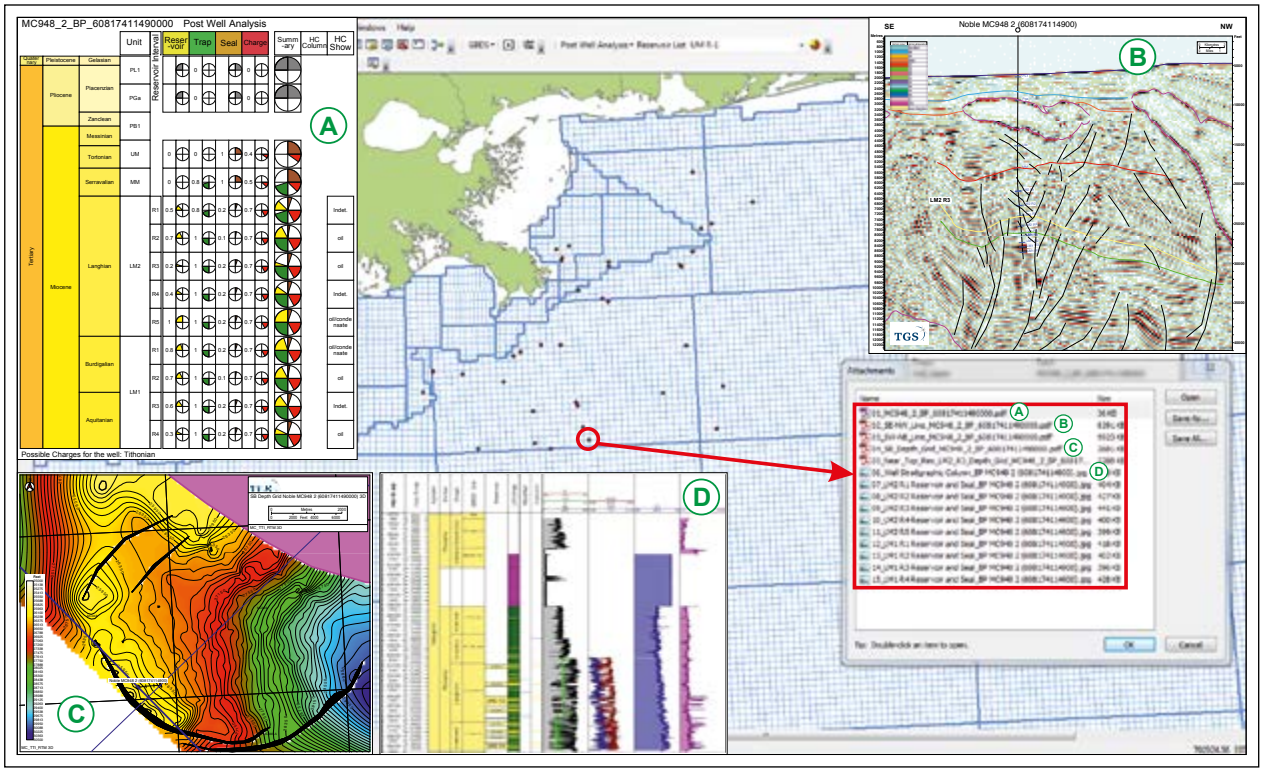
The Phase 1 work schedule included the first 50 project wells centered around the TGS 3D surveys in the Eastern Gulf, such as Mississippi Canyon, Atwater Valley, and Main Pass areas, and infilling with 2D seismic in areas including Green Canyon and Walker Ridge.

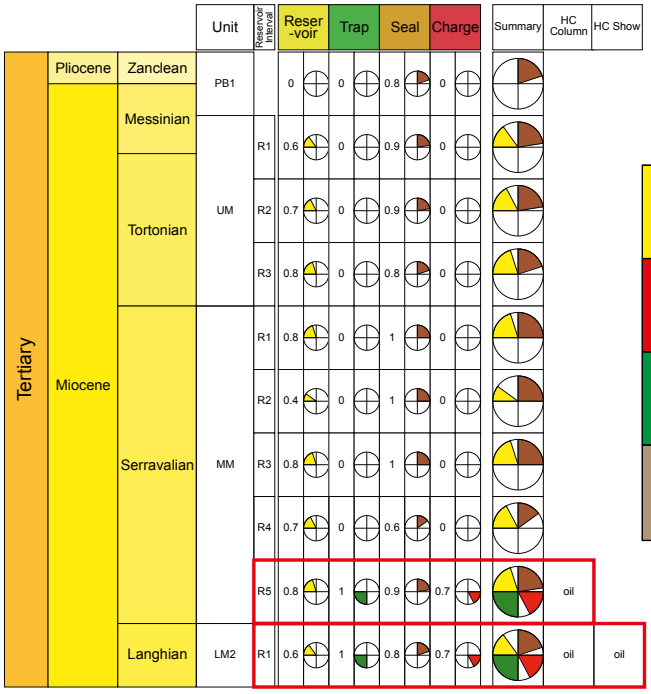
Phase 2 is focused on the Western Gulf, where an additional 50 wells are included across Alaminos Canyon, Port Isabel, Corpus Christi and East Breaks, with predominantly 2D seismic coverage. The focus of phase 2 is to analyze and refine the understanding of this region and to provide a robust platform for comparison with Mexican wells south of the border.

The four main elements assessed by the post well analysis (PWA) are reservoir, trap, seal and charge. By assessing wells from a holistic standpoint utilizing experience from geology, geophysics, petrophysics and basin modeling, we can determine the primary reasons for well success and failure.

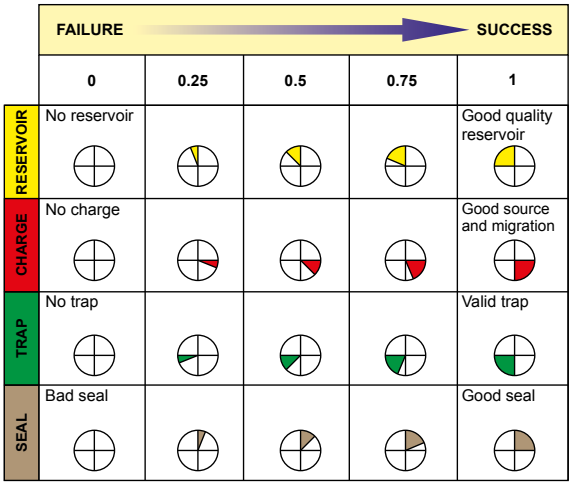
Reservoir: Reservoirs are selected based on lithology, CPI data, presence of hydrocarbons, and zones of interest or targets defined by the original operator. Up to five reservoirs per unit are analyzed in each well, though due to the nature of sand deposition within the Gulf of Mexico, two sands with the same reservoir name in different wells may not be part of the same sand-body,

Example PWA deliverables within the ArcGIS platform. Understanding the pitfalls and reasons for failure in an area of interest can help in avoiding similar issues in later wells.





Possible Charges for the well: Tithonian



Example summary table for a complete well section.

even in circumstances where the wells are less than a half a mile apart. Porosity and net-to-gross (N:G) values, along with thickness and lithology information, are utilized to determine the rating of each reservoir. Porosity and N:G data were determined from CPI calculations.

Seal: Assessment of the seal for each reservoir was split into two parts: top seal and critical seal. Top seal was assessed directly at the well, using the log interpreted lithology to determine the likely vertical thickness and heterogeneity of the section. The critical seal is assessed where structural elements away from the well are necessary to form a lateral seal, i.e. a closing fault in a faulted anticline. Lithology at the well is combined with seismic character around the well to determine the possible lithology across a fault from the reservoir interval in order to ascertain whether there are likely to be thief zones across the fault. The presence of gas clouds and bright amplitudes around the well are used as indications as to whether the fault itself is sealing, or a migration conduit away from the reservoir.

Trap: Assessment of the trap, as with the other parameters, is at the reservoir level. Within each section it is determined if there is a valid trapping mechanism seen on available seismic. When a trapping mechanism is identified on the seismic, as seen on the main foldout line on the preceding page, it is rated on likelihood of success or failure. Confidence ratings are applied on both the data available and the interpretation to allow for complete transparency in workflow. Any DHIs observed are also compiled and commented on. Analysis of trap timing and basic volumetrics are also included in this part of the study. Images are used to demonstrate the structures observed, using TGS multi-client 3D and 2D data. For each well assessed there are two seismic lines with TGS interpretation and depth grids for reservoir levels of interest.

Charge: Evaluation of the charge is based on effectiveness of source rock (expulsion), using source rock quality at the well when geochemistry analysis is available, and also thermal modeling. Kitchen depths plus migration pathways, maximum burial and maximum temperature are all accounted for within the database. The main source rocks defined by Hackley (2012) formed the basis of the source rock units assessed. If a unit is potentially a good source rock, but there is no migration pathway (e.g. lack of carrier beds or lack of communicating faults) for the hydrocarbons from the kitchen to the well, then the failure was considered to be due to lack of charge.

Well Summary Chart and Database

Upon completion of the analysis of the four main geological parameters a well summary chart is created to graphically represent whether the well is a success or a failure at each stratigraphic interval. Pie segments are representative of the overall rating that is applied for each reservoir interval. For example, the well above (M696_2_Chevron_60817410340000, Blind Faith), identified two successful intervals where the four primary pie segments display high values. Hydrocarbons have migrated updip via faults to charge the reservoirs at LM2 R1 and MM R5 level that have good structural trap and effective closure. The upper intervals are generally found to have effective reservoir and seal but failed due to lack of closure and charge/migration pathways.

The final project is delivered in an ArcGIS geodatabase format, so that each well can be scrutinized. Attachments of seismic and well images are provided for each well in the database and a query tool allows the user to further interrogate individual elements of the wells.

Rating Confidence

Hydrocarbon exploration is a high risk investment and risk assessment is essential for successful asset management. Exploration is a complex concept and by using the PWA we have provided an independent confidence rating on the four main geological elements that are required for a successful outlook on wells that have been completed.

References available online. ■

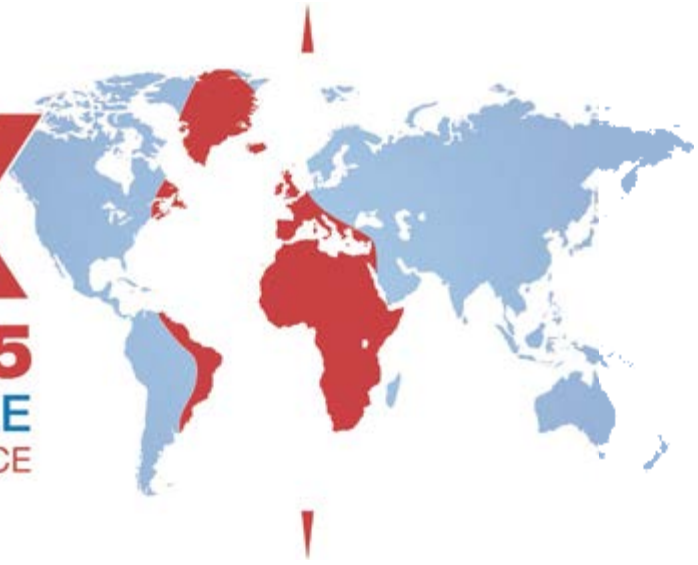
PROSPECT AND PROPERTY EXPO

APPEX

REGIONAL 2015

ATLANTIC POLE TO POLE

5-6 NOVEMBER 2015 | NICE, FRANCE



REGISTER NOW

Save €240 with earlybird discount

(Early bird discount ends 1 September)

This year's APPEX Regional Conference – taking place in Nice, France – will focus on exploration and production opportunities spanning the Africa and Atlantic Margin, from South America to Northern Europe – from "Pole to Pole".

Regions of Focus for APPEX Regional 2015

- North Atlantic
- Baffin Bay
- Arctic
- Barents Sea
- West of Shetland
- Atlantic Ireland
- Labrador Sea
- Canadian Maritimes
- Offshore Mexico
- Atlantic Margins
- South American Transform Margin
- Atlantic Pre-Salt
- South Atlantic
- West African Transform Margin
- North West African Rifts
- Mozambique Channel
- East African Rifts
- Horn of Africa
- Iberian Offshore
- Western Mediterranean
- Central African Rifts

AAPG

Europe & Africa Region

europeevents.aapg.org/APPEXRegional2015

Gas Hydrates

LASSE AMUNDSEN, Statoil, and
MARTIN LANDRØ, NTNU Trondheim

PART IX: Hydrates in Outer Space (2)

In the previous issue of *Geo ExPro* we discussed the possibilities of gas hydrates on Mars. Here, we look at such possibilities elsewhere in outer space.

Hydrates on Planets and Moons?

At the moment, the existence of hydrates on planets, moons and other solar bodies is based on our knowledge of their pressure and temperature conditions and gases present around them. The conditions for hydrate stability exist in both the atmospheres and the subsurface of a number of planets and moons in our solar system. In particular, gas hydrates are probably more abundant than rocky materials or all polymorphs of pure ice in the gas giant planets of Jupiter, Saturn, Uranus, and Neptune. It is therefore possible that the amount of gas in the form of hydrates in our solar system is surpassed in total quantity only by hydrogen and helium.

I don't think the human race will survive the next thousand years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars.

Stephen Hawking, Astrophysicist

The hydrate formation mechanisms and the resulting hydrate compositions in our solar system are highly varied. Possible formation mechanisms which have been proposed (Kargel, 2001) include:

- Direct condensation of amorphous CO-CO_2-N_2-rich hydrates from the Solar Nebula by the reaction of hydrate-forming gases with water ice. This process would be responsible for hydrate formation in comets and the

An artist's impression showing the formation of a gas giant planet in the ring of dust around the young star HD 100546. This protoplanet is surrounded by a thick cloud of material so that, seen from this position, its star is almost invisible and red in color because of the scattering of light from the dust.

ESO/L. Calçada

Kuiper asteroid belt.

- Heating of condensation products of the Solar Nebula to form N_2-CO-rich and CH_4-rich clathrate hydrates in comets, on Pluto, Charon, Triton, and Plutinos.
- Direct condensation of N_2-CO-rich and CH_4-rich clathrates from circum-planetary nebulae of the outer planets, such as Callisto and the moons of Saturn, Uranus, and Neptune.
- Formation of SO_2-, CO_2-, and N_2-rich clathrates in the primordial hydrospheres of Earth, Mars, Europa, Ganymede, and Callisto.
- Formation of SO_2- and CO_2-rich clathrates or CO_2-dominated clathrates in planets with more evolved hydrospheres (Martian permafrost and Europa's icy cryosphere).
- Formation from biogenic sources of CH_4 clathrate, forming methane-rich hydrate on the Earth's permafrost and seafloor, and possibly on Mars and Europa.
- Formation by thermogenic origin of CH_4-C_2H_6-C_3H_8-rich clathrates (hydrates related to petroleum and gas deposits on Earth).

In addition, Mars and Earth have a variety of other minor clathrate-forming mechanisms, including occlusion of air in polar ices (forming N_2-O_2-rich clathrates in the case of Earth and CO_2-rich clathrates in the case of Mars).

Thus, clathrates are believed to occur in large quantities on some outer planets, moons and trans-Neptunian objects, binding gas at fairly high temperatures. A trans-Neptunian object is any minor planet in the solar system that orbits the Sun at a greater average distance than Neptune.

Enceladus: Trans-Neptunian Object with Geysers

In Greek mythology, Enceladus was one of the Giants, the offspring of Gaia (Earth) and Uranus (Sky). In astronomy, Enceladus is the sixth-largest moon of Saturn, with a radius of 250 km and surface temperature of about -180°C. It was discovered in 1789 by William Herschel.

In 2005, NASA's Cassini spacecraft started multiple close flybys of Enceladus, revealing its surface and environment in great detail. Cassini immediately spotted geysers erupting from four 'tiger stripe' fractures near Enceladus' south pole, but their origin still remains the subject of debate. Over a period of nearly seven years, scientists have now mapped out 101 geysers shooting jets of water vapor, other volatiles, and solid material including sodium chloride crystals and ice particles into space, approximately 200 kg per second in total.

In April 2014, a scientific publication revealed that Enceladus harbors a big 10 km deep ocean of liquid water beneath its icy crust. The heat required to keep this water in a liquid state is generated within Enceladus, with much of that energy probably coming from tidal interactions between Enceladus and another of Saturn's moons, Dione. The water is in direct contact with a rocky seafloor, theoretically making possible all kinds of complex chemical reactions – such as, perhaps, the kind that led to the rise of life on Earth.

Some scientists think the geysers reach all the way down to the ocean of liquid water that sloshes beneath Enceladus' icy shell, and that they blast into space when the fractures open up.

It is interesting to note that another proposal is that the geyser activity originates from clathrate hydrates, where carbon dioxide, methane, and nitrogen are released when exposed to the vacuum of space by the tiger stripe fractures found in that area.

Hydrate Formation in Protoplanetary Nebulae

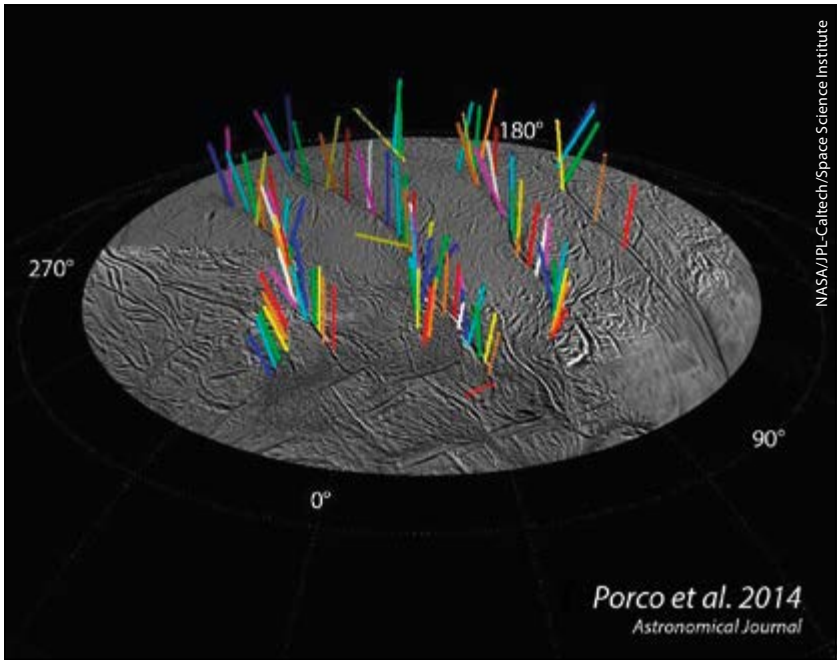
Stars form from interstellar gas, mainly hydrogen, and dust that is concentrated in clouds, locally raising the gravitational force. The cloud shrinks and starts to spin. This rotation causes the cloud to flatten out – much like forming a flat pizza out of dough – and take the form of a disk where a warm protostar forms. The protostar radiates heat and at the same time ejects matter outwards from its poles.

Eventually, the protostar becomes massive enough to start fusion in its core. The star starts its active nuclear life while gas and dust create planetoids around it.

The rotating circumstellar disk of dense gas surrounding a young newly formed star is called a protoplanetary disk or nebula. Conditions for hydrates in the protoplanetary nebula are considered to be fulfilled, the key being to document the presence of enough microscopic ice particles exposed to the gaseous environment.

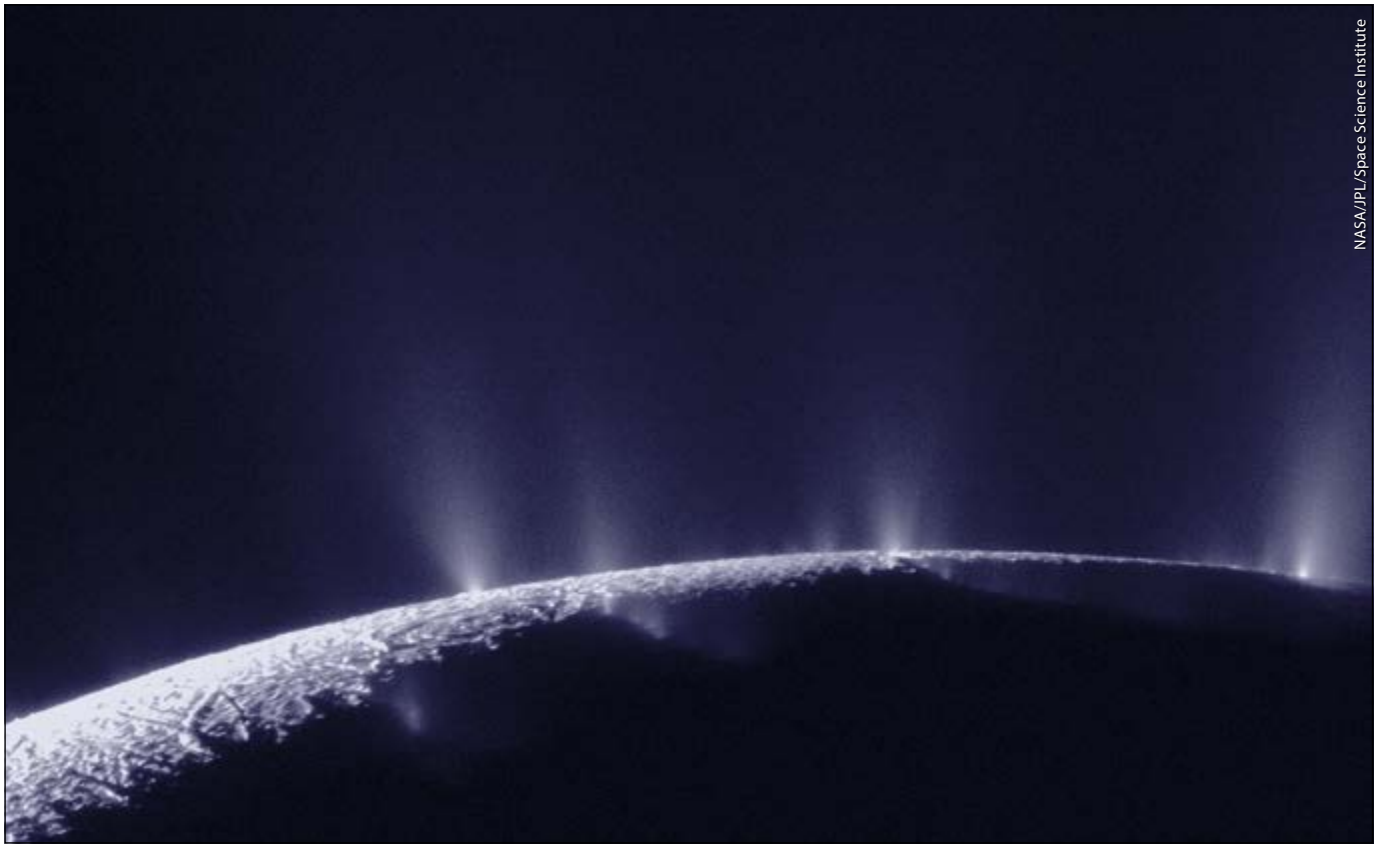
The Infrared Space Observatory (ISO), launched in 1995, was a space telescope for infrared light designed and operated by the European Space Agency. The ISO was designed to study infrared light at wavelengths of 2.5 to 240 μm and, among other things, it searched for and found several protoplanetary disks. In addition, broad emission bands of water ice at 43 and 60 μm were found in the disk of the isolated Herbig Ae/Be star HD 100546 in Musca. The one at 43 μm is much weaker than the one at 60 μm, which means the water ice is located in the outer parts of the disk at temperatures below 50°K. There is also another broad ice feature between 87 and 90 μm, which is very similar to the one in the Butterfly nebula in Scorpius.

Crystalline ices have also been detected in the proto-planetary disks of ε-Eridani and the isolated Fe star HD 142527 in Lupus. Ninety per cent of the ice in the latter was found crystalline at temperatures of around 50°K. ■



A six and a half year survey of Enceladus' south polar terrain (SPT) by the Cassini imaging experiment has located ~100 jets or geysers erupting from four prominent fractures crossing the region. The heat accompanying the geysers is believed to be transported, in the form of latent heat, from a sub-ice-shell sea of liquid water, with vapor condensing on the near-surface walls of the fractures. (Porco, DiNino and Nimmo, 2014)

A view from NASA's Cassini spacecraft. Plumes, both large and small, spray water ice and vapor from many locations along the famed 'tiger stripes' near the south pole of Saturn's moon Enceladus. The tiger stripes are four prominent, approximately 135 km long fractures that cross the moon's south polar terrain.



The Stratigrapher

Dr. Phil Copestake explains how stratigraphy fits into the cycle of petroleum exploration and why he enjoys his work.

Many stratigraphers are employed in the oil industry in both oil and service companies. They determine the geological succession in well sections, in terms of rock units (lithostratigraphy), age (chronostratigraphy) and environment of deposition, by an integration of lithological information, wireline logs and fossil content (biostratigraphy). In the industry, biostratigraphy is usually based on micropaleontology – the identification of microfossils small enough to survive the drilling process. The most important microfossil groups are organic (dinocysts, spores, pollen) and inorganic (foraminifera, ostracods, conodonts, calcareous nannoplankton). Microfossil extraction requires laboratory processing and identification of the recovered specimens by microscopic examination.

Microfossils are amazingly versatile. They often occur in high abundance, even in small well samples, and are found in paleoenvironments ranging from freshwater to deep marine, in sediments from the Paleozoic to the present day. Distinctive assemblages of microfossils may typify particular rock units; some reservoir limestones in North Africa and the Middle East contain foraminifera in such abundance that they are rock-forming and their presence and orientation also influence porosity and permeability.

To be a good stratigrapher it helps to have an interest in the natural world, and in fossils, something I became interested in at school, leading me to study geology at Nottingham University, where we had a module in micropaleontology. I enjoyed it enough to want to study the subject further, and was offered a PhD project at Aberystwyth University on the Lower Jurassic foraminifera from the well-known Mochras Borehole. This was the early 1970s, when the hydrocarbon industry in the UK was just taking off and I hoped this would lead to a career in the oil industry. I have worked in a range of companies, including consultancies like Robertson Research, IEDS and IHS, together with oil companies including BNOC, Britoil and BP. My current role with geoscience consultancy Merlin Energy Resources is both as a stratigrapher and petroleum geologist, working in small teams alongside geoscientists with specializations such as reservoir geology, petrophysics, structural geology and geophysics to provide high quality, integrated evaluations of the subsurface.

Eye for Detail

A micropaleontologist needs good observational skills, a keen eye for accurate identification of often poorly preserved fossils and the ability to recognize an evolutionary succession of species, the basis of biozonation schemes used to subdivide and correlate rock successions and provide evidence of age.

In any basin being newly explored there is the potential for finding something previously unknown to science, which might turn out to be a key marker, so a biostratigrapher is always looking out for new species. However, we work in the commercial world, where the main constraint is always time, and therefore, cost. Although we want to increase our knowledge base, an industry biostratigrapher can only spend a certain amount of time on each sample. Therefore for more complex stratigraphic successions, where additional detailed investigation is justified, industry will sponsor academic research, which has played a major role in the development and understanding of biostratigraphy over many decades.

A stratigrapher should aim to be at the forefront of new knowledge, either by pursuing or sponsoring new research. I carry out this type of research in my personal time, particularly on the Jurassic of the UK, often in collaboration with other researchers.

Biostratigraphers often work at the well site to support operational decisions, such as monitoring the biostratigraphic succession while drilling. With a prior knowledge of the successions in nearby offset wells, it is possible to predict what will be encountered ahead of the drill bit, which aids the setting of casing points and helps with TD decisions. Well site biostratigraphy can also guide horizontal drilling ('biosteering'), whereby knowledge of the expected microfossil assemblages above, within and below a reservoir helps steer the drill bit. It is therefore cost-effective to have a biostratigrapher at the well site as

these techniques can save considerable drilling time and aid safe and successful well completions to be made.

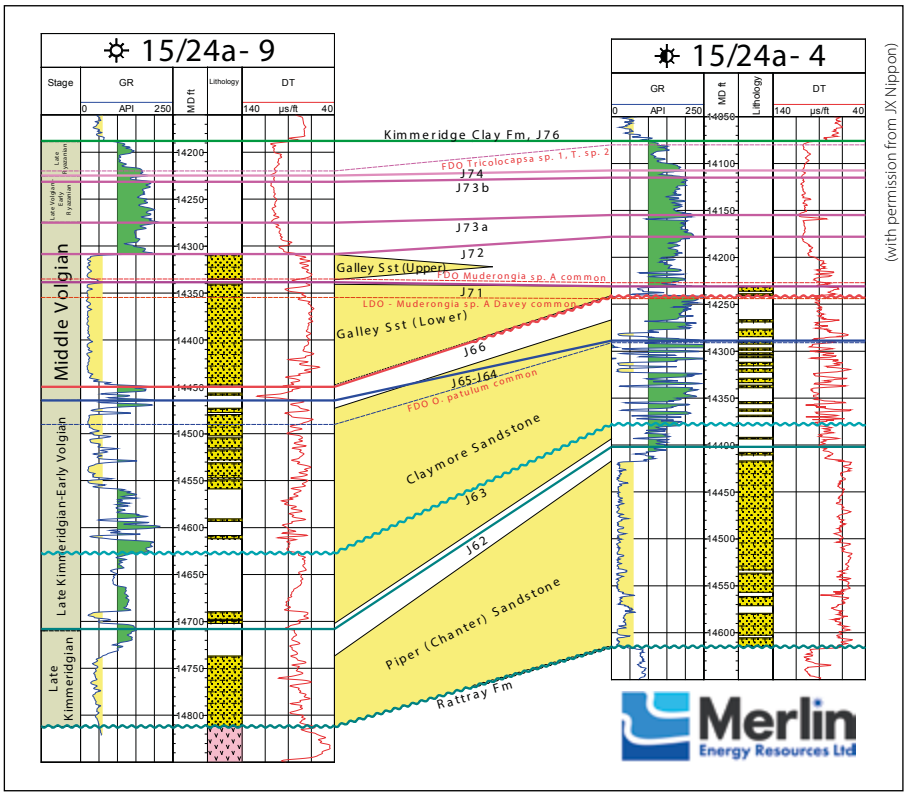
Well Correlations and Legacy Data

Much of a stratigrapher's work, however, is undertaken in an office, where one of the key tasks is correlating 'tops', the upper depth limits of formation and key biostratigraphic markers, between wells. The usual working dataset comprises completion logs and biostratigraphic reports from a number of wells, spanning a range of vintages. Access to modern stratigraphic data is useful, but many interpretations have to be based on legacy data.

If you take the legacy data at face value, it can be difficult to make accurate interpretations and well correlations; apart from anything else, there have been nomenclature changes over the years. In the early days, biostratigraphers were finding many new species and with little comparative information readily available identification of species could be uncertain. Companies developed their own nomenclatures, so species A in one company was species B in another and while this species may now be formally published, those old names still exist in the legacy biostratigraphic reports. The stratigrapher needs to be aware of this in order to understand the legacy data and to provide a consistent set of 'picks' for today's evaluations.

Demonstrating the lateral subsurface relationships between wells by means of well correlations is a fundamental technique used to determine the essential distribution of rock units, including reservoirs, source rocks and sealing formations. Lateral pinch-outs of reservoirs can also be demonstrated, together with intervals of missing section and horizons of major transgression/onlap – key features in sequence stratigraphic analysis.

One of the prime aims of defining stratigraphic tops is to help seismic interpreters determine the stratigraphic identity of key seismic horizons, and it is critically important that the stratigraphic control is consistent across the interpreted dataset. Another key role is in basin modeling, where knowledge of the geological history,



Detailed well correlation from the Outer Moray Firth Basin, UK North Sea. Note the variation in thickness of reservoir sandstones based on biostratigraphy and sequence stratigraphy.

geochronological timescale, breaks in deposition, and timing of major structuration is needed.

Sequence Stratigraphy

I have been fortunate enough in my career to have worked in emerging areas of the science, one of which is sequence stratigraphy. A biostratigrapher is often able to recognize unconformities on the basis of missing biozones and lithostratigraphic units. Early in my career, the realization that unconformities could be identified at the same geological levels from well to well over wide areas in the North Sea basin coincided with publication of research by Exxon describing how sequences could be recognized in seismic datasets from many basins globally. Well-based biostratigraphy is able to identify more sequence breaks than seismic and it is therefore a critical tool in sequence stratigraphic analysis.

Integration is the Key

Stratigraphy is but one, albeit fundamental, tool in the explorationist's toolkit, used as part of a wider spectrum of geoscience applications that combined together provide more robust subsurface evaluations than any single discipline alone. It is this integration that is key to successful exploration, and it is satisfying to see that biostratigraphy is now accepted as a core discipline in hydrocarbon exploitation – unlike early in my career when biostratigraphers had to prove their worth to mainstream E&P teams. The requirement for high resolution stratigraphy is as significant today as ever, both in mature areas where, for example, the exploration for subtle stratigraphic traps requires a detailed knowledge of subsurface stratigraphic relationships, and in frontier regions where the foundation of the subsurface understanding is based on stratigraphy.

I believe micropaleontology will continue to have a major application in the oil and gas industry and in geological science for many years to come. There is so much yet to discover, as more basins are explored in many regions of the world. Looking down a microscope and finding completely new species – that's good fun. But applying that knowledge to find oil and gas – now, that's *really* good fun!

References available online. ■

KEN WHITE

Guyana: ExxonMobil finds oil in controversial waters

One of the most exciting things happening in terms of Latin America exploration right now has been the discovery of oil by ExxonMobil in the deep waters off Guyana. The company's Liza-1 wildcat, located in 1,743m of water, is the first to be drilled in the Stabroek Block. Reaching a total depth of 5,433m, it encountered 90m of high quality oil-bearing sands in an as yet undeclared formation, although the source rock is thought to be Cenomanian Turonian. It is unclear if the well was tested. The company is now working to determine the commercial viability of the discovered resource, as well as evaluating other resource potential on the block. Esso Exploration and Production Guyana Ltd holds 45% interest, Hess Guyana Exploration Ltd 30% and CNOOC Nexen Petroleum Guyana Ltd 25%.

In 2012, the United States Geological Survey ranked Guyana as having the second most attractive under-explored basin in the world, with a potential of 15.2 Bbo.

One potential snag is that neighboring Venezuela has long claimed about two-thirds of Guyana's territory as well as the offshore area where ExxonMobil drilled this well. The Liza-1 discovery is in uncontested waters, but part of the Stabroek block extends into territory claimed by Venezuela. Guyana's new government has attacked a decree by Venezuelan President Nicolas Maduro, which it said seeks to annex Guyanese maritime space in the wake of an oil discovery. The decree creates a theoretical new 'defense' zone offshore that would leave the former British colony with little direct access to the Atlantic. ■


Agencia Brasil

President Nicolas Maduro of Venezuela recently claimed sovereignty over much of Guyana's territorial waters in the Atlantic Ocean, coincidentally shortly after the announcement of the Liza discovery.

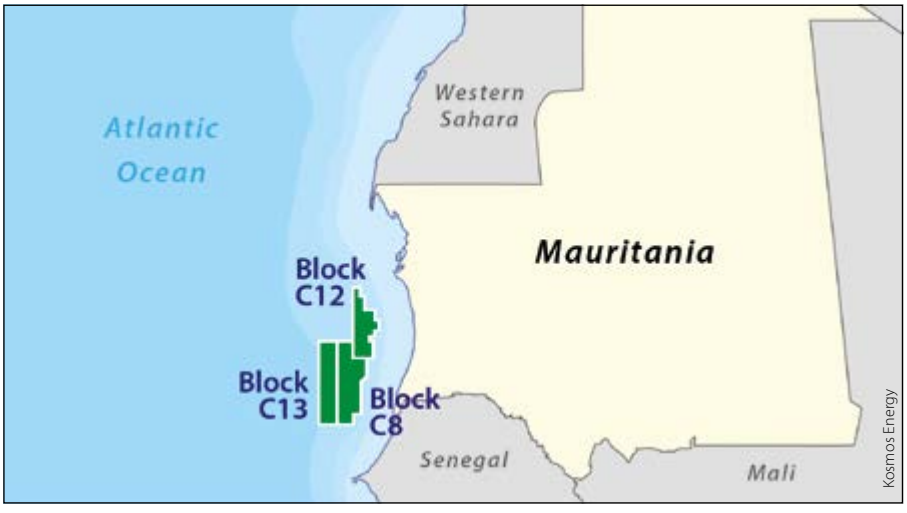
Mauritania: play opening first wildcat for Kosmos

Holding equity in three contiguous offshore blocks located in the Mauritania salt basin, where industry results confirm the presence of a working petroleum system, Kosmos Energy has made what the company describes as a significant and play-opening gas discovery with its first well, Tortue-1 on the Tortue West prospect in Block C8.

Located approximately 285 km south-west of the capital, Nouakchott, in 2,700m of water, Tortue-1 was drilled to a total depth of 5,100m and cost approximately US$ 125 million. The well intersected 107m of net hydrocarbon pay within the primary Lower Cenomanian objective and 10m of net pay in the secondary Lower Albian, both of which are gas-bearing. It was drilled beyond the primary objective to obtain deeper stratigraphic information and enable seismic calibration of the Albian, which will be tested in subsequent wells. Kosmos' interpretation suggests the Tortue West prospect, now renamed Ahmeyin, could extend to around 90 km^2, subject to an appraisal program now in planning.

Ahead of this the company plans a third quarter 2015 spud of the Marsouin-1 wildcat in the central part of Block C8. An exploration program is also being formulated to test the other prospects in the Greater Tortue Complex, which extends into the St. Louis Offshore Profond Block in Senegal, including the Tortue East and Tortue North prospects.

In a company webcast Kosmos indicated a resource base for this deepwater discovery of 5–12 Tcf, with a mean of 8 Tcf. If confirmed by the appraisal program, this would place the discovery as one of West Africa's largest, if not the largest, gas discovery. The Greater Tortue complex has a potential resource base of 6–22 Tcf. ■



Colombia: Anadarko unlocking ultra-deepwater potential

The partnership of Anadarko (operator) and Ecopetrol have made a gas discovery in the ultra-deepwaters of the south Caribbean area off Colombia, which they stated proves their geological model in this unexplored area. Located 53 km offshore in the Fuerte Sur block, the Kronos-1 discovery lies in 1,584m of water. Drilling encountered net gas pay of between 40 and 70m at a depth of 3,720m and will continue to a deeper and as yet unspecified target to determine additional reserves.

According to Ecopetrol president Juan Carlos Echeverry, this result and the earlier (December 2014) Orca-1 well located in the deep waters offshore Guajira, "are very important and confirm the potential of the Colombian Caribbean petroleum system in a vast area." He added that one of the key areas in the company's new strategy, despite the low oil price environment, is the exploration of high potential marine basins. On completion of operations the drillship *Bolette Dolphin* will be retained to drill the Calasu 1 well some 145 km north-east in the Fuerte Norte Block. The Calasu prospect is a large four-way structure on the north end of the block complex with multiple potential targets. Success at either well would de-risk multiple identified prospects over both tracts. Ecopetrol plans to invest around US$ 200 million in 2015 in offshore exploration.

The Caribbean region holds an estimated 126 Bbol and 679 Tcf of undiscovered natural gas in 31 geologic provinces, according to a 2012 report by the US Geological Survey. With very few exceptions, most Caribbean countries have yet to prove the extent of their offshore hydrocarbon reserves, let alone produce them. ■

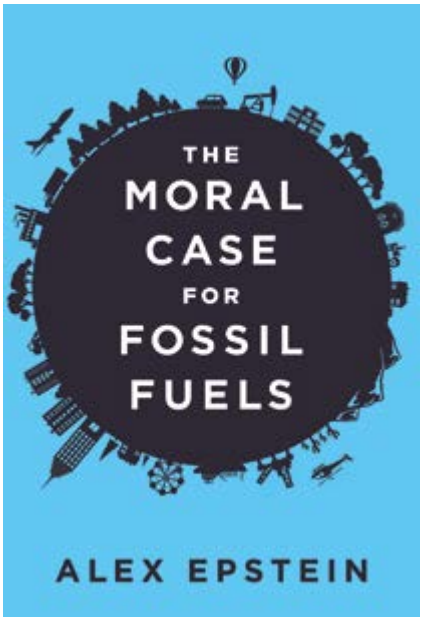
The Bolette Dolphin drilling in Colombia waters.

The Morality of a Zealot

NIKKI JONES

The Moral Case for Fossil Fuels *Alex Epstein: Penguin, 2014*

On the broad spectrum of views on environmentalism, Alex Epstein would undoubtedly put himself at the very far extreme. Not only do we all owe a very big thank you to the fossil fuel industries but we should, for the good of humanity, be consuming more of the stuff. 'There is no limit to how much cleaner and safer fossil fuel use can be'; we are becoming 'masters of climate' and our way of life will only improve if we do not succumb to 'pernicious sustainability' policies. 'If you love enjoying nature, you should love fossil fuels,' he says.



Buying Time

Let's start with some positives about this book. Maybe it is true that the public in the 'developed world' does not fully understand – or appreciate – how much of their comfort, safety and personal freedom comes from fossil fuels. As Epstein argues (borrowing from Ridley's *The Rational Optimist*), the energy packed into each tonne of hydrocarbons has bought us, as individuals, time; the 'irreplaceable and unrepeatable' resource 'to guard jealously'.

But Epstein is a zealot, refusing to acknowledge any costs or potential risks. However open you are to his optimistic message, the book can't be read without a feeling of being manipulated. It is a religious tract that studiously ignores and misrepresents inconvenient facts, in exactly the same way that he asserts environmentalists do.

Global North Perspective

Epstein's arguments seem to be based on a few disconcerting premises. Although he pays lip-service to development issues, it is written from an absolute Global North perspective. He repeatedly asserts that fossil fuels are 'cheap, plentiful and reliable'; not if you live in one of the world's poorer countries, struggling to obtain dollars to buy oil or refined products. The IMF estimates that beyond the cost of the fossil fuels themselves, poorer countries spend $480 billion subsidizing fuel, a massive weight on their economies. To be part of the modern world is to be 'hooked' on fossil fuels, leading to perpetual trade imbalances and debt. This is true for both net energy-importing developed countries and the less developed. The deficit – and accruing debt – are simply better masked.

Epstein's rich country perspective is amplified with comments such as 'Of course, there are places such as China that have high levels of smog', and 'human beings have generally thrived the warmer it has been'. His answer to increased temperatures is air conditioning; to rising sea levels, more sea defences; for other natural disasters we can just move. These answers don't make sense if you are outside the world's economic elite.

The 'cheap and plentiful' argument also ignores the 'externalities' that governments and individuals find themselves paying – pollution, congestion, poor health, corruption, inequalities. Epstein describes vividly the environmental disaster brought about in Batou, Mongolia, from the mining of rare earths, implying they are used only in wind farms, though these elements also go into GPS, cell phones and electric cars . This is, indeed, an issue that environmentalists should be more aware of – but the refusal to intelligently discuss pollution associated with fossil fuel usage undermines his argument. Without a tax that adequately captures the 'externalities', it is almost impossible to compare the true costs of the energy resources we use.

Epstein's argument is based on the premise that we haven't done much damage so far, so what's the problem? He describes 'the very mild warming trend overall – less than 1°C over a century' as 'unremarkable'. 'In terms of the global climate system,' he asserts, 'scientists have not identified any significant impact'. Given this (highly contestable) analysis, he argues that we should ramp up consumption to industrialized-nation level world-wide, seemingly disregarding the real scientific position that there is much that we don't know; the scientific argument is simply for the precautionary principle.

Missed Opportunity

Epstein implies that environmentalists are anti-development. He ignores the issue of the future affordability of fossil fuels, and does not consider the arguments of energy sovereignty or reduced reliance on global fuel markets that come with renewables. In fact, green economists argue that less developed countries should not be denied the advantages of the industrialized countries: the issues are about cutting waste and over-consumption in the Global North, while helping developing economies get access to energy to boost their independence and growth.

Fundamentally, Epstein's argument contains all the errors he lays at the door of 'greens' – a lack of rigor, an extrapolation of the past to presume the future, and an unwillingness to allow for inconvenient truths. I doubt that this highly unbalanced, low-on-analysis tract has done the fossil fuel industries any favors. It feels like a missed opportunity to really focus on how we equalize the benefits of energy and industrialization across the world.

References available online ■

UNDER THE PATRONAGE OF
HIS HIGHNESS SHEIKH TAMIM BIN HAMAD AL THANI, THE EMIR OF THE STATE OF QATAR

IPTC
International Petroleum Technology Conference

Conference: 6–9 December 2015
Exhibition: 7–9 December 2015

Qatar National Convention Centre
Doha, Qatar

Technology and Partnerships for a Sustainable Energy Future

REGISTER TODAY
TO ATTEND THE 9TH IPTC

- **Multi-Disciplinary Conference Programme** featuring 2 CEO Plenary Sessions, 5 Panel Sessions and 62 Technical Sessions with 350 Papers
- ***NEW FEATURES AT IPTC 2015:*** 'Ask The Expert' Sessions, Society Presidents Session, Project Case Study and the Top Rated Papers from **AAPG, EAGE, SEG and SPE**
- **Knowledge Sharing and Networking Opportunities** including the IPTC Excellence in Project Integration Award Ceremony, Project Finalist Sessions, Training Courses, Non-Technical Seminars, Field Trip, Education Activities for students and teachers and more
- **Over 5,000 attendees expected at the 5,000 sqm free-to-attend Exhibition** showcasing the latest technologies, new product launches and valuable industry services

Official Airline

QATAR AIRWAYS القطرية

25% OFF
YOUR FLIGHT TO IPTC

www.iptcnet.org/go/2015

Host Organisation: Qatar Petroleum قطر للبترول

Co-Host Organisation: Shell

Sponsoring Societies: AAPG; EAGE European Association of Geoscientists & Engineers; SEG Society of Exploration Geophysicists; SPE Society of Petroleum Engineers

Principal Sponsors: ConocoPhillips Qatar; ExxonMobil; Maersk Oil; OXY; RasGas راس غاز; saudi aramco أرامكو السعودية; Total Committed to Better Energy

Putting Science into Policy

The American Association of Petroleum Geologists (AAPG) set up the Geoscience and Energy Policy Office in Washington, D.C. in 2005. Edith Allison, Director of the Office since 2012, explains its role.

Why did the AAPG feel it needed a presence in Washington?
AAPG members were concerned that decisions were being made in Washington that were not well grounded in science, so the AAPG set up the office, offering the expertise of members to help inform the legislators. Our focus is threefold: to advise and educate government officials and science and energy policy organizations; to communicate to AAPG members timely information on relevant legislative and regulatory actions; and to create opportunities for AAPG members to get involved and deliver their expertise directly in the policy making process.

Edith Allison has bachelor's and master's degrees in geology and worked in industry for many years as an exploration and development geologist in the Mid-Continent and Permian basins. She also worked for the U.S. Department of Energy for over 20 years, initially conducting reservoir characterization research and later managing unconventional oil and gas research programs.

How did the legislators react?
They are very appreciative of our input. Congressional staff in particular desperately need reliable information to help them prepare material for the elected representatives. I realized we were definitely making progress when staff members started approaching us for science input to help them prepare better legislation, or for an expert to talk to on a particular subject. It's often at short notice, so we have to be able to react fast.

What are your day-to-day activities?
They are two-fold; I communicate what is happening in Washington to the AAPG membership, as well as pass information to the representatives. We need to know the right people to talk to on relevant matters 'on the Hill' and my colleague Colleen undertakes that role, while I keep track of the current issues and liaise with the AAPG members and experts. The office is small – there are just the two of us – but we often work with the American Geosciences Institute policy staff, who are in the same building.

What experience and skills do you think are needed in this role?
Scientific knowledge is key but it is also important to know what AAPG members are working on. I have been active in the industry in a number of roles and also on committees in the AAPG, so I can use this knowledge within my position. It is useful to understand how Washington, D.C. works, so it helps that I previously worked in the executive branch of the federal government, in the Department of Energy. I was initially doing research, but ended up moving to Washington, where I found myself explaining to Congress, on behalf of the Department, the scientific aspects of budgets and laws; more an educator than a lobbyist.

What do you consider one of the Policy Office's major achievements?
We realized that Congress and staff members didn't really understand the basic concepts of subsurface geology, so in 2014 we coordinated with other geoscience societies to set up a series of briefings entitled 'Energy from the Earth'. These have been met with enthusiasm.

How do you think the average Congressman or woman views the hydrocarbon industry?
Well, they represent their districts, so they need to know what is relevant and important to their local area and electorate. With the rise of 'unconventionals', the hydrocarbon industry is more geographically spread than it was, so more representatives are knowledgeable. Republicans are almost universally favorable towards the industry while Democrats tend to be less supportive, but it really depends where they live.

What one important change would you like to see as a result of this role?
I would like to see a Congress less polarized in its views – although I have to admit that this polarization is probably a good reflection of the opinions of the population as a whole. ■

Sarawak Discoveries Boost Malaysia

DAVID UPTON

Malaysia's bid to turnaround the decline in its ageing petroleum reserves has exceeded expectations thanks to a series of major discoveries offshore Sarawak.

Malaysia has long been a heavy hitter in the petroleum industry, based on world-scale developments such as the Bintulu LNG complex in Sarawak. While it still had abundant oil reserves of about 4 Bbo as of January 2014, the fourth-largest in South East Asia, the long-term future of the country's petroleum sector demanded new gas discoveries to replace produced reserves.

Back in 2010, the government launched a determined bid to address the problem by introducing new fiscal incentives to encourage exploration and development in deepwater and marginal fields. In more recent times it has also been aggressive in response to the downturn in oil prices, with further tax concessions.

The resultant new wave of exploration has made Malaysia a star performer in South East Asia in terms of resource growth, accounting for 71% of the region's discovered resource in 2014, according to Wood Mackenzie. The consulting firm expects Malaysia, and Sarawak in particular, to remain an exploration hot spot, with SapuraKencana Energy (SKE), Shell and Petronas all drilling prospects this year. Petronas is also a major driver of elevated activity in the country's petroleum sector, despite the price-led slowdown worldwide. The state-owned company is pressing on with a number of major projects, including floating LNG and a ninth train at the massive Bintulu, Sarawak complex that will lift capacity to 25.7 million tonnes of LNG per annum.

Impressive Discoveries

Exploration success has been broad-based, with discoveries made by supermajors such as Shell and ExxonMobil and independents SKE of Malaysia and US company Newfield Exploration. The most impressive discoveries of 2014 were made by the SKE joint venture in the SK 408 block in shallow waters, about 120 km offshore Sarawak in the Central Luconia Gas Province. In fact, the joint venture partners of SKE with 40%, operator Petronas with 30% and Shell with 30%, had a 100% success rate with a five-well campaign last year. The final well in the campaign, Bakong-1, encountered a gas column of more than 600m in the primary target reservoir within the late Miocene carbonates. The previous four wells also discovered gas within the same Late Miocene Carbonate reservoirs. The five discoveries to date have found in excess of 3 Tcf of gas in-place. The JV plans another five-well campaign, targeting additional significant potential.

Shell made two other gas discoveries offshore Sarawak in its own right in 2014, with the success of Majoram-1 and Rosmari-1 in the deepwater block SK318. The block represented a new play for Shell, which has operated in Sarawak for decades. Rosmari-1 encountered a gas column of more than 450m and followed three other discoveries by Shell in its core areas.

In other discoveries, the Bestari-1 exploration well, drilled in April 2015, made a significant oil discovery in Malaysia's deepwater Block R, offshore Sarawak, intersecting 67m of net oil pay in multiple sand packages within the primary Miocene target.

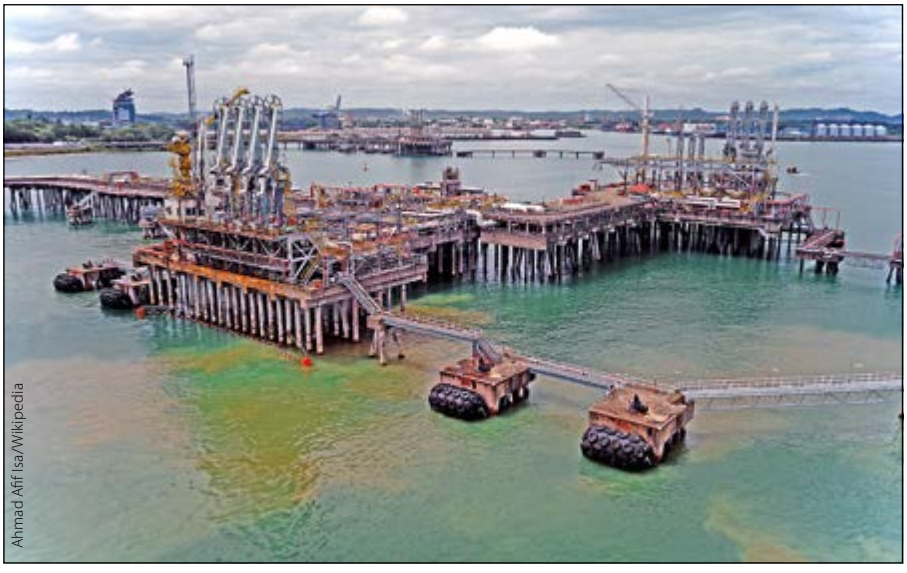
String of Successes

The string of recent successes began in 2013 with one of the biggest petroleum discoveries of the year worldwide – the B-14 well in SK310 block, 80 km off Sarawak in shallow water. Operator of the block, Newfield Exploration, announced it had encountered 480m of net gas pay and estimated gas-in-place of between 1.5 and 3.0 TcF. Newfield subsequently sold the block along with the rest of its Malaysian petroleum assets to SKE in February 2014. The B-14 discovery was made in a pinnacle carbonate reef, and was the second of its kind in SK310. This was followed in late 2013 with the discovery of a 292m gas column at the Sintok-1 well in SK320, operated by Mubadala Petroleum.

The new discoveries will add to Malaysia's production growth, which has begun a resurgence with the recent commissioning of new projects such as Bentara (oil), Phase 1 of the Kumang Cluster Development Phase 1 and the Shell-operated Gumusut-Kakap deepwater oil project.

See GEO ExPro Vol. 9, No. 4 for further information about the geology of Sarawak. ■

Marine loading arms at Bintulu LNG port, Sarawak, Malaysia.



Ahmad Afif Isa/Wikipedia

Freedom to imagine.

Geometric Freedom™ lets you focus strictly on your ultimate goals, obtaining the highest quality data despite any geological or operational challenge.

Nodal technology illuminates subsurface mysteries like never before. No one knows that better than we do. We pioneered the technology and have more experience with it, by far, than anyone else around. Our nodal systems, acquisition, proprietary nodal processing techniques and licensing expertise come together to solve the world's most daunting seismic challenges. What can we do for you?

Visit us at EAGE Madrid, booth numbers 760 and 630.

fairfieldnodal.com

fairfieldnodal

Oil and Gas are Here to Stay

We can expect a dramatic increase in *new* renewable energy by 2040. Nevertheless, both oil and gas production, along with coal, will also increase over the next 20–25 years.

Statoil presents three different scenarios in its recent *Energy Perspectives 2015*, all of which forecast a dramatic increase in the use of *new* renewable energy sources (not including hydro, biomass and waste) up to 2040. BP in its *BP Energy Outlook 2035* does the same, predicting that in 20 years, renewables will constitute 24 MMboepd (compared to 7 in 2015). For decades ahead wind and solar energy are expected to account for 7% of the primary energy generated.

Today, however, "the world's rivers and waterfalls remain the biggest renewable source of electricity generation by a wide margin", according to Statoil. Even more important, we must remember that 82% of the energy used today comes from fossil fuels; only 1% comes from wind and solar.

The three cases presented by Statoil reflect different scenarios for how the world will develop over the next 25 years.

Reform is a scenario where the countries meet their self-imposed commitments and energy-policy ambitions. This scenario is based on a significant improvement in energy efficiency.

Renewal describes a combination of major changes that are necessary to meet the so-called '2-degree target' in 2040. This scenario requires a dramatic change towards 'a sustainable energy system', where global CO_2 emissions have reduced by 39% from 2012 and are still declining.

Rivalry describes a world dominated by conflicts, power struggles and inability to resolve common challenges, resulting in the highest consumption of coal and the least growth in renewable energy.

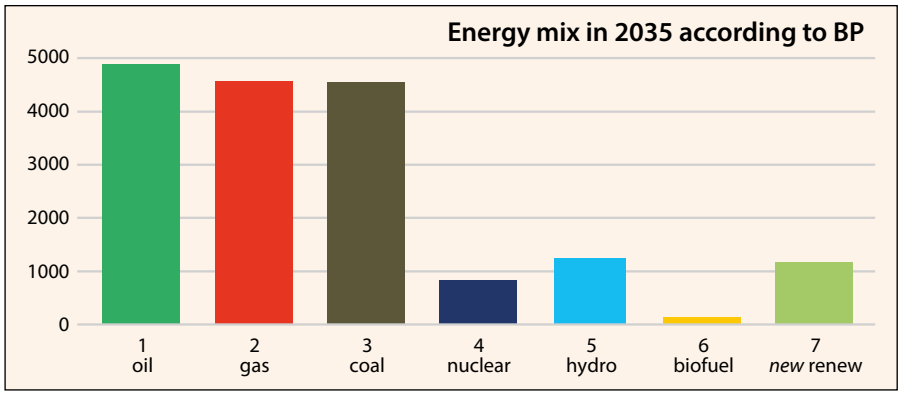
In the reform scenario – which seems to be closest to 'business as usual' – renewables will increase by almost 8% each year, resulting in an energy mix with 7% solar and wind, compared to today's 1%. Water constitutes 2% in this view. In the renewal scenario, solar and wind could constitute as much as 11% in 25 years, and in the rivalry scenario, renewables will also play a key role with 6% of the energy mix. New renewables have definitely come to stay.

The energy forecast from the Norwegian company points out that the use of new renewable energy will change the energy mix considerably. However, by looking at the statistics it is also clear that there will be – in absolute numbers – a continuous increase in the production of oil, gas and coal towards 2040.

BP agrees with this, and its prediction is that oil output will increase from 85 to 98 MMbopd, gas from 65 to 92 MMboepd and coal from 78 to 92 MMboepd, meaning that there is a "considerable need for new investments, irrespective of scenario", according to Statoil.

The oil age is here to stay. ■

Halfdan Carstens



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.

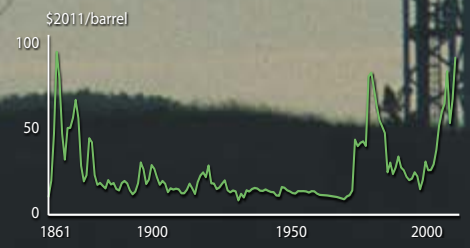
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

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



Earth.
Covered.

The world's largest 2D seismic library

Spectrum now holds the world's largest library of Multi-Client 2D seismic data and a significant collection of 3D surveys. This data covers all of the world's major sedimentary basins.
But size isn't everything...

With access to this vast collection of seismic, Spectrum's team of Geoscientists are examining the data to identify exciting reprocessing projects and developing new seismic acquisition opportunities to further enhance our library.

Follow us:
SpectrumGeo

Spectrum
spectrum**geo**.com/**mc**

XARRAY™

Controlled Soundfield Sampling

Better Cross-Line sampling

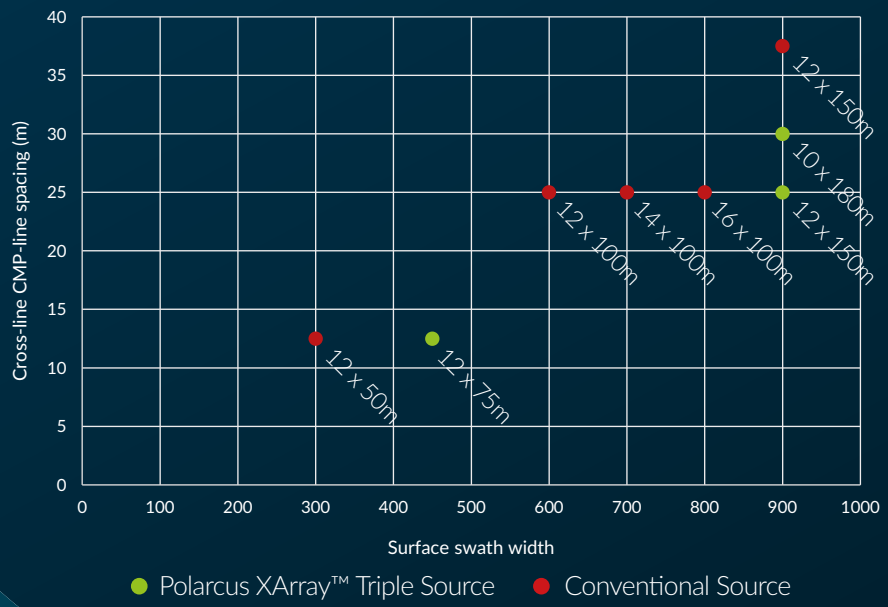
By using multiple sources to increase cross-line sampling density for any selected streamer separation.

Improved In-Line sampling

By acquiring overlapping shot interval data that can be de-blended in processing to produce clean shot records of any desired record length.

Significantly improved productivity

XArray™ paired with larger streamer separations saves our clients both time and money without compromising seismic data quality.



In 2015 Polarcus demonstrated the operationally viability of using multiple sources to increase cross-line sampling density for any selected streamer separation. Coupled with that infield operational uplift, Polarcus has also demonstrated on a separate project the feasibility of acquiring overlapping 12.5m shot interval data that can be de-blended in processing to produce clean shot records of any desired record length. Combining these two initiatives presents an opportunity to take full advantage of the operational productivity of large streamer spreads without compromising the geophysical integrity of the acquired data.

Imaging tomorrow's energy™

www.polarcus.com/xarray