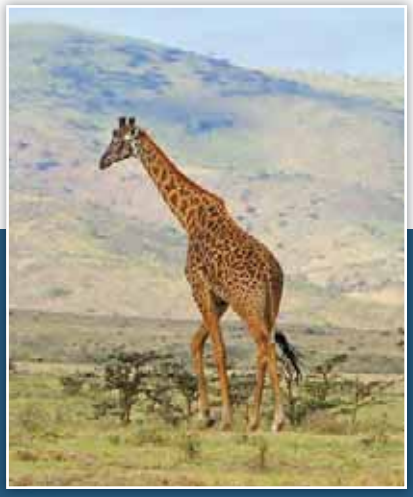
VOL. 8, NO. 4 – 2011

# GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED



GeoTourism: Ngorongoro

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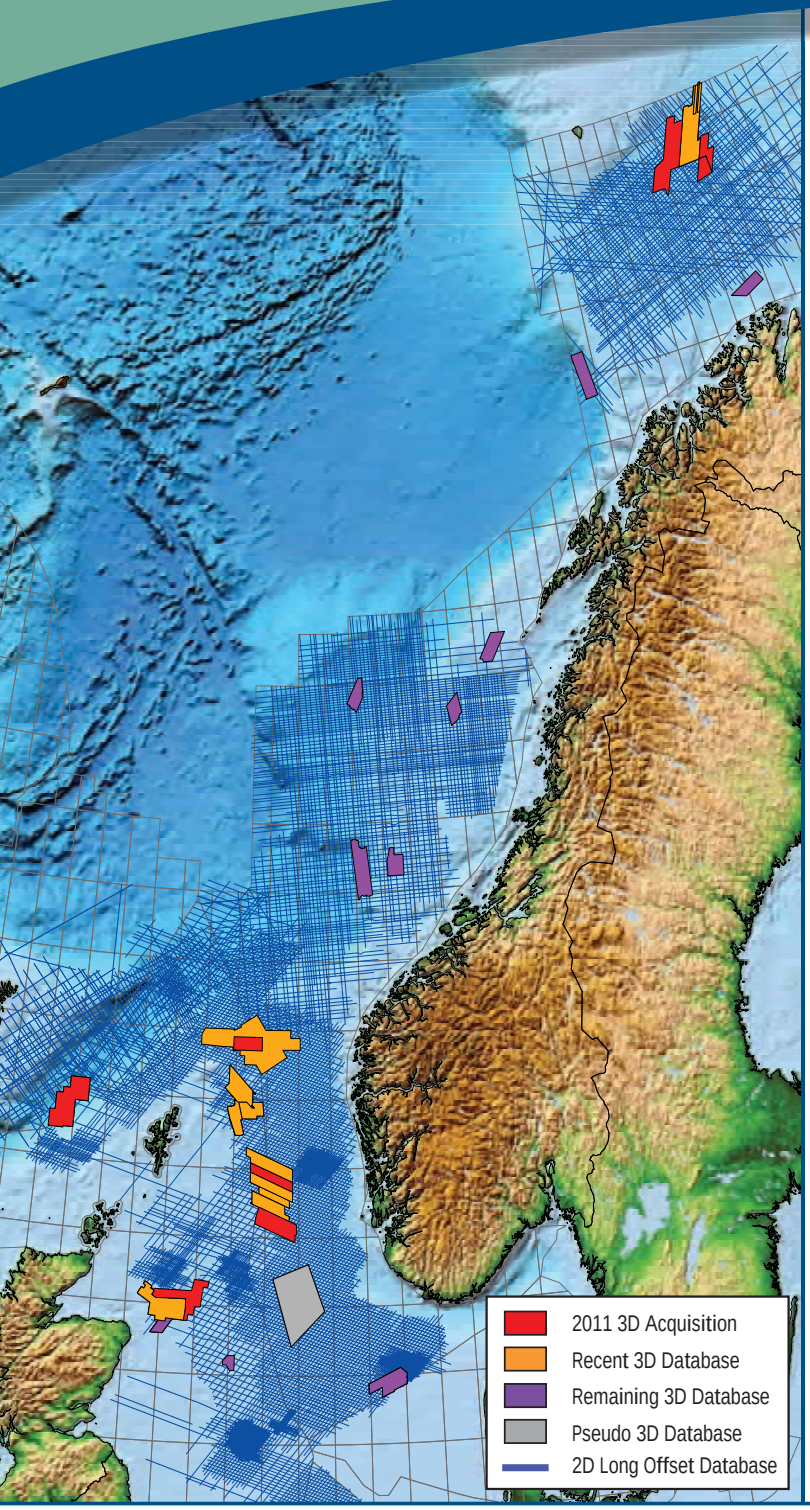
## EXPLORATION
## The East African Rift System – A View from Space

## TECHNOLOGY
## Beyond Macondo

## GEOPHYSICS
## Has the Era of Cableless Seismic Surveys Arrived?

GEOLOGY GEOPHYSICS RESERVOIR MANAGEMENT

# Searching for Modern 3D Data?

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  - Multi-client PSTM and PSDM volumes available
  - In partnership with PGS
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  - Acquired using GeoStreamer® technology
  - Stradles UK/Norwegian border
  - Highly prospective province of the North Sea
  - In partnership with PGS
- Moray Firth (MF10 and MF11)
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# CONTENTS

**This edition of GEO ExPro Magazine focuses on Africa, Geophysics and New Technologies**

## COLUMNS




*Iceland is known for hot springs and volcanoes, but its deep water may hold surprises.*


*'Juggies' laying cables for a land geophysical survey – but is the age of seismic upon us?*

## FEATURES

# Petrel 2011

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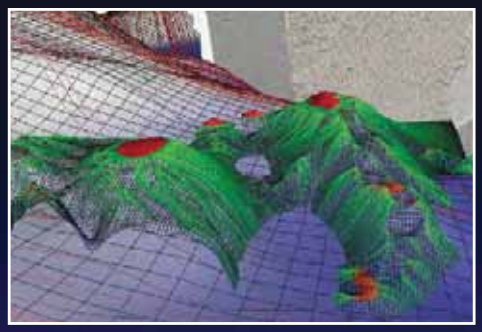

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# Learning from the Past?

As this edition of GEO ExPro Magazine bears out, some of the most exciting areas in the oil and gas industry at the moment are in Africa; and not the traditionally 'oily' places, like the Niger Delta, equatorial West Africa or the Libyan Desert, but previously disregarded regions like the West African Transform Margin, presalt Angola and the East African Rift Valley – the latter featuring on our dramatic front cover. Since the discovery of the Jubilee Field in 2007 in the relatively unexplored deep waters off Ghana, estimates of the resources held by that country and its neighbours in the Gulf of Guinea have increased several fold to over 11 Bboe.

So what will the discovery of such riches mean to the impoverished people of Western Africa, many of whom still live on less than a dollar a day? In oil rich Nigeria, it is estimated that 80% of revenues from oil and gas benefit a mere 1% of the population. And in Luanda, the capitol of Angola, a country which exports over a million barrels of oil a day, 90% of residents do not have running water. Millions of dollars of oil revenues earmarked for infrastructure, schools and healthcare in many countries appear to end up in the pockets of private individuals. Why is it that resource rich economies seem unable to transform this natural good fortune into savings that will benefit all their people? And can we as an industry do anything about it?


*Installation of the Kwame Nkrumah FPSO on the Jubilee Field in Ghana in 2010*

Recently, Nigeria has been looking to restructure its oil industry through an Oil Reform Bill in an effort to enforce sustainability, transparency and greater control over resources, but both external and internal pressure make it unlikely that it will be effectively implemented, or even passed. The Extractive Industries Transparency Initiative (EITI) was formed in 2002 with the aim of setting a global standard for transparency in oil, gas and mining through the coalition of governments, companies and civil society – an effort to make natural resources benefit all and a standard for companies to publish what they pay and for governments to disclose what they receive. Many oil companies and at least 35 resource rich countries throughout the world have signed up to this, which must be a step in the right direction.

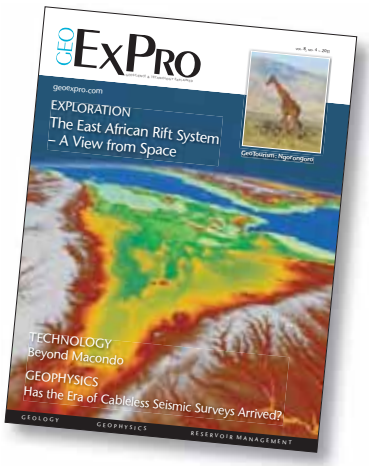
Will African countries newly emerging into the family of oil producing nations learn from their predecessors and allow the discovery of oil be a catalyst for sustainable development and growth? We must hope so – but only time will tell.

**JANE WHALEY**
**Editor in Chief**

## EAST AFRICA FROM SPACE

Perspective view of the Afar Depression, located at the northern limit of the East African Rift System, generated from the 90m resolution Shuttle Radar Topography Mission (SRTM) elevation model. Pale green colours represent low elevation areas, with white representing high elevation areas. Remote sensing is increasingly being used by new ventures teams in oil companies to aid geological understanding and to help efficiently target hydrocarbon exploration.

*Inset:* The Ngorongoro Conservation Area in Tanzania is steeped in both geological and anthropological history, as well as being a haven for wildlife



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# Open Source Technology Proves the Way

The seismic interpretation solutions company dGB Earth Sciences has experienced exponential growth since 2009, and the company puts its success down to a single decision – moving to an open source technology platform.

"Having spent nearly ten years developing our niche interpretation product, d-Tect, we were finding it difficult to commercialise it to the market," explains Paul de Groot, co-founder and President of the Netherlands-based company. "The software, which uses attributes and modern visualization techniques to aid interpretation of multi-volume seismic data, was proving very popular, but customers wanted more freedom to generate cubes and interpret the data their own way, to fit in with their systems and methodologies."

"In 2003 we re-engineered the package to make the basic module open source, so users could develop their own plug-ins to work with it, but this still did not give our customers the flexibility they wanted. So in 2009 we made the major decision to go completely open-source."

The company adopted a completely public 'copy left' licence – the model used so successfully by Linux, among others. This means that anyone using the software has access to all the underlying code, and can freely do what they like with it, adding bits on or making plug-ins, but anything they produce must also be open source. The software, renamed OpendTect, is freely available and downloadable from the dGB website.

"Since 2009 over 61,000 copies have been downloaded," says Paul. "Our clients vary from individual consultants needing help with a single project, to major oil and gas companies running multiple projects. Many students also download it to help with projects, and once they have been exposed to the software, for free, at that stage in their careers, they often come back to it in their professional lives."

"There is also some idealism behind this idea," he adds. "Students need software and data, so we have developed the 'Open Seismic Repository' which has datasets from the public domain, plus some government and research agencies, ready loaded into OpendTect. The user can download this data, plus the interpretations, which can be used as an education tool."

Since the software is free, the profit to the company lies in the many supplementary products and services which are offered. OpendTect is a complete, standalone interpretation package that supports a wide range of functionalities for analysing, visualising and interpreting G&G data. The open-source software is complemented by a line of revenue generating 'plug-ins' to undertake additional tasks such as sequence stratigraphy, fluid migration, rock property predictions and velocity modelling. The company also offers consultancy and training services.

"We are the first to do this in our industry. By going open source our whole business picked up dramatically," Paul explains. "To develop good software you need a wide user base for feedback, to ensure that your product is fulfilling the needs of your clients. This feedback and funds from the industry drive our product development. Being open source creates an environment of collaboration and transparency, sharing ideas for the benefit of the whole community."

**JANE WHALEY**

*Paul de Groot (left) is President and co-founder of dGB, and Kristofer Tingdahl (right), CEO, is a software specialist. They attribute the company's recent growth to moving the core software to an open source platform.*

## ABBREVIATIONS

**Numbers**
(U.S. 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

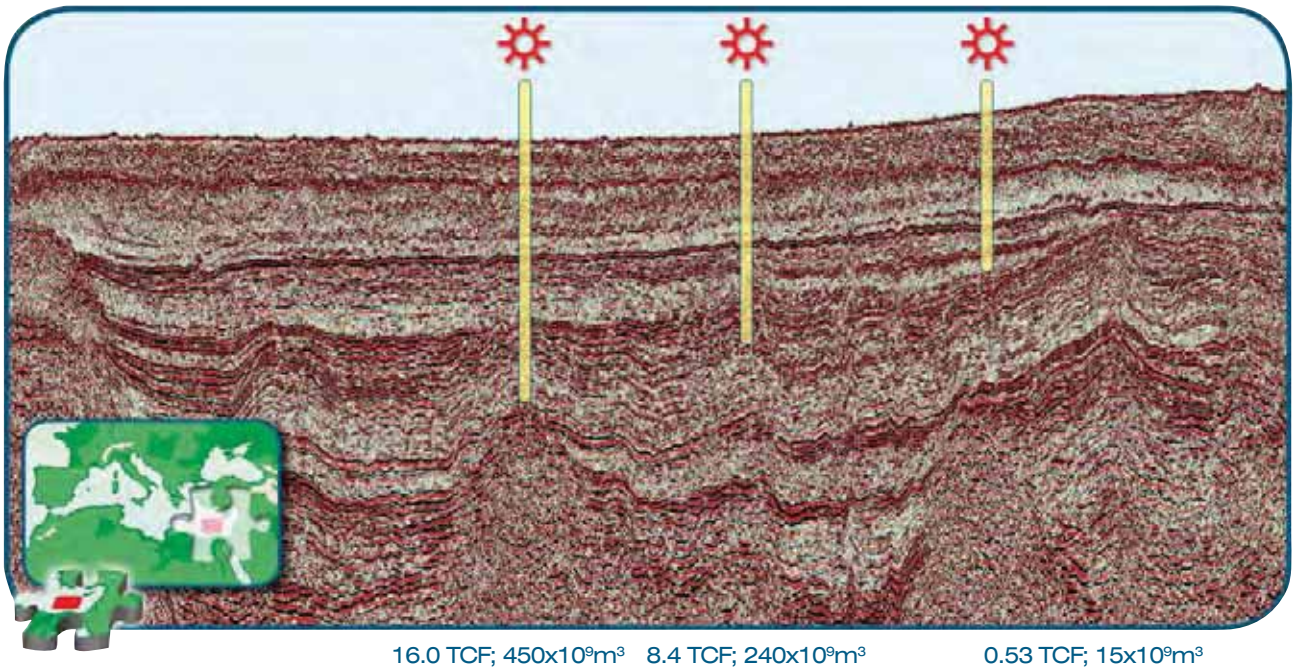
**P2 reserves:**
Quantity of hydrocarbons believed recoverable with a 50% probability

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

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

# Solved: The exploration puzzle in the East Mediterranean...

## ...three world class gas discoveries.



16.0 TCF; 450x10$^9$m$^3$ 8.4 TCF; 240x10$^9$m$^3$ 0.53 TCF; 15x10$^9$m$^3$

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# China Ready to Exploit Shale Gas

## China holds first auction of shale gas blocks

The U.S. Energy Information Administration recently announced that it estimates that China holds 1,275 Tcf (36 Tcm) of technically recoverable shale gas reserves, the largest in the world (see GEO ExPro Magazine Vol. 8, No.3). In a move to start to exploit these riches China's Ministry of Land and Resources held its first shale gas block auction in late June, covering four blocks and an area of 11,000 km$^2$ in south-western Guizhou province and Chongqing city. A number of companies were invited to participate in the auction, including PetroChina, CPCC, CNOOC, Shaanxi Yanchang Petroleum Group, China United Coal Bed Methane Co. and Henan Provincial Coal Seam Gas Development and Utilization Co.

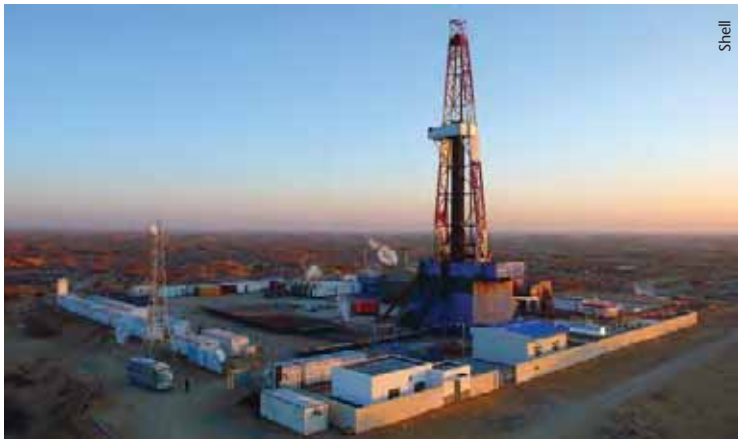
Overseas explorers are barred from bidding in Chinese auctions for shale areas, but a number of the major international companies are working closely with the Chinese. Shell, for example, is collaborating with China National Petroleum Corporation (CNPC) and PetroChina, not only within China but also globally, while Norway's Statoil ASA is in negotiations to buy stakes in shale-gas assets in China, and China Petrochemical Corp. recently agreed with Exxon Mobil to jointly assess shale gas potential in the south-western province of Sichuan.

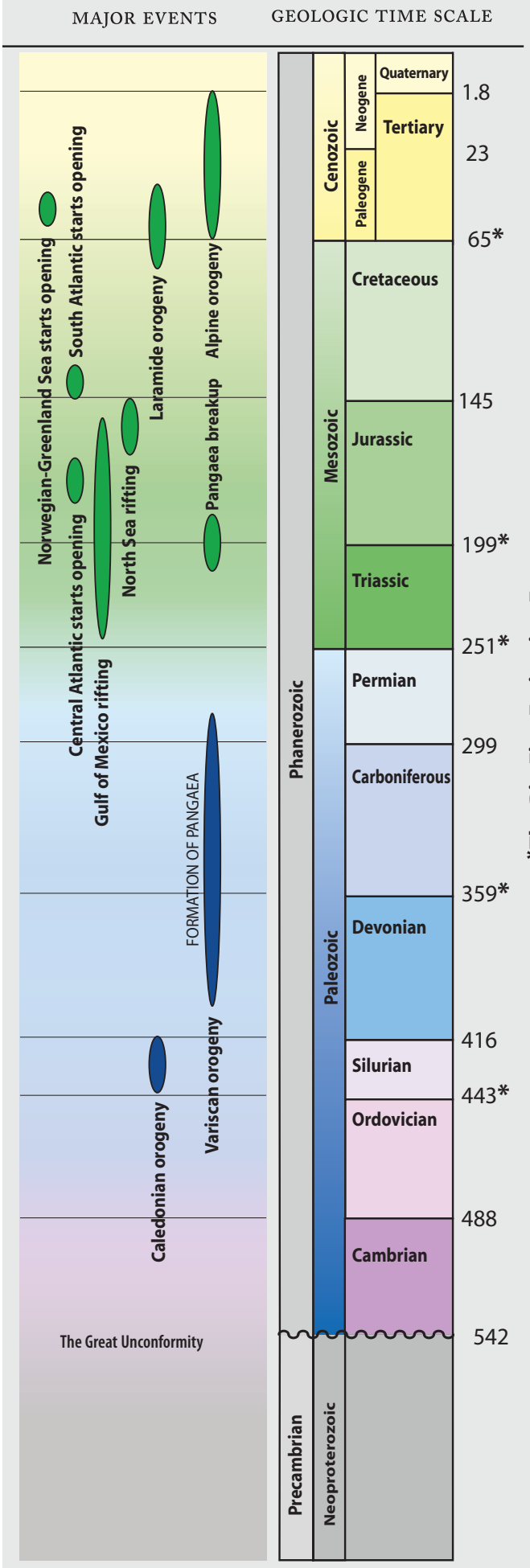
Earlier in the year, CNPC had announced that it had successfully drilled China's first shale gas horizontal well at Weiyuan, in Sichuan province. Although production from this well is minor, at about 353 Mcf (10 Mcm), the pilot project was deemed a success because it proved the effectiveness of drilling equipment, with the final thousand metres of the well being bored in just 34 days.

The Chinese Ministry of Land and Resources calculates the size of shale gas reserves at 918 Tcfg (26 Tcm) – more than 10 times the country's known holdings of conventional natural gas, and expect to offer further shale gas blocks later in the year. However, it is thought that it may prove less easy to exploit these reserves than those of the United States, since the mainland Chinese geology is older, contains less shale gas per volume of rock and it will require increased technology to access and extract the gas. In addition, large quantities of water are required for the fraccing process, a vital part of the exploitation of shale gas. While this poses little problem in the US, it is a greater issue in drought-prone China, particularly since one of the most promising regions for shale gas accumulation, the Turpan Basin in Xinjiang, is a desert.

**JANE WHALEY**

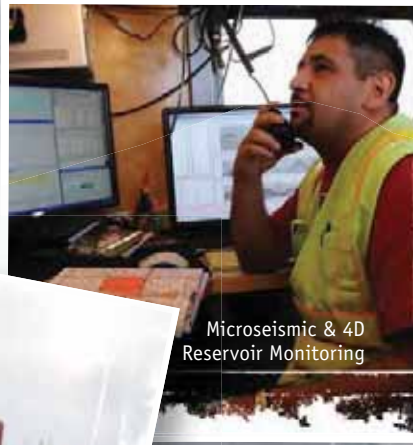
*Shell is working with PetroChina at the Changbei Natural gas field in northern China.*



# COMPLEXITY SIMPLIFIED





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# Mr. 4D – Distinguished with a Gold Medal

**Martin Landrø**, renowned petroleum geophysicist, in June received the highly prestigious Eni award in the *New Frontiers of Hydrocarbons* category. This is probably the closest one can get to the Nobel Prize.


*Professor Martin Landrø receives the gold medal from Italian President Giorgio Napolitano in the Quirinal Palace in Rome.*

In June, Professor Martin Landrø of the Norwegian University of Science and Technology (NTNU), Trondheim, was presented with the Eni award at a formal ceremony in the famous Quirinal Palace in Rome. This exceptional building has housed thirty popes, four kings and eleven presidents of the Italian Republic, and is now the official residence of the President of Italy.

The prize, a gold medal weighing 330 grams, and a cheque for 150,000, was handed over to Landrø by no less than the current Italian President, Giorgio Napolitano.

Landrø received the *New Frontiers of Hydrocarbons Prize*. This is one of five award categories which also include the *Renewable and Non-conventional Energy* Prize, the *Environment Protection* Prize, the *Debut in Research* Prize and the *Eni Innovation Award*. The purpose of the *New Frontiers of Hydrocarbons Prize* is to promote research on the technologies regarding the complete cycle of hydrocarbons (exploration, production, transport, distribution and transformation), meaning that the competitors are to be found among researchers along the entire value chain.

"This is probably the most prestigious award that a geophysicist specializing in petroleum exploration and exploitation can expect to receive, and definitely the most prestigious prize that I will ever receive," says Landrø. Another way to put it, as many have done, is that the *Eni* award is the *Nobel Prize* of energy research.

At the ceremony, Landrø had the pleasure of meeting two Nobel laureates in physics. One of them, Charles Townes, invented the laser and has long served as a model for the aspiring geophysicist. Meeting him was a treat. The Award's Scientific Committee – which has the role of evaluating the candidates and assigning the prizes – is of the highest level and made up of scientists from some of the world's most advanced research institutes, including the Nobel prize-winner Sir Harold Kroto.

For *GEO ExPro* readers, Landrø is best known for authoring the column "Recent Advances in Technology" together with Lasse Amundsen. So far, the two of them have co-authored 24 articles within the field of seismic acquisition, processing and imaging, and there are more to come. (see page 64 for their latest offering).

Landrø, to be found in a modest office close to his students, is Professor of Applied Geophysics at the Department of Petroleum Engineering and Applied Geophysics at NTNU. His research interests are mainly fluid and pressure prediction from seismic data, but he has also researched other geophysical aspects essential for seismic imaging and reservoir monitoring. "My main fields of interests are reservoir geophysics, including time-lapse seismic, seismic inversion methods, rock physics, four-component seismic, marine seismic acquisition, analysis of CSEM data and gravimetric methods for monitoring purposes," Landrø says, thereby also explaining how he has been able to contribute with numerous articles in *GEO ExPro*.

Above all, Professor Landrø has been instrumental in the development of 4D seismic in order to predict reservoir behavior. For his breakthrough work in discriminating between pressure drawdown and saturation changes in the reservoir during production he received the *SEG best paper in Geophysics* award in 2001.

He has, however, received many other recognitions, including the EAGE Petroleum Geoscience award (Norman Falcon Award), the Norwegian geophysical award in 2004, Statoil's research prize in 2007, SINTEF's award for outstanding pedagogical activity in 2009 and in 2010 the Louis Cagniard award from EAGE.

*Want to know more? Go to You Tube and search for the "Eni award" and watch the ceremony.* ■

**HALFDAN CARSTENS**

## 'New Frontiers of Hydrocarbons' Prize

According to the Scientific Committee for the Eni award, "Landrø has developed a highly advanced technique of seismic analysis that makes it possible to precisely establish changes over time in gas and oil reservoirs. This enables improved management and development of reserves and the opportunity of significantly increasing the quantity of hydrocarbons extracted."

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# The Origin of the Barrel Award

After reading the Q&A in the last GEO ExPro Magazine, Professor Dick Selley fills us in on some history

In 1975 I returned to the Geology Department of Imperial College after years working for oil companies, where I had learnt that exploration success depended not only on technical know-how, but also on professional skills: to work to a deadline or in a team; to make decisions on inadequate data and to give lucid oral presentations. Accordingly, I restructured the Masters programme around a series of projects, the foremost being the 'Barrel Award'. The class was divided into teams, carefully constructed with respect to gender, ethnicity, and experience, with a mix of raw graduates and geologists with industry experience. After two months, the teams had to present and defend their recommended blocks in the North Sea before a panel of North Sea Exploration Managers. The winning team was awarded the barrel – not of oil, but of beer. This was enjoyed by students, staff and panellists in a modest fiesta at the conclusion of the day.

The first Barrel Award project was in 1976 when there was no publicly available North Sea data, but in subsequent years, as more data became available, the projects assessed successive rounds of UK Continental Shelf licensing. Teams had to identify three blocks that they considered the most prospective, in terms of reservoir, source rock, burial history and seal. Competition was fierce, and industrial espionage between teams common.

The examining panel of North Sea Exploration Managers were consistently amazed, not only at the professional expertise of the students, but also their acumen. One year a panellist remarked "How come these guys, with only limited data, zeroed in on the same blocks as my company?" The high point of the Award, however, came when one team identified the future Beatrice Field in the Moray Firth as their hottest prospect. All four oil company Exploration Managers in the panel had rejected farm-in offers on the block…

Over the last 30 years the Barrel Award has evolved dramatically. No longer do students stay up into the small hours hand colouring prints of their montages. Seismic data are more readily available, accessible in workstations, and can be integrated with logs and incorporated into presentations. Thus, the technology of the Barrel Award keeps pace with the industry. Nonetheless the intellectual challenges remain the same as students manipulate data, develop play concepts, learn teamwork, meet deadlines and present to expert panels.

The AAPG developed the Imperial Barrel Award into an international competition in 2007. Imperial College was allowed a place in the final for the first two years, gaining second prize on both occasions. It is unlikely that they will progress to the finals ever again, because under AAPG rules participating departments may compose their teams of their top students. Imperial's Barrel Awards teams are not its top students, but still a mix balanced by gender, ethnicity and experience. An illustration of a great British tradition: to invent a game, teach it to foreigners – and let them beat us at it.

**DICK SELLEY**

# The Great Crew Change – Fact or Fiction?

The "Great Crew Change" has been widely reported in the upstream oil and gas press, referring to the fact that, because of the age demographics of our industry, a high proportion of the workforce will be eligible to retire in the next few years, resulting in a sudden and irrecoverable loss of knowledge and expertise. In May 2011, specialist recruitment company Working Smart, with the support of the AAPG, conducted research to establish whether this concern is justified, and what steps can be taken to alleviate its effect.

Using the Working Smart online questionnaire capability, people in the industry aged 55 and over from 45 countries were asked about their future employment intentions. There was a good response, with 10% of respondents already retired, 43% employees, 34% contractors, and 13% seeking employment. Of those working, 63% were with operators and 36% with service companies. And 78% of respondents considered the "Great Crew Change" to be a fact.

The average intended retirement age of respondents was 65, with nearly a quarter seeking to work beyond their intended retirement age. The main consideration for continuing to work was not for financial gain but because they enjoy working.

When asked how companies can overcome the problem of skills shortages, the most commonly held view was that mentoring younger staff was a pre-requisite to minimising the effect of the "Great Crew Change". Respondents stressed that senior managers – especially "the accountants who are now running many of our companies" – need to understand that without this knowledge transfer to the younger generation we risk losing a sustainable industry for the future. Deirdre O'Donnell, Managing Director of Working Smart, says "perhaps we need a "SunShade" program, in which every experienced professional mentors at least one junior member of staff, actively involving them in their projects, to create a more balanced and technically and commercially enriched workforce".

Other ideas to alleviate skills shortages included companies building a more multicultural workforce; removing barriers to hire, such as insisting on minimum MSc or two years' experience; better succession planning, and greater flexibility for contractors. It was suggested that companies should support more MSc students and be more active in schools and universities. It was also proposed that an effective PR machine is needed to promote our industry and encourage students to enter it in the first place.

**JANE WHALEY**

# South Sudan Gains Independence

## Political tension in Sudan may add to market tightness.

THINA MARGARETHE SALTVELT, PH.D


Generals of South Sudan's army celebrate during official Independence Day ceremonies.

On the 9 July 2011, South Sudan officially gained its independence from the Khartoum administration. The oil market will monitor the development in the region closely as many critical issues yet have to been resolved. The North has reluctantly accepted the principle of separation, but disputes over oil fields near the border continue to undermine the transition.

### Important African Producer

Sudan is an important oil producer and exporter and accounts for almost 5% of Africa's oil production and 0.6% of total world production. Although the North and South have agreed to continue negotiating on outstanding oil issues after independence to prevent an immediate conflict with the North over its loss of oil revenues, with the recent unrest in the Middle East and North African region in mind, we are concerned that increasing political tension in the aftermath of the split may add to tightness in the oil market. Our worries are not unfounded, as Sudan has had two civil wars since 1955, the political unrest on the border between the North and South has intensified recently and Khartoum implemented an unofficial fuel blockade this spring.

The oil sector contributes only modestly to Sudan's overall economic output, but its impact on the external and fiscal balances is substantial. In 2010 oil accounted for some 92% of Sudan's exports and 54% of government revenues. For South Sudan (Juba), oil represented 98% of total revenues compared to Khartoum at 65%.

In 2010 Sudan produced 486,000 bopd and consumed around 90,000 bopd. The remaining crude was almost exclusively exported to the Asian market, with 65% being shipped to China, 15% to Indonesia and 13% going to Japan. Other importers of Sudanese crude are India, Malaysia, the Netherlands and Thailand, according to the IEA.

The Sudan National Petroleum Corporation (Sudapet) often develops joint ventures with foreign companies in oil projects but remains a minority stakeholder. Foreign companies involved in Sudan's oil sector are primarily from Asia, including China's CNPC, India's ONGC and Malaysia's Petronas, but European oil producers such as Italian Eni, Luxembourgian Star Petroleum and Norwegian Hamla are also participating in the exploration and production of the country's oil reserves. Nilepet, South Sudan's national oil company has also been involved in allocating licences which has led to some conflict, especially in southern blocks that were previously licensed by the Northern Government (EIA).

### Political and Security Issues

While most of Sudan's oil is produced in the South, the export and refining infrastructure, including the major pipeline, refineries and the Red Sea export terminals, is entirely in the North. The South has limited delivery options for its oil as its reserves are landlocked with no export routes in its territory. To become less dependent on its relationship with the North, a 1,400 km pipeline to ship oil from the South to a new port in Lamu, Kenya, has been proposed, but to make it economically viable the South needs a major boost to output. With neither political stability nor proper legal infrastructure expected in the near-term, companies will likely remain reluctant to undertake major investments.

Tension between the National Congress Party (NCP) in the North and the Sudan People's Liberation Movement (SPLM) in the South are expected to exacerbate current obstacles to capacity expansion. This, together with aging fields and poor reservoir management, will continue to keep production and export below Sudan's potential (PIRA). We expect Sudan's oil production to decline by more than 30% within the next 5 years unless the political climate changes soon.

There is a risk that political tension may increase in the short term and halt oil production, transportation or shipments and add to the market tightness. The oil market is already struggling from lost oil production in Libya, peaking summer holiday demand, electric power problems in China and the reconstruction in Japan. This is an upside risk to our oil price estimates at US$ 110/barrel in Q3. The biggest threat to the oil industry of the situation is not in our opinion the short term disruption in oil production or export. The predominant threats are the political and security issues arising from Southern Sudanese independence which are likely to hinder investments and efforts to expand output capacity. ■

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# New Vessel For Russian Waters

Dubai based seismic company Polarcus took delivery of its newest vessel, Polarcus Selma in mid-August, and promptly signed a Bareboat Charter Party Agreement with OAO Sovcomflot of Russia, which will see the ship serving the growing Russian seismic market for the next five years. Polarcus Selma, the sixth 3D seismic vessel to join the Polarcus fleet, is an Arctic-ready 8-streamer 3D seismic vessel capable of towing both conventional and wide tow spreads, including the company's First Pass™ 3D technique. The vessel was built at Drydocks World – Dubai in the UAE. Polarcus have also agreed to provide specialist onboard crew and shore-based services and systems support to the Russian company.

The agreement gives both companies unparalleled access to the Russian market, and most significantly, to possibly the world's last and largest oil frontier, the Arctic. Polarcus have developed a strong focus on the Arctic and Arctic-ready technologies, confirmed by the recent announcement that Selma's sister ship, Samur, launched earlier this year, is soon to commence a 3D multi-client project over the south-eastern part of the Bjarmeland Platform in the Barents Sea, offshore Norway. The project, with the potential to cover an area of up to 1,100 km$^2$, has strong industry pre-funding and targets an area where wells drilled in the late 80s proved the presence of hydrocarbon bearing sandstones with good reservoir properties in Late Triassic/Early Jurassic formations. The survey is expected to take 60 days and data processing will be undertaken by GX Technology, the imaging solutions group of ION Geophysical. A preliminary dataset will be available within one month after completion of acquisition, with delivery of the final migrated data volume expected to take place by February 2012. ■

*Polarcus Selma during construction in Dubai*


Polarcus

# Faculty for the Future

'Faculty for the Future' allows women from developing and emerging countries who are studying science and engineering to undertake their advanced graduate study at top universities abroad. Recognizing the link between science, technology, and socio-economic development, the program was launched by the Schlumberger Foundation in 2004, and it has now assisted 194 women from 54 countries to achieve their goals. The long term aim of the project is to generate conditions which will allow more women to pursue the physical sciences and related disciplines, so recipients of the awards are selected as much for their leadership capabilities as for their scientific talents. They are also expected to return to their home countries to continue their academic careers and inspire other young women.

In 2011 alone, 53 women from 31 countries were awarded Faculty for the Future fellowships to continue PhD or post-doctoral studies in 18 disciplines, including civil and environmental science, computer engineering, chemistry, physics, mathematics, and hydrology. The program has also encouraged the development of forums, both on line and face to face, where the young women involved can meet to share research and life experiences, provide moral and professional support and discuss the relationships between gender, science and economic development.

The Schlumberger Foundation, a private, non-profit organisation which supports science and technology education, recently announced that it has received a $50 million grant from Schlumberger Limited and its subsidiaries to support the Faculty program. This will enable more young women from developing and emerging countries to follow successful scientific careers and become role models for the next generation. ■

# Beaufort Sea Drilling

Shell first started looking for oil in Alaska back in 1918, and has had a presence in the state almost continuously since the early 1950s. It was one of the most prominent explorers in all of the frontier basins and in 1963 drilled the first offshore oil field in Alaska. The company temporarily pulled out of the state in 1997, but returned just four years later.

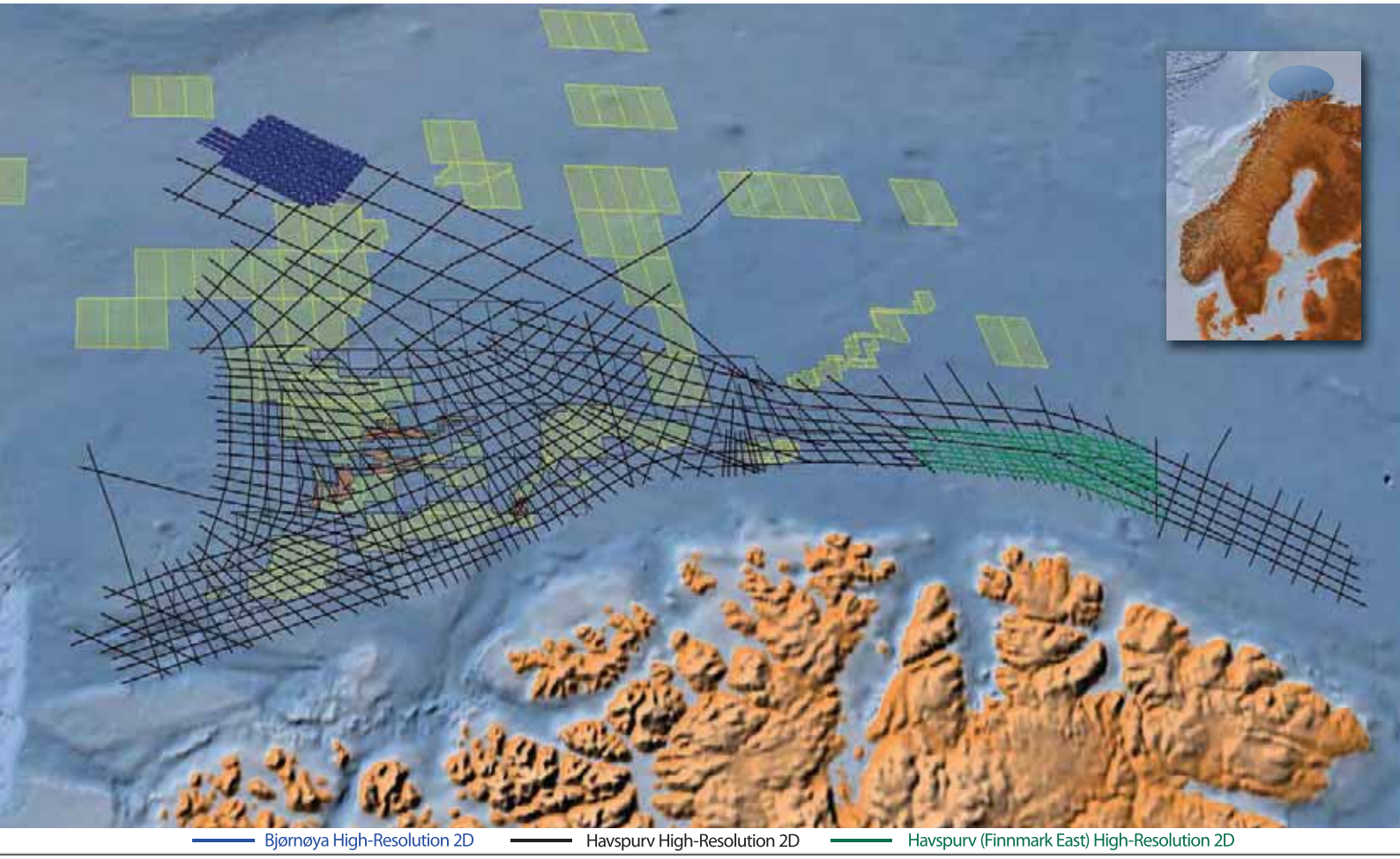
In 2005 Shell took acreage in the environmentally sensitive Beaufort Sea, on Alaska's northern coast, expecting to drill in 2008. However, the necessary permits were not issued, and the plans have been in abeyance ever since. They moved a step nearer fruition in early August this year, when the company won conditional approval for its exploration plan from the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement. It still has to get permission from the Environmental Protection Agency and other services. If Shell can prove that the proposed activities will be "conducted in a safe and environmentally responsible manner," it may be able to begin exploring in July 2012. ■

*Shell's drilling vessel Nanuk in Alaska*

Shell

# HAVSPURV & BJØRNØYA HIGH-RESOLUTION 2D SEISMIC SURVEYS

## BARENTS SEA - NORWAY




## The Havspurv & Bjørnøya surveys have been optimised to image the shallow section (<3 seconds).

- A dense, regionally consistent seismic grid covering the main basins in the Barents Sea.
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- Data available in Q4 2011.

Havspurv Project Sponsor: north energy

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Email: sales@searcherseismic.com
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# Spectrum and CGGVeritas Combine MC Library

Specialist 2D seismic company Spectrum has increased the total amount of data in its multi-client library through a major strategic link with CGGVeritas, announced in late July. Over 500,000 km of 2D marine – all of CGGVeritas' 2D library, with the exception of select Joint Venture datasets such as Kazakhstan – will now be available through Spectrum. As a result, the new combined Spectrum library will exceed 1,000,000 km of 2D multi-client seismic data, covering all major sedimentary basins worldwide, and there are several ongoing reprocessing projects, both by CGGVeritas and Spectrum.

As part of the transaction, CGGVeritas will become a major shareholder in Spectrum with a 25% stake and will have one board member on the Spectrum board of Directors. CGGVeritas will also provide seismic expertise, technology and services including acquisition, processing and data management to Spectrum. ■

# WGP in Arctic Exploration

Independent British geophysical contractor, WGP Exploration Limited, is currently assisting ION's GeoVentures group with their on-going Arctic exploration program. WGP provided the source array, recording office and source workshop components of the Thalassa-owned Portable Modular Source System PMSS™ in addition to the technical crew required for the 2011 seismic program.


*The Portable Modular Source System used by WGP on ION's Arctic exploration program*

The vessel utilized for the operation was selected due to its ice-class and research capability. As a non-seismic vessel it was recognised at an early stage that a custom umbilical winch design would be required, a solution was quickly designed by WGP Engineering and subsequently installed under the supervision of the field crew. The PMSS's BOLT Technology Annular Port Gun (APG) is ideally suited to the deployment methodology whereby conventional tow plates, spreader bars and external air and electrical lines are negated. The PMSS's self-sufficient recording office and gun workshop were quick and easy to install providing instantaneous instrument and workshop facilities.

According to James Pryor, WGP Sales & Business Development Executive, "the PMSS™ systems were initially designed and constructed to target the Permanent Reservoir Monitoring market. This sector has been slow to develop but with WGP's innovative approach and the equipment's flexibility we are delighted to provide a custom source solution to ION". ■

# Study Improves Deepwater Capability

Ikon GeoPressure, part of global geoscience technology company Ikon Science, recently completed the first large scale pressure study in Africa, which will be a major resource for the future of the Nigerian oil and gas industry. The study incorporates a new database of 304 wells, sourced from all deepwater operators, which includes 94% of the exploration and appraisal wells drilled in the Nigerian deep and ultra deep waters. Using such a large number of wells has enabled Ikon GeoPressure to build predictive relationships critical to the planning of safe deepwater wells. Patterns of pressure mapped across the study area have implications for fluid migration and trapping, enhancing the hydrocarbon potential of this area of the Niger Delta. This will improve offshore drilling safety and enhance exploration opportunities for identifying additional hydrocarbon reserves in Nigeria.

The study comprises a set of digital maps and reports, compiled by a team of five geologists from the two companies. It was sponsored by deepwater operators, Shell Nigeria Exploration and Production Company (SNEPCo), Total E&P Nigeria, Chevron Nigeria, Addax Petroleum Development Nigeria, Petroleo Brasileiro Nigeria (Petrobras) and Nigerian Agip Exploration and is now available for purchase by other deepwater operators and their partners. ■

# New Faroe-Shetland Basin Survey

Two major seismic players, PGS and TGS, have joined forces to undertake a new mulit-client 3D survey in the Faroe–Shetland Basin. The survey will cover 2,500 km$^2$ over Quads 6004 in Faroese waters and 204 and 205 on the UK side, about 200 km west-north-west of the Shetland Islands. It is being undertaken by the Ramform Viking, which will acquire data over the area through the third quarter of 2011, returning to complete the survey in 2012. The vessel is towing twelve 6,000m long streamers with 75m separation and utilizes PGS' unique GeoStreamer® technology. The survey has been enthusiastically supported by industry funding.

This survey enhances the existing data in the PGS 2D and 3D Mega Survey library, which has been acquired over recent years to help unlock the hydrocarbon potential of this area of prime prospectivity. ■


*Exploration in the deep waters off the Shetland Islands has been reinvigorated by a number of recent discoveries*

Astrium/ArcGlobe

# The East African Rift System

## A View From Space

Remote sensing data has given a unique perspective on the East African Rift System, allowing both large regional structures and more subtle features to be identified and placed in context

**MICHAEL HALL AND JOHN DIGGENS**
**Astrium Geo-Information Services**

East Africa, overlooked in terms of its hydrocarbon potential for many years, is increasingly viewed as an exploration hot spot, with recent discoveries in the Albertine Rift and offshore Tanzania leading to a resurgence in interest. Dominated by the East Africa Rift System (EARS), the region has a complex geological history and provides the potential to bring together modern techniques to aid geological understanding and to help efficiently target hydrocarbon exploration.

One technique particularly suited to frontier exploration is the use of medium resolution Earth Observation data in the form of satellite imagery and Digital Elevation Models (DEMs). These geo-information datasets can contribute in two main ways. Firstly, optical satellite imagery and DEMs can provide information on surface structure, geomorphology and stratigraphy, enabling a consistent regional interpretation of the surface geology to be undertaken. Secondly, radar imagery can assist in the identification of natural oil seeps that have been reported both offshore and on many of the rift lakes such as Albert, Tanganyika, and Nyasa (Malawi).

Astrium has recently completed an ambitious project to interpret the complete EARS, an area of approximately four and a half million square kilometres, at a scale of between 1:100,000 to 1:500,000. The project incorporates a broad range of territories including, from north to south; Eritrea, Djibouti, Somaliland, Eastern Ethiopia, south-east Sudan, Uganda, Kenya, Rwanda, Burundi, eastern border area of Democratic Republic of Congo, Tanzania, Malawi, Mozambique, and the border zones of Zambia, Swaziland and South Africa.

*Geological interpretation overview of the East African Rift System, illustrating surface structure and stratigraphy, and completed using Earth Observation data.*

## Active Continental Rift Zone

The EARS is an active continental rift zone with an elongate morphology, extending approximately 5,000 km from the triple plate junction of the Afar Triangle in Ethiopia to the Inhambane region in Mozambique. Dominated by extensional faulting, the area is characterised by two main rifting trends, defined as the Eastern and Western Branches, with several phases of superimposed rifting having occurred.

When studied in detail, the full complexity of the rift system becomes clear. As well as the main rift structure, smaller grabens are also apparent, running parallel or branching from the main rift feature. The orientations of the rift basin and grabens are controlled by the tectonic regimes the region has experienced since the Late Permian. By far the most significant control on the current rift morphology is the Tertiary to Quaternary rifting, manifested in the general north-south orientation of the rift structure. This dominant trend truncates structures formed during previous rifting events, namely the Late Permian to Early Jurassic 'Karoo' events and the Cretaceous event. Karoo rift basins are concentrated in the south of the EARS, predominantly in Mozambique and Tanzania, and include the north-north-east trending Luangwa rift and the Selous graben, trending north-east to south-west.

The East Africa Rift lakes form striking elongate features on the satellite imagery, with well-reported surface oil seeps on many of the larger water bodies. Many of the smaller lakes are also thought to have oil seeps. Radar imagery was used to screen for the presence of natural oil seeps and to try and establish the spatial pattern of oil seepage between individual lakes.

## Main Rifting Events

Rifting events took place in the Permian to Jurassic, Cretaceous and Tertiary-Quaternary periods. The older Karoo grabens represent the Early Permian to Early Jurassic phase of rifting trending north-east to north-north-east (Selous Graben, Luangwa Valley, Mpotepote Basin, Metangula Basin) or east-west (Upper Zambezi, Tete Basin), or occasionally north-west (north-west flank of Lake Malawi/Nyasa, the Kalemie Basin off Lake Tanganyika). Late Jurassic to Cretaceous rifting is represented by the north-west to south-east trending Anza Rift in Kenya, and a continuation of the Sudanese Rifts such as the Muglad Basin. North-south trending Tertiary rifting in the Turkana Depression, located between the Afar and Kenya Domes, truncates this Mesozoic rifting event.

The Eastern Branch of the Rift runs from the Afar Triangle triple junction in Ethiopia and Eritrea to the South Tanzania Divergence where the rift meets the Tanzania Craton. In the north, the eastern rift trends north-east to south-west, then north-north-east to south-south-west at the Ethiopia-Kenya border, before deflecting north-south at Lake Baringo. A series of small rifts branch off from the main structure at Lake Turkana, before terminating directly north in southern Ethiopia. A number of oil slicks have been identified on Lake Turkana and there have also been reports of good quality source and reservoir rocks in the adjacent Lokichar and Kerio Basins.

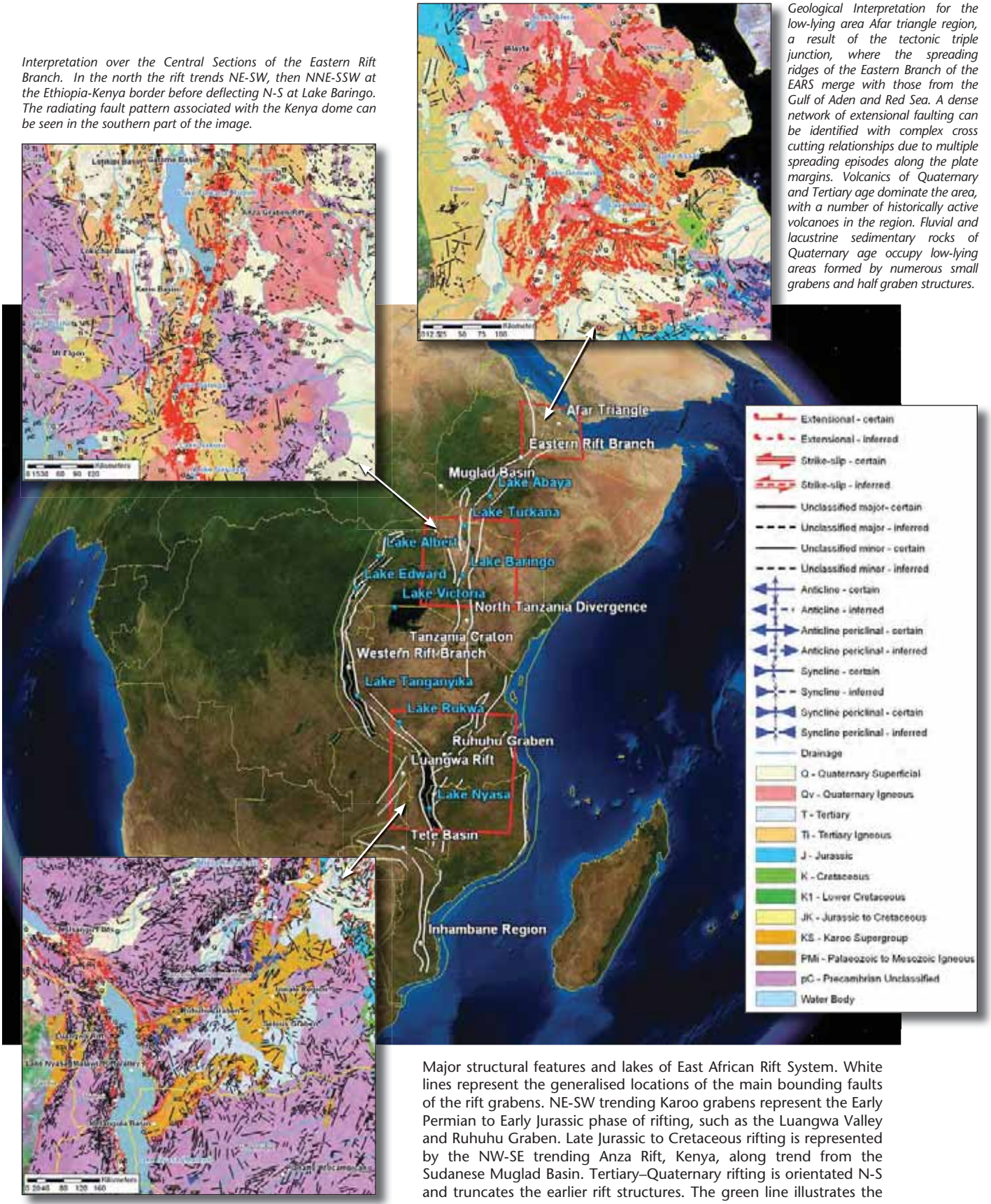
The Western Rift stretches from the border between Uganda and Sudan in the north, to the major rifts of Lake Tanganyika and Lake Nyasa (Malawi) – predominantly trending north-south except where it diverts around the Tanzanian Craton near Lake Tanganyika. The extensive lakes in the Western Branch, including Lakes Albert, Edward, Nyasa (Malawi) and Tanganyika, have a significant number of oil seeps identified from Radar imagery, with the potential for associated good quality source rocks.

In the southern section of the Western Rift, the surface expressions of geological features are dominated by the Tertiary-Quaternary fracture sets associated with the EARS. These mostly trend approximately north-south and cut the older, failed north-east, east-west and north-west trending rifts of the Permo-Triassic Karoo grabens, as well as the multi-temporal, multi-directional tectonic elements of the Precambrian Basement. The intracratonic basins containing the Karoo Supergroup are distinct features on the remote sensing imagery, and can be accurately defined. Further south, the Inhembane area of Southern Mozambique is transacted for over 300 km by Quaternary north-south intersecting narrow graben structures, 9–11 km wide, that are coaxial to the present-day coast and indicate that the extensional forces which formed the system are still active in this region. ▶

John Diggens is a senior geoscience consultant with over 29 years regional experience in different parts of Africa, including field expeditions to Kenya, Tanzania and Madagascar. After lecturing in Geology at Liverpool and Kingston Universities, he spent several years with Robertson Research and JEBCO, and 10 years with Texaco, before joining Infoterra in 2000. Since 2008, John has been working as an independent consultant with his own company, D.I.G.R.S. Limited.

Remote Sensing Geoscientist Michael Hall has a B.Sc. from Exeter University and a M.Sc. from University College London. He spent a number of years at the British Geological Survey before joining Infoterra (now part of Astrium Services' GEO-Information Division) in 2008, where he specializes in the use of Earth Observation data for geological applications.

*Interpretation over the Central Sections of the Eastern Rift Branch. In the north the rift trends NE-SW, then NNE-SSW at the Ethiopia-Kenya border before deflecting N-S at Lake Baringo. The radiating fault pattern associated with the Kenya dome can be seen in the southern part of the image.*




*Geological Interpretation for the low-lying area Afar triangle region, a result of the tectonic triple junction, where the spreading ridges of the Eastern Branch of the EARS merge with those from the Gulf of Aden and Red Sea. A dense network of extensional faulting can be identified with complex cross cutting relationships due to multiple spreading episodes along the plate margins. Volcanics of Quaternary and Tertiary age dominate the area, with a number of historically active volcanoes in the region. Fluvial and lacustrine sedimentary rocks of Quaternary age occupy low-lying areas formed by numerous small grabens and half graben structures.*

*An extract of the interpretation for West Tanzania and Lake Malawi with the Luangwa Valley and Ruhuhu Graben illustrating the NE-SW Karroo trend cut by the later Tertiary to Quaternary N-S trend. Frequent oil seeps have been identified in Lake Nyasa (Malawi) (not shown), probably emanating from sub-lake Karroo or younger Mesozoic to Tertiary sections.*

Major structural features and lakes of East African Rift System. White lines represent the generalised locations of the main bounding faults of the rift grabens. NE-SW trending Karoo grabens represent the Early Permian to Early Jurassic phase of rifting, such as the Luangwa Valley and Ruhuhu Graben. Late Jurassic to Cretaceous rifting is represented by the NW-SE trending Anza Rift, Kenya, along trend from the Sudanese Muglad Basin. Tertiary–Quaternary rifting is orientated N-S and truncates the earlier rift structures. The green line illustrates the extent of the onshore interpretation.

*Images: Astrium/ArcGlobe.*

# MultiClient Europe: Faroe-Shetland Basin MegaSurveyPlus

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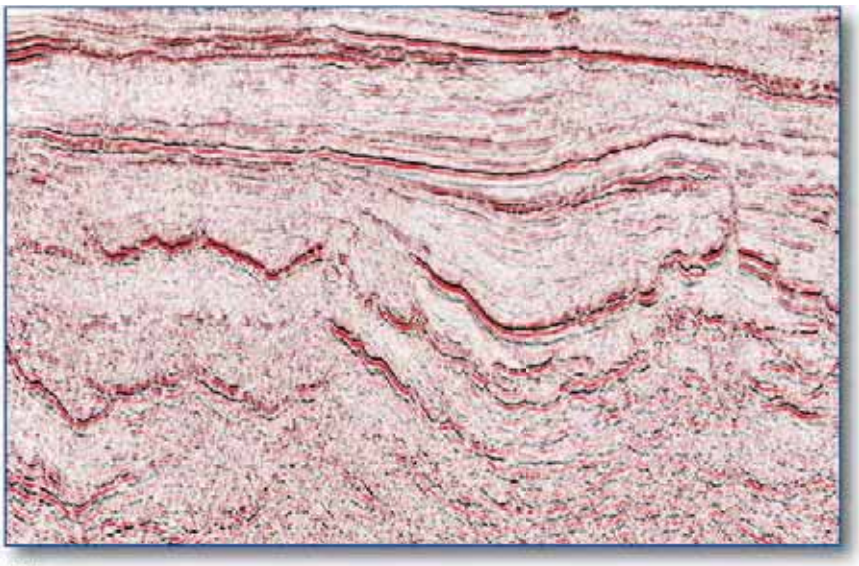
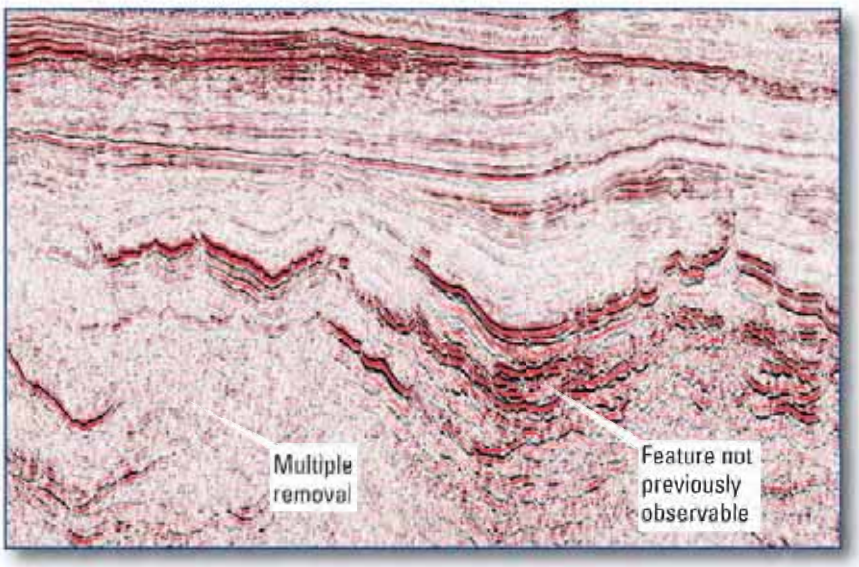


*Before*

*FSB MegaSurveyPlus*




*After*

## Data improvements include:

- excellent noise attenuation & multiple removal revealing features and structures not previously observable
- clear characterisation of intrusives aiding interpretation
- greatly improved imaging of faults at all levels enhancing understanding of the area
- footprint of constituent surveys removed to provide a seamless dataset enabling basin wide interpretation

**This dataset is now available for review and license**

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### Hydrocarbon Opportunities

Tertiary fluvio-lacustrine deposits within the rift grabens and older Karoo Supergroup deposits are the main onshore Petroleum Systems. In Somaliland, similarities are also thought to be found with the Petroleum Systems of Southern Yemen.

In the northern section of the study area, contrasting characteristics of the Eastern and Western Branches of the rift have been observed. The Western Branch, initiating in the Albertine Graben in northern Kenya, displays a high level of seismic activity, has less active volcanism and generally a greater thickness of sediment in comparison to the Eastern Branch, excluding the rifts of the Turkana Depression. These factors are likely to have a corresponding influence on prospectivity, supported by recent discoveries in the Albertine Graben. However, previous studies of the Turkana Depression region have also emphasized hydrocarbon opportunities in the Northern and Central Kenya Rifts of the Eastern Branch. These are thought to be the oldest and longest-lived sedimentary basins of the Tertiary-Quaternary EARS because they represent an overlap area with the Cretaceous rifts.

The oil seeps identified by this study – in the rift lakes of Lake Tanganyika, Edward and Nyasa (Malawi) – may indicate the presence of a similar petroleum play involving the Tertiary sections, as discovered recently at Lake Albert. Additionally, for the lakes in the south, there is the potential for the seeps to be derived from older Karoo sediments common in the southern part of the EARS. Recent exploration on the Karoo basins such as the Ruhuhu and Upper Zambezi Grabens has revealed large reserves of Gondwana coals within the lower part of the Karoo Supergroup. These may yield commercial amounts of coal-bed methane as well as reasonable quality coals for future exploitation. Other prospective regions include the Ogaden Basin in Eastern Ethiopia. This is an area of proven hydrocarbon reserves with large gas discoveries and frequent oil shows from the Mesozoic.

Similarities exist between the Petroleum Systems in Somaliland and the proven hydrocarbon regions of Yemen, with the Balhaf Graben in Yemen thought to be a continuation of the Berbera Basin in Somaliland. Jurassic shales are the main source rocks in this region and the satellite imagery has identified numerous roll-over anticlines, closely associated with listric fault growth, that are likely to be most significant structural traps.

Incorporating a structural and stratigraphic interpretation this 1:100,000–1:500,000 study has identified evidence of the main rifting events that have defined its current morphology. There is considerable potential to add further detail to the study using higher resolution satellite imagery over specific sub areas, as can be seen on page 22. ■

## GEOLOGICAL EARTH OBSERVATION

Medium resolution Earth Observation data provides a rich information source for efficiently undertaking geological interpretation over extensive onshore areas. Primary data collection includes structural information such as relative bedding dip and orientation, fault identification and classification, together with spectral and textural information allowing the assessment of surface stratigraphy. An understanding of the regional setting, provided by satellite data, gives important context not achievable from ground-based observations alone.

Two main remote sensing datasets are used in this study; Landsat 7 mosaics in a 742 (RGB), with a resolution of 15m, and the Shuttle Radar Topographic Mission (SRTM) 90m DEM. Since 1972 the Landsat series of satellites have been acquiring information about the Earth's Surface. Launched in 1999, Landsat 7 is the most recent, and is the standard imagery dataset used for regional scale mapping down to 1:50,000, having seven spectral bands. Typically for geological mapping, three of the bands – in this case Bands 7, 4 and 2 – are combined in a pseudo-colour composite band combination. Utilising Band 7 in the Short Wave InfraRed, this 7/4/2-band combination offers maximum lithological discrimination, significantly improving the ability to distinguish between different rock types. The SRTM dataset was acquired from a radar system that flew onboard the Space Shuttle Endeavour in 2000, and is a three dimensional digital representation of the Earth's surface that can be processed to enhance subtle geomorphological information.

Interpretation of satellite data and the assessment of other spatially-referenced information was completed digitally in an ArcMap environment at scales ranging from 1:100,000 to 1:500,000. Although the primary source of information was the satellite imagery, existing geological mapping was also integrated into the study, where available, in order to provide virtual ground truthing.

Additional datasets have also been incorporated into this study, including an extract from Astrium's global oil seeps database that includes oil slicks derived from EARS natural lake bed oil seeps and from the sea bed of surrounding offshore areas and identified using Radar Imagery. The offshore areas include the Gulf of Aden, the Seychelles, Madagascar, Somalia, Tanzania, Mozambique and Kenya, with over 800 radar scenes assessed and over 500 separate slick points recognised. Identifying seeps from radar imagery is an established method, often applied to screen offshore basins and based on observing the variation in return signal and noting any anomalous areas caused by the dampening effect the oil has on wave heights. By collecting imagery from multiple dates and studying the morphology of the slick, a greater level of confidence can be assigned to the features, reducing the likelihood that an area of pollution or local weather conditions are being observed.

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# Beyond Macondo

DAVID BAMFORD

"The major difference between a thing that might go wrong and a thing that cannot possibly go wrong is that when a thing that cannot possibly go wrong goes wrong it usually turns out to be impossible to get at or repair."

*Douglas Adams, 'Mostly Harmless'*

No doubt the CEOs of various other Majors have sound reasons in their minds for suggesting that the Macondo disaster was a 'BP problem' – as though blowouts are new…

In fact, in 2005 an analysis of incidents in the Gulf of Mexico by researchers from Texas A & M University showed that offshore blowouts had continued at 'a fairly stable rate' since 1960 despite the use of blow-out preventers (BOPs). To be specific, the Presidential Commission that investigated the Deepwater Horizon disaster found that oil companies lost control of Gulf wells 79 times between 1996 and 2009.

## Is Regulation Enough?

Turning to Europe, I do not believe we can or should be content with a position which says that regulation is that much tougher in the UKCS and NOCS than in the US OCS and that therefore things are OK.

Regulation is necessary, but not sufficient.

My personal view is that there seems to be an industry problem, rather than one confined to BP or to the Gulf of Mexico. In addition to the large output from the aforementioned Presidential Commission, evidence for this view comes from various sources, some of which are reviewed below. As a consequence I want to make the case that we need to find technology solutions, as well as improve internal processes, set new standards and so on.

David Payne, Chevron's Vice President of Drilling, speaking at an industry meeting in Florence in January 2011, reportedly said "It is apparent that the Deepwater Horizon crew had information they needed to know [to prevent disaster] and took no action….These were experienced men. My theory is that the interface [providing information about drilling operations] was too complex. The Macondo incident is a wake-up call to the fact that as wells become more and more complex we have to think about how we manage the man:machine interfaces. We need to get engineering solutions to match up with the people. Simplifying the human interface is an engineering problem most engineers don't want to deal with."

## Understanding Complex Systems

In mid-March 2011 the Deepwater Horizon Study Group from the University of California, Berkeley, listed up to a dozen separate decisions made on the rig that increased risk. These ranged from not cementing well drilling liner overlaps and delaying installation of the casing hanger seal assembly lock-down, to not using recommended casing centralisers and running underbalance tests with most of the drill pipe out of the well instead of running a full string to total depth.

With so many reports from different

BP p.l.c.

*The Transocean* Discoverer Inspiration *arrives to install the Capping Stack Blow Out Preventer at the Macondo site on 10 July 2010.*

investigative bodies, there is a very large amount of information to digest. However, it does seem that it may be necessary to consider not simply the performance of the individual technologies that have received so much attention, such as BOPs, cement jobs and acoustic triggers, but also the interaction between these technologies and the decisions related to them, in what is a somewhat complex system.

This raises a number of questions. For example: can such systems be understood; whose role is it to assert that the whole system will function correctly; can any one individual respond quickly enough if something goes wrong; can more intensive simulator-based training help; can better rig-to-onshore communications help? And if the worst happens, do we have rapid containment facilities and what new rules might we see put in place by regulatory authorities?

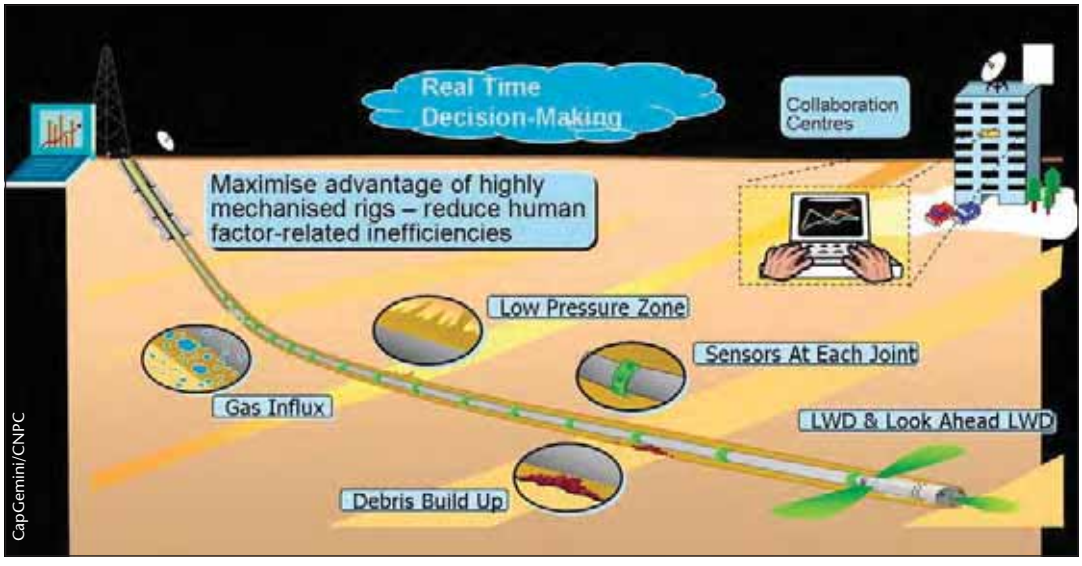
At a recent ***Finding Petroleum*** forum in London, these issues were probed in greater depth, resulting in a number of insights.

## Risk Management

Perhaps the most significant insight, aside from those directly connected with actual drilling operations, was a risk management one – that issues of personal or occupational safety are more or less unrelated to issues of operational integrity. In particular, an emphasis on safety metrics, such as the number of Lost Time Incidents and "golden rules" which focus on trips and slips and lifting, whilst essential and laudable, has little or nothing to do with assuring operational integrity.

Thus it behoves companies to have a system of performance and risk management that is relevant to maintaining operational integrity and that is necessarily different from, and in addition to, one that maintains occupational safety.

Relating to critical relationships during drilling operations, gaps were identified in three key areas: training; control systems and the measurement and




*The fundamentals of integrated operations.*


Halfdan Carstens

*Effective collaboration is needed to ensure the best information flow between onshore 'command centres' and drilling rigs.*

control of well parameters; and rig to HQ communications.

We need to build drilling personnel competency through training, particularly the ability to 'think downhole' in an era of data overload. Outsiders to the oil and gas industry sometimes refer to either the nuclear industry or the civilian air industry as examples from which we might learn. Recent events in Japan rather undermine the former suggestion, and I am not sure that the latter is an appropriate analogue for the oil and gas business – I don't think oil and gas operations in Texas or Siberia resemble operations at London's Heathrow airport, for example!

Nonetheless, I am struck by the analogue with flying modern planes and by the extraordinary amount of time that pilots spend training, especially in simulators, which can replicate more or less every eventuality that a pilot may face in flight and in combat. Isn't there a case for such intensive simulator-based training in our industry?

## Communications and Information Flow

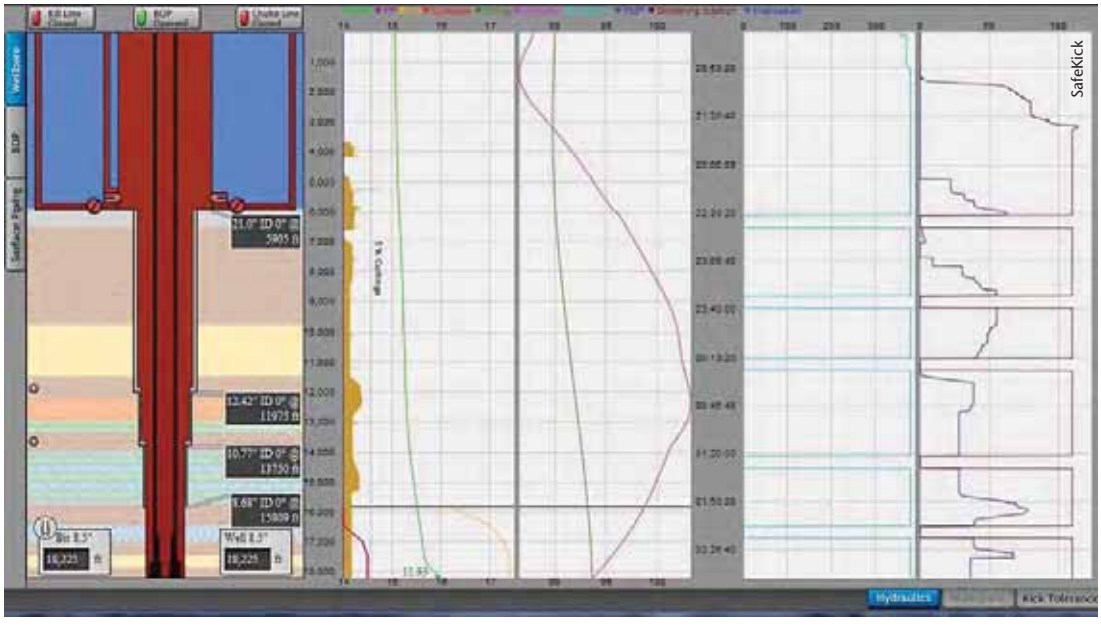
With regard to measurement and control of well parameters, instead of looking at raw data the drillers need to be able to know the answer to operational questions. Where is the bit – inside the casing, open hole or riser? Are the BOP and choke/kill line open or closed? Where are and what are the fluids inside the drill string and annulus? What is the pore/fracture pressure and pressure along the wellbore? All these and many more are real time questions needing rapid answers.

This implies getting better data to begin with, having systems to clean up data and make it easy to understand, and systems to make this information easier to work with, for example more precise alarm systems, so that all available expertise can be brought to bear on remote operations, especially in anticipating and dealing with problems.

Effective collaboration needs the ability to visualize and understand current conditions through valuable information rather than raw data, with a notable lack of a common platform to convey the same information to individuals and companies, both local and remote.

We may need to introduce a step-change in communications and information flow between onshore 'command centres' and drilling rigs and remote installations. Many things come down to the crew on a rig not only not knowing the right information at the right time but also not being able to bring all potentially available expertize to bear on a problem, for example being unable to access onshore technical experts and/or share critical knowledge with them quickly.

*It is imperative for drillers to know what is happening below the rig floor, instead of having to interpret raw data. This display shows the actual condition of the well, such as depths, distances, pressures, as opposed to technical measurements that need expert interpretation.*



## Who Sets the Standards?

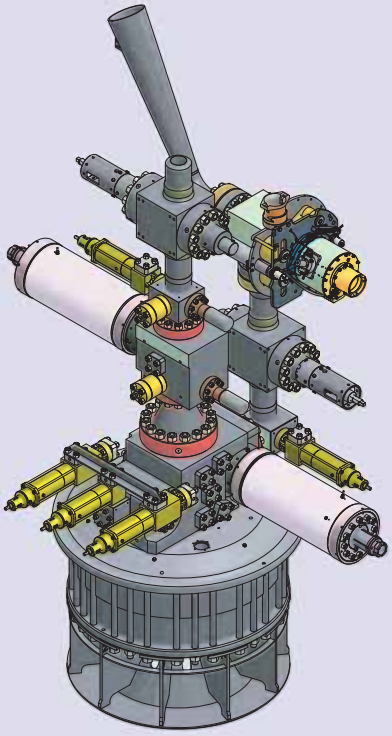
I think we as an industry need to respond along these lines… because the alternative is not attractive.

While the UK government, for example, believes current regulations are adequate, globally regulators may well move in the direction of requiring operators to post a bond to deal with the cost of any spill. Bearing in mind that BP's Macondo-related costs have long since passed US$12bn, these bonds would need to be quite large, beyond the scope of oil and gas companies capitalised at less than say US$10bn or even US$15bn. This has serious implications for small to medium sized oil and gas companies.

In addition, one of the more scary concepts touched on in the aforementioned Forum is that of 'extraterritoriality' – the suggestion that any company headquartered in the EC will have the same rules and regulations applied to all its global operations. My objection to this is not that companies should be held to the same high standards of behaviour everywhere they operate – of course they should – but that a bureaucrat in Brussels should feel capable of figuring out what these standards are!

This problem isn't just confined to Europe, it seems. According to Mississippi Governor Haley Barbour and Gulf Coast employers, as told to a US House of Representatives committee on 2nd June 2011, the Obama administration's reactions to the Macondo oil spill did more damage than the crude itself. Barbour said little oil reached Mississippi's shores, but the administration's May 2010 decision to impose a five-month ban on most deep-water drilling has left a lasting impact. The moratorium "not only cost jobs in all the Gulf states, it hurt the economy nationally by reducing domestic oil production," Barbour told the House Oversight and Government Reform Committee.

Let's hope we don't get reminded of the insight of President Ronald Reagan about the scariest words in the English language: ***"Hi, I'm from the Government and I'm here to help you"!*** ■



*OSPRAG (UK Oil Spill Prevention and Response Advisory Group) has been instrumental in designing a capping device which is now rated for deployment in water depths up to 3,000 km on wells flowing up to 75,000 bopd.*



# SOUTH ATLANTIC PALAEOGEOGRAHY: Reconstructing Palaeolandscapes for New Ventures Exploration

PAUL MARWICK PhD, GETECH

*Evidence of late Cenozoic uplift indicated by deep fluvial incision: Fish River Canyon, southern Namibia.*

The use of palaeolandscapes is an essential tool for understanding the South Atlantic Petroleum Provinces, where the interplay of plate tectonics and landscape evolution has a direct influence on the development of hydrocarbons.

Palaeogeography has too often been considered as simply a backdrop for presentations and posters. But methodological advances over the last 20-30 years, coupled with advances in Geographic Information Systems, mean that plate tectonic modeling and palaeogeography are now becoming an essential and powerful tool for New Ventures exploration. This is nowhere better demonstrated than in the Equatorial and South Atlantic Petroleum Provinces, in which the interplay of plate tectonics and landscape evolution affects not only the geometry and nature of basins around the margins, but source to sink relationships and depositional systems, with direct implications for exploration risking.

## Fundamental Questions

The fundamental problem of New Ventures (NV) exploration, or perhaps its very scientific attraction, is that it is focused on areas at the edge of our knowledge. These are geographic areas with few, if any, wells or seismic lines. Such areas provide the geological puzzles that attracted many of us to geology in the

first place, but are a serious headache for explorationists.

The South Atlantic and Equatorial Atlantic hydrocarbon provinces, north of the Walvis Ridge, are a case in point. With proven oil reserves of over 285 Bbo (CIA Fact Book, 2010) and recent major discoveries in the sub-salt of the Santos Basin and in the deep water off Ghana, interest in new plays in this region has increased considerably over the last few years. But existing discoveries are not evenly distributed, and with high costs and risks associated with deep water exploration, low cost NV tools to mitigate this risk are essential.

At this early stage in the exploration process, even the most fundamental questions are critically important and need answers before additional, expensive resources are purchased. Quite simply, is there a basin present with enough sediment to generate hydrocarbons and what is the composition and timing of the fill of these basins? Is there a potential source, reservoir and seal rock? Does a play exist?

Industry experience in the South Atlantic means that we can also anticipate more specific facts that will be important, such as the extent of source facies and reservoirs in the sub-salt and the nature of timing of uplift along each margin that can affect maturity modeling. What, for example, is the spatial variation in source and reservoir facies and how does this relate to tectonics, especially the interaction with transforms in the Equatorial region, but also hinterland reactivation and sediment supply. We also need to ask what is the location, timings, volume, provenance and character of clastic accumulations along the margins and how does this relate to changes in hinterland evolution?

## Plate Modeling and Palaeogeography

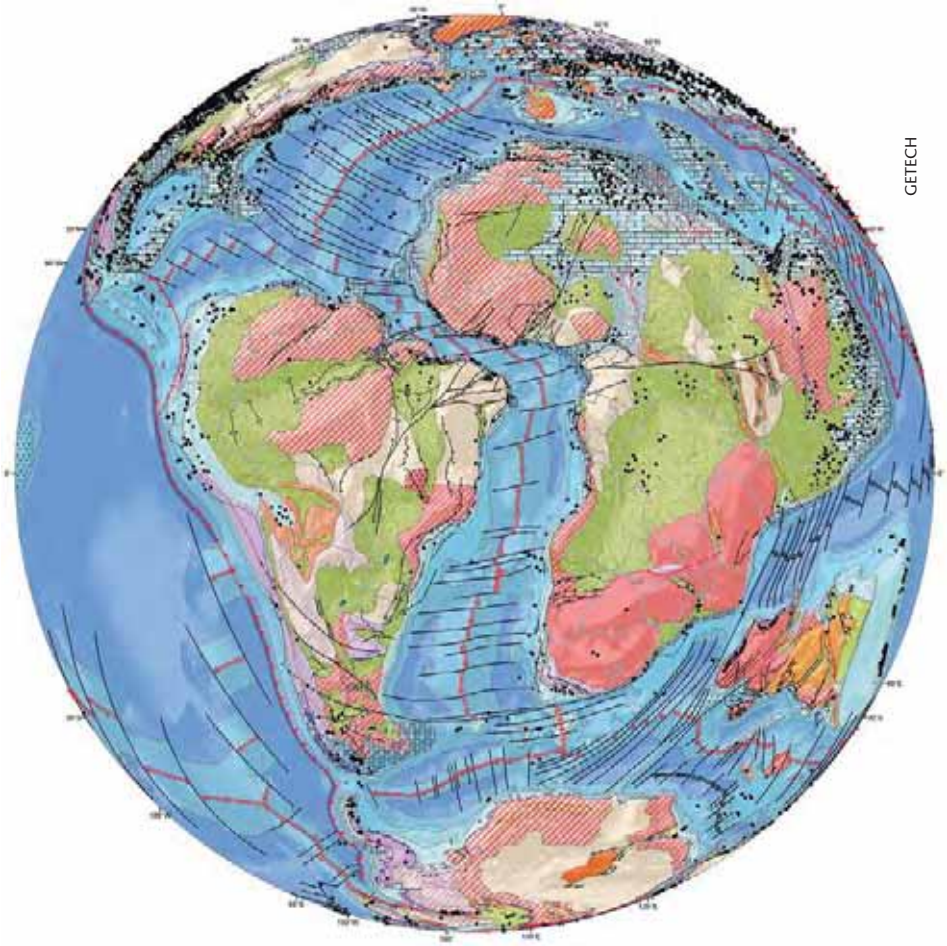
This is where plate modeling and palaeogeography can provide part of the solution.

Plate modeling sets the limits to the geodynamics of an area and thereby the potential development and evolution of basins along a margin (including geometry, crustal type and thickness, which leads to heatflow, subsidence and uplift). It also provides the platform on which Gross Depositional Environments (GDE) and landscape models can be compiled and developed; this includes hinterland uplift histories (driven by geodynamics including mantle dynamics), which then affects source to sink relationships, sediment flux and character.

The palaeoenvironmental reconstruction adds flesh to this plate reconstruction, through mapping what we know and what we think may have existed, either by extrapolation from adjacent areas or lithofacies prediction based from process-based modeling. This helps define the depositional setting of frontier areas. By converting this to elevation (palaeotopography and palaeobathymetry) and adding interpretations of palaeodrainage, the maps become more powerful predictive tools, since this level of analysis does not only indicate where sediment might be expected, but goes some way to allowing us to predict what that sediment would comprise (given reconstructions of weathering and erosion, climate, bedrock composition and so forth). This can be taken even further using process-based predictive lithofacies models which use the palaeolandscape as a boundary condition for vegetation, climate, ocean, tide and wave models, that in turn provide the input for lithofacies modeling.

## Building the Framework

Building robust plate models and palaeolandscapes is not a trivial matter. Both are labor intensive, requiring large, multi-disciplinary teams of specialists, sizeable databases and constant testing and iteration. But they are only one part of a more extensive integrated workflow



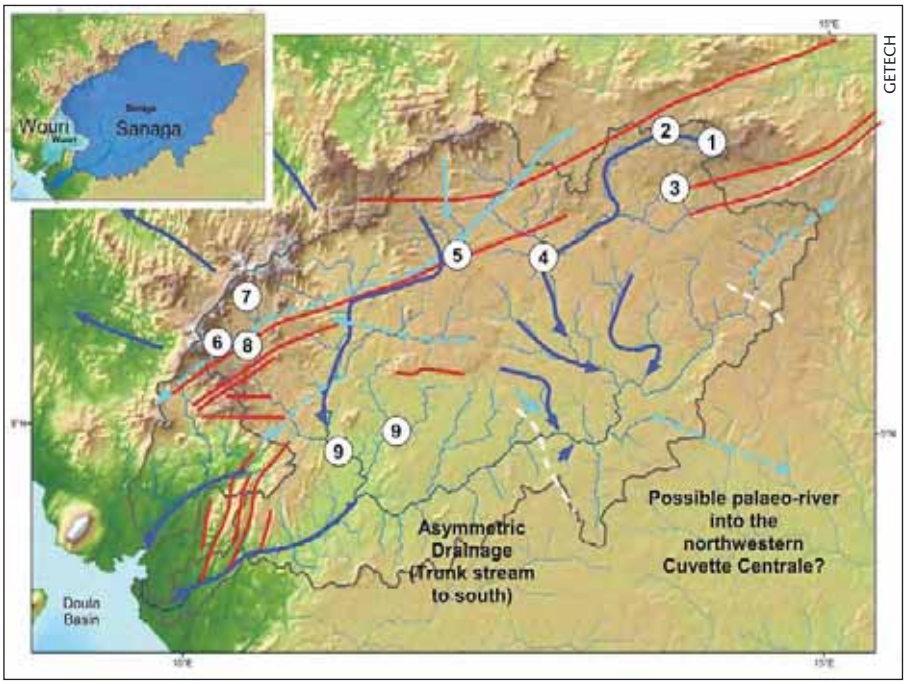

*Palaeoenvironmental (GDE and tectonic) reconstruction of the Cenomanian, centered on the South and Equatorial Atlantic provinces.*

designed to solve NV problems, which also includes petroleum geochemistry, stratigraphy, sedimentology and petroleum geology.

To build the foundations of a model in an area of sparse well and seismic data, greater reliance must be placed on potential fields and other remote sensing datasets. Interpretation of these data is the starting point of the workflow and is used to map the structural framework of each area, as well as the extent of volcanics and salt. For the South Atlantic and Equatorial region reconstruction, 16 2D profiles were then used to define the crustal type, geometry and thickness, the limits of stretched crust and position of the Continent-Ocean Transition zone. These were employed as boundary conditions for the plate modeling and to calculate beta-factors as tests of the modeled fits. Differentiation of the transitional crust into attenuated, continental, under-plated and intruded segments provides additional important information for estimating heatflow in developing basins. Depth to basement calculations defined extensions to known depocentres as well as identifying deep-seated structural partitioning in basins with a complex history such as the Santos Basin.

For the South Atlantic about 17,000 structures were compiled using interpretations based on potential fields, Landsat and radar altimetry (SRTM3) data. These were constrained by comparison with seismic lines where available, and by onshore geological maps and publications.

These structures were then used in conjunction with the results of the 2D geophysical modeling to redefine basin geometries along the margin and to understand the nature and kinematics of plate boundaries used in the plate modeling. This includes intra-continental plate boundaries within Africa and South America, which have to be considered in order to account for the timing and geometry of the developing South Atlantic rift during the Late Jurassic to Aptian. This is also true in the model generated in this study, although uncertainties remain about the exact amount of deformation on many of the large,




*The results of a drainage analysis of the Sanaga and Wouri Rivers showing substantial differences between the modern day river trends (dark blue arrows) and interpreted palaeo-river trends (light blue arrows) resulting from Oligocene-Miocene uplift of the Cameroon area and southward tilting of the Gabon Craton.*

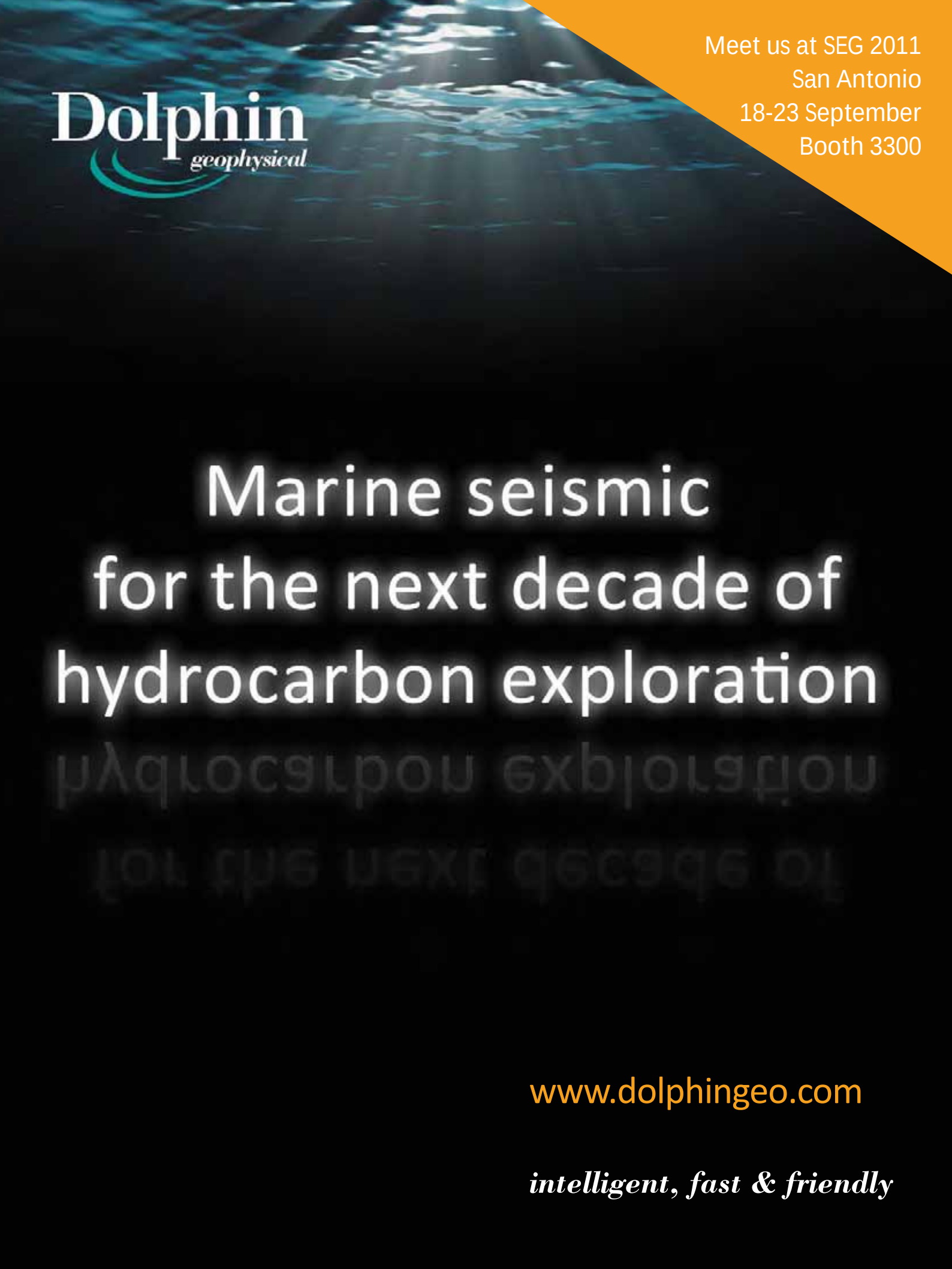
Precambrian Shear Zones. What is clear is that neither the simple northward 'scissor-opening' of the South Atlantic of Bullard et al (1965: *Philos. Trans. R. Soc. London.,* Ser. A, 258: 41-51) or the idea of a single, simple translational opening of the Equatorial Atlantic, fits observations. This has a major affect on not only basin development and history, but also the response of the hinterland, which in turn affects source to sink relationships.

## Reconstructing Contemporary Base-level

With the structural and tectonic framework established, the next step is to map the depositional systems. Traditionally this is restricted to compiling facies or GDE maps for what is preserved, but in our methodologies this is extended to include the probable contemporary full extent of deposition at the time of the map. Differential symbology is used to distinguish between those interpretations of depositional environment that are known (preserved) or inferred, with a further division applied to lithologies as to whether the designation is based on 'outcrop', 'subcrop' or 'inferred', providing an immediate indication of confidence. Sediment source areas (areas above contemporary base-level) are then mapped and defined according to the last thermo-mechanical event affecting that area (at the simplest level this is assumed to be the reason that such an area is above base-level, but in reality most upland areas are a consequence of multiple causes). Structural and tectonic elements are also mapped on these reconstructions, together with exploration and cultural data, well information, source rock distribution and so forth, including any key datasets held by the NV team. Given the complexity of the system, it is perhaps of little surprise that frequently findings from this phase of the mapping can lead to modifications in the underlying plate model, which increases the accuracy and precision of the map, but adds considerably to the workflow.

## Lithofacies Prediction

Whilst GDE, tectonic and base-level maps provide an explicit representation of source to sink relationships and the extent and nature of depositional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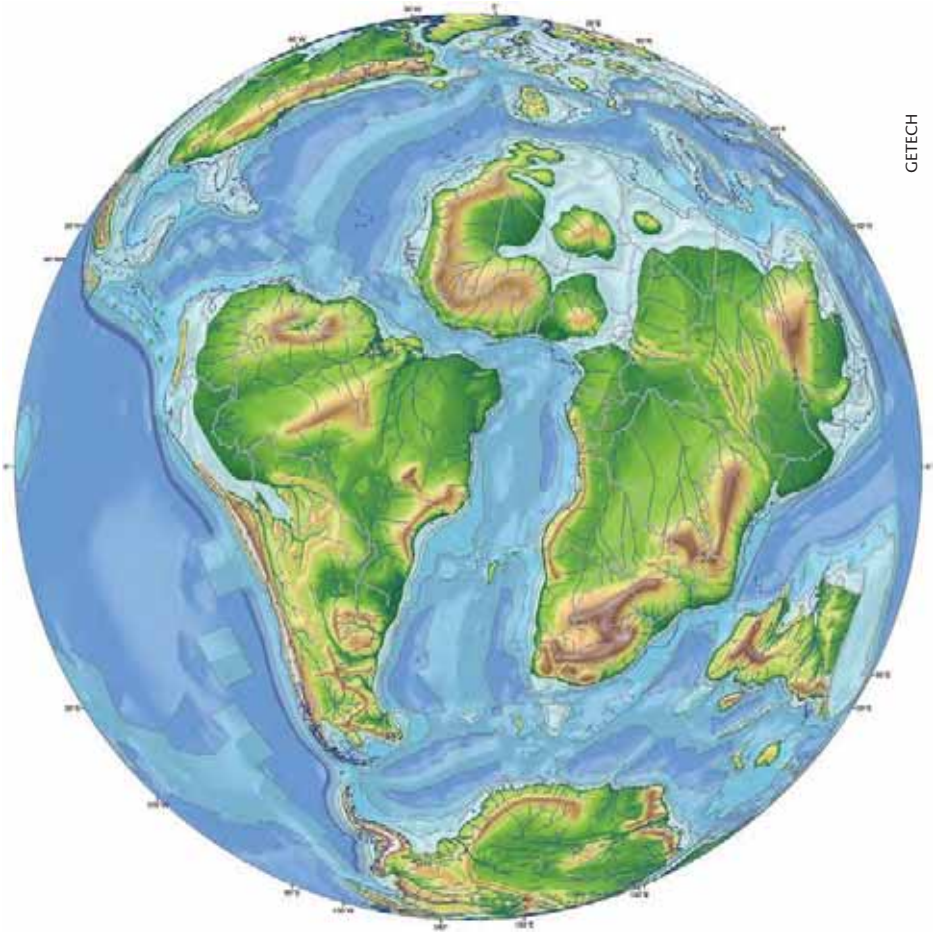
environments, high on any NV wish list is the ability to predict confidently the extension of the various play elements. With potential fields data providing a robust means of reconstructing the geometry of basins and crustal types, including possible extensions and structuralization, converting palaeoenvironmental maps to landscape maps provides the boundary conditions for quantitative analysis and lithofacies prediction.

There are several stages to this process. The present day landscape is analyzed to identify the relationship of geology and tectonics in landscape formation, and then the drainage networks are examined in order to identify potential changes in river systems and thus past sediment transport pathways. These analyses point to substantial changes on both West African and South American margins of the South Atlantic, with major changes in the river systems including the Congo, Orange, Niger, Amazon and Sao Francisco. These can be tied to tectonic and base-level related causes that have affected the region through the Mesozoic and Cenozoic, and can therefore be mapped through time.

With rivers defined, elevation is added to the tectonophysiographic and depositional systems. First, the Present Day topography is rotated back through time as a very cursory backdrop to the analysis, and the elevation distribution represented by each tectonophysiographic terrain in the present is applied to its past representation on the palaeogeography maps. Fission track and other palaeoaltimetry data are used to refine elevations, palaeosols to assess areas of low denudation, and mass balance calculations to evaluate whether elevational changes are realistic with respect to downstream sediment accumulations. The methodology is fraught with uncertainties and there are constant iterations back and forth through time to ascertain whether defined changes are consistent.

The resulting landscape maps form the boundary conditions for Earth System Modelling experiments, the results of which can be directly used in predictive lithofacies modeling. In the South and Equatorial Atlantic the results are dominated by two main effects: long wavelength uplifts associated with mantle anomalies in southern and eastern African hinterlands, north-eastern Brazil and northern South America; and reactivation of uplifts, often affecting whole cratonic blocks such as the Gabon Craton, due to changes in the pole of rotation in the South Atlantic (for example, the Santonian Event, which resulted in uplifts across the Equatorial African hinterland and inversion in the Central African Shear Zone). These two types of tectonically driven hinterland change have very different expressions in the landscape. Denudation rates are much lower on the plateau highs associated with the long wavelength uplifts, with sediment supply to downstream basins dominated by incision around the margins of these uplifts, especially if there is associated reactivation of fault scarps. The inversion related uplifts seem to lead to much more intense erosion and sediment supply because of the rate of uplift but especially the resulting relief changes.



GETECH

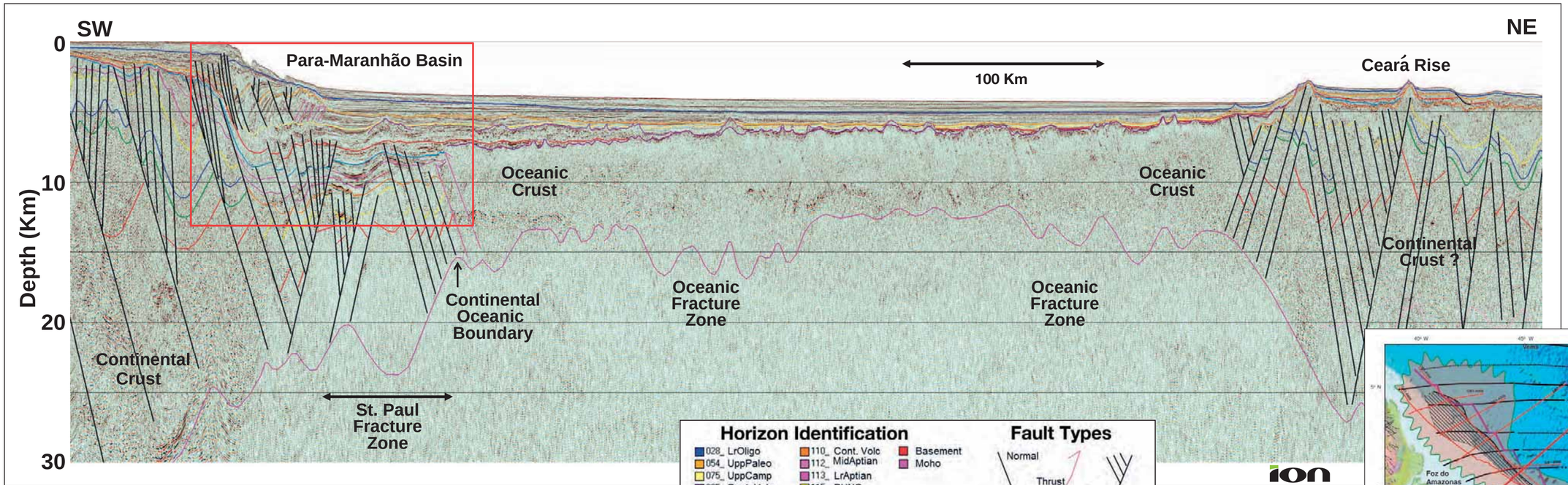
*Reconstruction of the palaeolandscape and drainage of the Cenomanian, centered on the South and Equatorial Atlantic provinces. At this time the South Atlantic margins are drained by short-headed rivers; major changes in sediment fluxes occur flowing uplift associated with the Santonian 'Event'. In the Equatorial Atlantic, longer rivers drained the long wavelength relief of the West African Plateau, in contrast to the developing larger river systems draining North-east Brazil, while the Amazon flowed west.*

## Invaluable Tools

The tectonic and landscape evolution of the South Atlantic and Equatorial Atlantic is complex, with numerous periods of reactivation that affects source to sink relationships as well as downstream accommodation space, and the geometry and nature of depositional systems. Only by pulling together all of these various processes can such tools provide robust solutions for NV exploration. But when done correctly, the results are invaluable. ■

# Ghana/Sierra Leone Lookalike Plays in Northern Brazil

Following the recent major discoveries in West Africa, a new focus has been placed on the conjugate margin in northern Brazil, where over the entire 2,200 km margin only 20 wells have been drilled in water depths greater than 500m. Using the analogy from equatorial African discoveries, it appears that the highest potential may be in the deep waters on the slope and continental rise of the Brazilian margin. ION's Greater BrasilSPAN™ data is being used to identify and map new plays similar to those currently being drilled on the African margin.

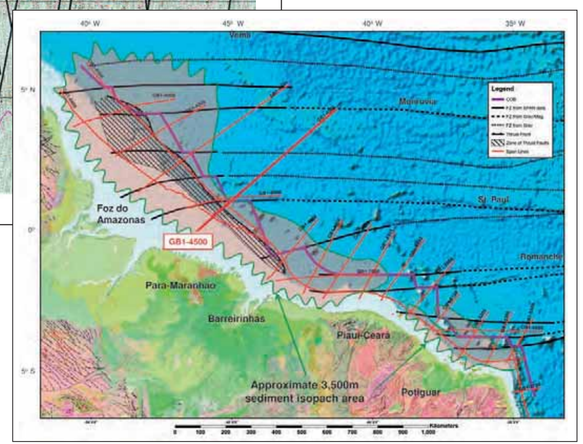



A regional deep imaging pre-stack depth migrated (PSDM) seismic line, Line GB1-4500, from ION's Greater BrasilSPAN project. The blue and green horizons at the south-west end of the line have been interpreted as sediments within a Jurassic sag basin, and Jurassic-age reflectors have also been interpreted to underlie the Ceará Rise at the north-east end of the line. About 25 km of continental crust lies above the Moho (purple), which is probably responsible for the preservation of the Jurassic sediments. The Ceará Rise is shown here as a possible continental fragment that was abandoned due to a ridge jump south of the Monrovia Fracture Zone.

Thick sections of Aptian and Albian sediments have been interpreted along the Brazilian equatorial margin, predominantly north of the Chain FZ, with the thickest accumulation north of the Romanche FZ. These sediments, more than 2.5 km thick, can be seen on the foldout line between the break-up unconformity (115_BUNC, yellow) and the top Albian (100_Albian, blue) horizons. They do not appear to have been deposited on the Ceará Rise, or have been removed by erosion. Thick (1-3 km) continental volcanics (110_ContVolc, orange) have been interpreted on the Ceará Rise, overlain by younger Santonian volcanics (085_Sant. Volc, violet) of likely mid-ocean ridge composition.

The south-western end of this line also shows evidence of Tertiary extensional and compressional faulting, with the Paleocene thrusted, and deformation lasting through the Lower Oligocene time.

Map (below) showing the five sedimentary basins of the Equatorial Brazilian margin, together with the location of the BrasilSPAN seismic lines, with Line GB1-4500 shown in bold. A total of 17,500 km of data were acquired using a 10-km long streamer between 2009 and 2010. The lines are approximately 50–100 km apart, and two strike lines follow the entire length of the shelf, almost 2,200 km. The final data has been Prestack Depth Migrated (PSDM) to 40 km, and images the crustal architecture, including the Moho, as well as providing high resolution imaging in the overlying sedimentary section. The map shows the locations of major fracture zones mapped from the combined seismic, gravity and magnetic data. The area underlain by at least 3,500m of sediment is shown in green, as this thickness has been arbitrarily used as the limit for petroleum plays in the area. (The landward boundary of this isopach is not defined because of lack of coverage in the shallow-water areas of the shelf). The area in cross-hatching (extending from Foz do Amazonas Basin to Barreirinhas Basin – a distance of almost 800 km) marks a zone of gravitational thrust faults along with other potential trapping opportunities and highlights the hydrocarbon potential of equatorial Brazil.

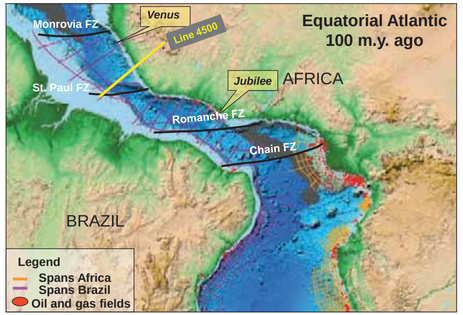


# Brazil Equatorial Margin Shows Promise

STEVE HENRY, NARESH KUMAR, AL DANFORTH, PETER NUTTALL AND SUJATA VENKATRAMAN, Ion Geophysical

As the Equatorial Atlantic opened, major oceanic fracture zones, ranging from the Chain Fracture Zone (FZ) in the south to the Monrovia FZ in the north, controlled the synrift tectonics of the basins on both sides of the Atlantic. These fracture zones were established at the time of initial separation along zones of crustal weakness in the original western Gondwana continent, and played a significant role as tectonic barriers for the sedimentary evolution of the basins.

Oceanic circulation in the early basins was highly restricted, a setting conducive to the deposition of the source rocks which are now known to have generated the hydrocarbons in the major accumulations in Ghana and Sierra Leone. The traps in these African discoveries are structural/stratigraphic and the reservoirs consist mostly of deep-water turbidites.




*A GPlates* reconstruction for Africa and Brazil at 100 Ma (Late Albian/Cenomanian). Progressive opening of the Atlantic began in the south-east in the Aptian and continued to the north-west until full oceanic circulation was established by the end of the Turonian.*
**http://www.gplates.org/*

## Complex Tectonic History

The tectonic history of the area, as exemplified by Line GB1-4500, the long regional seismic line shown on the preceding pages, is complex because the fault and subsidence pattern suggests multiple unsuccessful attempts to break the thick cratons. The first attempt documented in the sedimentary section was in the Late Jurassic (~155 Ma), followed by a second in the Valanginian (~140 Ma). The successful separation, between 115 and 105 Ma, progressed along a series of continental strike-slip faults that were the initiation points for the major oceanic fracture zones. Mapping from the BrasilSPAN project suggests that the separation initiated in the south and progressed north-westwards: Chain FZ at ~105 Ma, Romanche FZ at ~100 Ma, and St. Paul FZ at ~ 95 Ma.

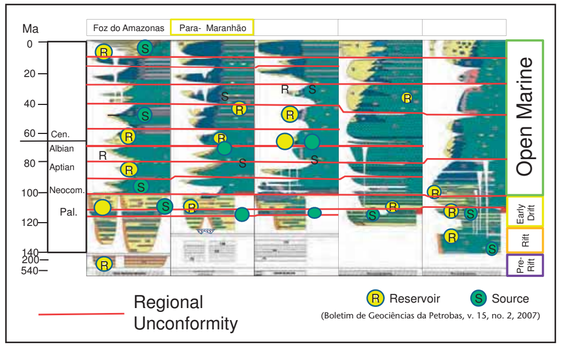
Horizons 5-12 km below the shelf in the south-west end of the foldout line are thought to be sediments within a Jurassic sag basin. Reflectors with a similar character have been drilled in eastern Brazil offshore from the Recôncavo Basin. Jurassic-age reflectors have also been interpreted to underlie the Ceará Rise at the north-east end of the line. Thick crust (> 25 Km), defined on the foldout line by the seismic character change at the Moho (purple) appears to be an important component in the preservation of the Jurassic sediments.

In the Santos and Campos Basins to the south, the rich Lagoa Feia source rocks were deposited in the Valanginian sag basin overlying a failed rift. Likewise, in eastern Brazil in the narrow offshore basins north of the offshore Recôncavo, Valanginian-age sediments have been interpreted in sag basins along the edges of the thick cratons. Similar Valanginian sag basins have been interpreted from the BrasilSPAN data in the Potiguar and Paiuí-Ceará Basins, although no sediments of Valanginian age have been observed on data from north of the Romanche Fracture Zone.

The progressive opening of the South Atlantic that began in the Barremian (130 to 125 Ma) appears to have utilized the continental strike slip faults of the north Brazilian margin. These faults would have been active at the same time as the faults that are part of the Central African Shear Zone. In Central Africa, large pull-apart basins developed in the Aptian and Albian, including the Benue Basin in Nigeria, and the producing Doba and Doseo Basins in Chad. The presence of Aptian and Albian source rocks in Central Africa, and the recent Jubilee (Ghana) and Venus (Sierra Leone) discoveries provide good support for a similar petroleum system along the Brazilian equatorial margin. Similarly, thick sections of Aptian and Albian sediments have been interpreted along the Brazilian equatorial margin, predominantly north of the Chain FZ, with the thickest accumulation north of the Romanche FZ.

Following the separation of the continents, a steep continental slope developed, as is typical for transform margins. South of the Romanche FZ, Late Aptian and Albian sediments rapidly transgressed onto the newly formed oceanic crust. North of the Romanche, where slopes were steeper, up-dip extensional faulting resulted in down-dip compression and thrusting. The age of the extensional and compressional faulting becomes progressively younger to the north-west, with recent faulting in the Foz do Amazonas deforming the sea floor. Line GB1-4500 is midway along this thrust trend and, as can be seen, the Paleocene is thrusted with deformation continuing through the Lower Oligocene.

There is also a period of igneous activity that has been estimated to be of Santonian age. It is only seen overlying the oceanic fracture zones and is probably the result of a 'leaky' Fracture Zone. The detachment for the thrusting appears to be in the high-stand shales of Upper Campanian age (75 Ma). The gravitational flows were likely triggered by the influx of sediments associated with the Maastrichtian through Paleocene low stand.

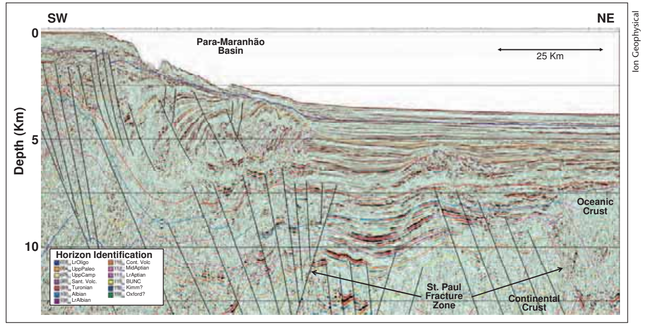



*A regional correlation chart of the stratigraphy of the northern Brazilian basins. The foldout line is an example of the stratigraphy and structure seen in the shelf to deep basin of the Para-Maranhão Basin. Equivalent sedimentary sequences can be seen in all the basins from the Foz do Amazonas to the Potiguar. Thick red lines show regional unconformities that can be traced across the basins. Either producing fields or non-commercial hydrocarbon accumulations have been discovered in each of these basins, but so far almost all the drilling has been carried out in water depths of less than 500m.*

## Promising Margin

Source rocks exist in all the basins in the Aptian/Albian interval, as well as in the Cenomanian and Upper Cretaceous/Lower Tertiary sequences in some of the basins. Sand-rich potential reservoir intervals as well as outer shelf carbonates are also present in the each of the basins. Opportunities for stratigraphic traps on the outer shelf and upper slope are abundant, while structures related to the gravitational extension updip and compression farther downdip are also prevalent in at least half the length along the shelf margin.

With the successes from the African margin in mind, explorationists need to set their sights now on the Brazilian equatorial margin. ■




*South-western end of foldout line GB1-4500, expanded so that thrust structures and the tectonic control exerted by the St. Paul FZ can been seen. The dominant fault type is strike slip, forming pop-up structures and pull-apart basins through the Campanian (075_UppCamp, lt. yellow). There is also an older period of igneous activity that has been estimated as Santonian (085_Sant. Volc.; deep violet). The line clearly shows possible traps in thrust structures as well as in the sub-thrust, in features here interpreted to be in Turonian and younger rocks.*

# Seismic Surveys Without Cables

## Cableless systems have been the long-time dream of exploration seismic for many years. Has it finally been attained?


Wireless Seismic Inc

*Cable seismic systems require large numbers of personnel, known as 'juggies', so called because the original geophones were big cylindrical devices resembling jugs.*

**DOUG CRICE, Wireless Seismic Inc**

The desire to conduct surveys without cables has been an elusive, perhaps unattainable goal since the dawn of seismic exploration. A fundamental problem is that channel counts – the number of geophones on the ground – have been growing faster than wireless technology grew to support them. Has technology finally caught up to make cableless seismic surveys practical?

### Strings of Geophones

In the late 1970s, seismic surveys were done with cabled, multi-channel acquisition systems, conducted in what we now call 2D: a string of geophones in a line connected by multi-conductor cable, typically hundreds of wires in a heavy polyurethane jacket. The cables consisted of short sections connected by hermaphroditic connectors, the length of individual segments set to what a person could carry. As the number of channels grew, the lines got longer and the segments got shorter. Each segment had what are called 'takeouts' where geophones were attached.

With the introduction of 3D surveys, 'distributed systems' were developed to support the larger arrays of parallel lines of geophones. Modules called remote


Wireless Seismic Inc

*A Wireless Remote Unit in the field*

boxes digitized the signals from a handful of geophone groups. The digital data was sent down a coaxial or fiber-optic cable to a central recording system, eliminating electrical noise after the remote box, allowing for very long transmission paths and wide areal coverage.

However, because the geophones were separated by as much as 50m between stations, th ere were still analog cables connected to the boxes, plus the longer digital cables. Systems expanded to thousands of channels. As they grew, new problems appeared. A typical 3D seismic crew might have 150 km of a ssorted cables on the ground, so road, river and railway crossings were a problem. In many areas, animals chewed up the cables overnight, so that a few hours were required every morning for repairs. Once a system grows to 10,000 channels in West Texas, it becomes difficult to manage repairs, although much larger systems could be deployed in places like North Africa, where there is a lot of open ground and few animals.


*With a cabled seismic system, special protective covers are needed to cross a road, and even then, if something heavy like a truck comes along, the cable will take abuse. Rails and rivers are even more problematic. Cableless systems provide the answer.*

## Early Cableless Systems

Meanwhile, geophysicists considered the advantages of eliminating cables. As is the usual pattern in geophysics, patents were filed and granted long before the technology became available to make these ideas practical. People worked with what was available: there were no portable hard disk drives, cheap A/D converters, GPS timing signals, or low-power solutions suitable for easily portable batteries.

The earliest cableless seismic systems used cartridge tape drives to store the data, but because of their complexity, power consumption, weight and cost they never achieved wide acceptance. They were used only when cables were impossible, generally for environmental concerns. The OpSeis Eagle and the Fairfield BOX® offered wireless recording for modest numbers of channels, limited by the bandwidth available in the RF band.

The first cableless system to become broadly successful was the RSR™, built by Input/Output (now ION Geophysical®). This was a six-channel acquisition unit that stored its data on a disk drive. The units operated autonomously, and could be located almost anywhere. Data was collected by visiting the unit periodically and transferring it to a second device used to transport it to a central computer. The RSR features VHF radio communication that can send quality control information to a central recorder, and if you were patient, you could even display a screen image from a shot. Bandwidth was too limited to provide more than the occasional snapshot of the data.

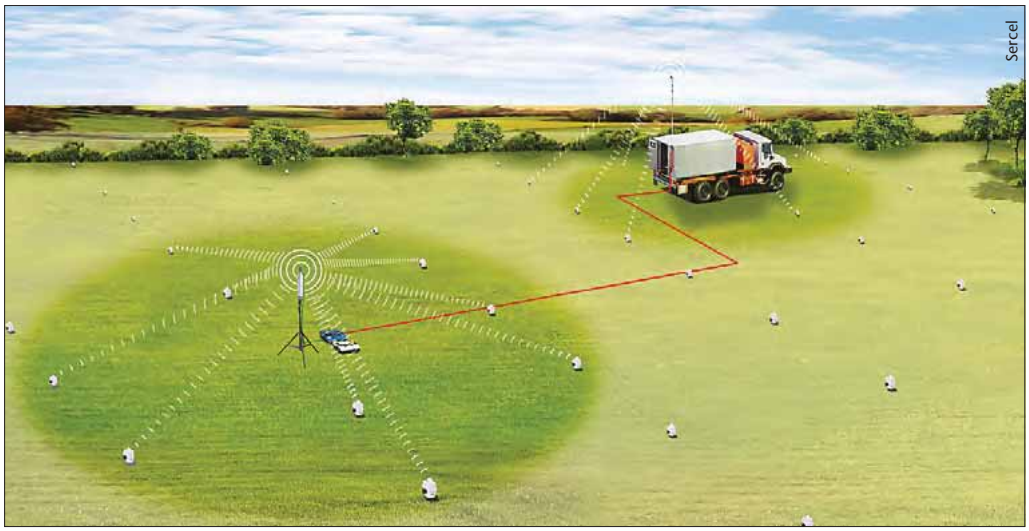
The RSR was introduced in 1996, and despite its age, is still in use today for surveys with access problems. Dawson Geophysical®, for example, used an RSR system to survey the grounds of the Dallas-Ft. Worth airport for Chesapeake Energy Corporation® – a project that would have been virtually impossible with a cabled system because of the runways, taxiways, and large buildings.

Similarly, environmental and access problems restrict the deployment of cable systems in many areas – you cannot run a bulldozer through a national park or lay cables across roads in cities and some rugged terrain.

## First Real-Time System

The first serious attempt at a full-record, real-time wireless seismic system was by Vibtech Ltd, founded in 1996 in Scotland. The system was based on cellular technology, where a group of individual units in a cell communicated with specially erected towers spread around the survey site, and (initially) connected by a fiber optic cable to a central computer. This required quite a bit of infrastructure, and still suffered from bandwidth problems. The company was

*The Fairfield Nodal self-contained sensor has minimal environmental impact. It is the only truly cableless system since there are no geophone cables.*




*Real-time Data retrieval and QC: The UNITE system allows a purpose-built wireless network to be established for the real-time transmission of recorded data to the central recorder.*

sold to Sercel® in 2006, who developed the system further under the name UNITE."

Also in 2006, Input/Output introduced a cableless system called "FireFly®" at the annual meeting of the Society of Exploration Geophysicists. This operated similarly to the RSR, with VHF radio communication to a central recorder with QC status and samples of data. The initial Firefly system was only available with VectorSeis™, Input/Output's 3-component MEMS sensor, although an adapter to allow use with conventional geophones became available later.

### Representative Systems

OYO Geospace introduced the GSR™ in September 2007. This is a blind acquisition system, with a relatively efficient transcription method, and has become the most successful of the autonomous recording systems. As of June 2011, OYO had sold about 100,000 channels; a small percentage of the number of channels of cable systems sold in any typical year – there is much room for growth.

UNITE from Sercel is a cable-free system which offers a lot of flexibility. Within a 1000m range area, remote acquisition units are able to communicate directly to the dog house, so an operator will receive data and QC information automatically and can adjust the parameters as necessary. The system can also be integrated with cabled systems such as Sercel 428XL, recording data in a single SEGD File and sending data and conducting QC in real time. It has a useful capability – drive-by data retrieval, whereby a technician carries a data retrieval device past each of the units at regular intervals. This collects data wirelessly from the units and also affords an opportunity for QC checks on battery level, sensor quality and memory status can be at the same time. ▶

## Types of Cableless Systems

Modern technology has made different cableless solutions practical. High resolution A/D converters are now affordable and easy to use, as are GPS radios for timing and location. Microprocessors and memory are practically free, and with a battery the size and weight of a brick it is now possible to power an acquisition unit for as long as required for normal seismic crew operations.

The simplest systems are autonomous units that sit on the ground and store seismic data digitally. Often described as "blind" systems, they are easy to deploy, left in the field until it is time to relocate them, and then brought back to a central computer where the data is retrieved and the batteries charged or replaced. A little higher on the scale of sophistication are the semi-blind systems. They also collect data into memory, but data can be retrieved either partially or sooner.

Highest on the performance scale are the real-time wireless systems, which transmit the complete set of seismic data to the doghouse immediately. There are tradeoffs: because of the large amounts of data, infrastructure is required. Some systems use local towers to concentrate the data into something with higher bandwidth, while others use WiFi, or radio relay methods and backhauls.

There remain a number of concerns with autonomous systems: is the unit working properly, is the survey going well – are the vibrators shaking enough, is there too much wind noise – and is the geology cooperating?

Worrying whether the acquisition units were working properly proved generally unfounded. Because contractors were concerned about spending a few weeks shaking the ground only to find that the data was not there, the manufacturers developed sophisticated field test equipment to verify that the units were meeting their specifications. It now appears that over 98% of data is successfully retrieved, and that the failures are randomly distributed. On a modern 3D-survey, data is stacked from hundreds of different source and receiver locations, and if a small percentage is missing, the quality of the final dataset is not discernably lowered.

The second concern is a little more problematic: is it too windy to collect decent data and are we using enough source energy? One project underway in Arizona is dealing with summer winds, and when the wind rises, they increase the number of impacts from four to six to ensure data quality. Is that the right number? Too few are unacceptable and too many, uneconomic. Or do you just quit collecting data for that period? Real-time data collection matters in that case.

Getting enough data to interpret the geologic structure is also a function of time and effort put into the survey. Unless the geology and acquisition parameters are well understood, real-time data collection is important to allow adjustments to the survey parameters, and to show the client the work in progress – especially if you are being paid for delivering the data.

# From rugged landscapes to stringent environmental standards, whatever your survey dishes out, the GSR can take.

The cableless Geospace Seismic Recorder (GSR) is transforming the seismic industry from Tierra del Fuego to Turkey. It's allowing contractors to work quickly, safely and nondisruptively in terrain they never thought possible – with the smallest environmental footprint ever.

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*The field-proven OYO Geospace GSR cableless seismic acquisition system is reliable, easy to use, very portable and has become the most successful of the autonomous recording systems.*

Fairfield Nodal has an autonomous system similar in concept to their successful ocean-bottom recording packages. They combine the acquisition circuitry, geophone, and battery into a single, self-contained plastic cylinder that is placed on the ground or buried flush with the surface. The units are collected after use and placed in a rack that extracts the data and charges the battery.

Wireless Seismic Inc. has also introduced a real-time cableless seismic system, eliminating much of the usual wireless infrastructure by using the acquisition units as radio relays. The seismic data is collected from the local geophone group and relayed down the line from station to station. Because the relay distance is short, the radios can be low power and still achieve a reasonable bandwidth. After the data from all the units in the line is collected at the base station, it is passed on wirelessly to a central recorder. Instructions and acquisition parameters can be sent back up the line using the same approach. Because the system operates in real time, it provides a noise monitor and a complete suite of interactive self-test functions. The central recording system resembles that of a cable-based system in form and function.

## Cableless More Efficient?

Much of the work being done with cableless systems has been for "in-fill," in combination with a cable-based survey. This is typically an area with particularly difficult access, or where extra channels are required to improve resolution over an interesting target. At present, very few crews are operating exclusively with high-channel-count cableless acquisition units, but the number is expected to grow. There have been some anecdotal reports of significant improvements in efficiency, resulting in faster surveys with smaller crews.

So, are seismic systems without cables finally within reach? Contractors are working today with cableless systems or with partially cableless systems filling in. Cables are still the norm, and probably will represent a significant percentage of seismic surveys for the immediate future, but sometimes they can't be used because of logistic, regulatory, or environmental reasons. If the anticipated economies are substantiated, crews will have to go cableless to remain competitive. Seismic surveys are continually evolving, driven by the demand for more channels on the ground, larger arrays, and tighter resolution, and of course by the fruits of technological innovation. ■



*With a real time seismic system, a central control room receives all the data being collected from the cableless sensors, allowing real time quality assurance.*


*An array of Wireless Seismic Inc. acquisition units deployed in the field.*


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# $E^3 = ST$

Harnessing **Dr. Scott Tinker's** enthusiasm and boundless vivacity may not instantly solve the global energy equation; however he is delivering a clear directive on energy that we all can embrace.


Thomas Smith

THOMAS SMITH

*Dr. Scott W. Tinker became Director of the Bureau of Economic Geology at the University of Texas at Austin in 2000 and is also State Geologist of Texas and a Professor, holding the Allday Endowed Chair. Before becoming Director, Scott had 17 years of geologic experience with the oil industry. He is Past President of both the American Association of Petroleum Geologists (2008-2009) and the Association of American State Geologists (2006-2007).*

**E**nergy, **E**nvironment, and the **E**conomy are important topics to Dr. Scott Tinker. Through nearly nonstop travels and lectures, he is working to educate us all about our use of energy and where it will come from in the near future.

"My family put in efficient lights and appliances, we drive an electric golf cart, and save some energy," says Dr. Tinker. "And although sometimes it feels like my small contribution makes little difference in our overall energy usage, if we all begin to use energy more wisely, huge savings will be realized."

"We all have passions. Mine is to educate the public on energy issues and to help bring academia, government, and industry together in a balanced approach to energy generation and use."

Scott also has a passion for the science of geology. "Geology is at the heart of all sciences! It is such a creative science with far-reaching impact." he says with a smile.

## The Film

The cornerstone of Dr. Tinker's education program will be a documentary film on energy, the working title of which is "The Bridge". (*see GEO ExPro Magazine, Vol. 7, No. 2.*) Scott did not reveal the final title of the documentary, which is very near completion and currently being marketed to major networks such as HBO.) The film will have a

complementary web site that will contain much more detailed information than the film and additional links addressing energy issues.

"One of the greatest issues facing society today with energy is our lack of understanding of the subject," says Scott. "There are many misperceptions on energy out there. We educate ourselves on health, drugs, crime, and so on. Because energy is critical to all the other systems we have in the world, an understanding of energy is a must. This is why I have been working and speaking on energy issues for many years and the film is an outgrowth of my desire to educate people on energy issues."

In order to appeal to a broad audience and establish an understanding of the concepts presented in the film, they are introducing a unique energy unit. As he explains, "When people hear about world energy consumption quantified in quadrillion BTUs, billion barrels of oil (we consume one large tanker filled with oil every 13 minutes) or generation of electricity in Gigawatt hours; well, we really cannot relate to numbers so large. To help put this into perspective, we have created a new energy unit. We consider the average amount of energy one person in the world uses in one year – about 20 million watt hours – and call it 1 Energy Life. Everything we look at is examined in terms of "energy lives."

"This new energy unit is an attempt to create an energy conversation," says Scott. "It will allow a person to compare scales of energy generation and consumption and how each person's use of energy does really make a difference. At the end of the day, *it is about each of our individual behaviors; each energy footprint matters."*

## Our Energy Future

"The most common end use energy is electricity, which we think of as clean," says Scott. "However, electricity means plugging into coal, our largest fuel source, to boil water, make steam, turn a turbine and create electricity. Natural gas is the next largest source followed by nuclear. This mix is going to be slow to change, but change it must to meet the world's future energy demands."

World energy demand is increasing at an average 1.25% annual rate and growing economies in China and India will likely accelerate global demand. Currently, about 85% of this energy comes from fossil fuels. Petroleum supplies the largest amount followed by coal and natural gas, with smaller contributions from nuclear, hydroelectric, biomass, geothermal, solar, and wind. Dr. Tinker projects fossil fuels will still make up 80% of our energy 20 years from now.

"Energy usage is not something that lends itself to quick transitions. We need to be very patient with the pace of change in our future energy mix," says Scott. "It will take probably half a century before combined coal and oil go below 50% in the energy mix. People need to understand that the renewable energy sources, although growing and valuable, currently make up a very small percentage of supply; it will require huge financial and land investments to make a big difference."



"In the meantime, we are moving towards cleaner sources of energy," says Scott. "We are gradually transitioning away from oil and solid coal towards natural gas, which is globally abundant. We are now producing natural gas from coal and shale, rocks that have never produced in the past. These unconventional resources are vast and are found in many more places than conventional oil and gas, which helps with security of supply. Although expensive, coal gasification – burning the syngas rather than pulverizing and burning the coal – with sequestration is cleaner in terms of emissions and could help address some of the supply issues we face with oil and natural gas. We also have new technologies for tapping tar sands, heavy oils, and oil shales. And of course nuclear is a vital form of power generation, with essentially no carbon emissions. This all adds up to a more diverse, cleaner and reliable supply."

## Breakthroughs

"I think two things could bring massive changes to the way we live and use energy," says Scott. "One would be the way energy is stored. We are terrible at storing energy whether it is in a flashlight, cell phone or car battery – none last very long. Energy sources such as wind and solar are intermittent by nature. The real challenge is to develop a way to store the energy when the wind is blowing and the sun is shining, to be used later when it is needed. This also provides a way to level out the huge demand peaks we see during a heat wave or a severe winter storm."

"The second breakthrough will come from the efficient use of energy," Scott continues. "Our energy system is very inefficient

in the way we transport it along wires or burn it to move cars, trucks and other vehicles.

"Some very interesting research is starting to address these challenges," says Scott. "We are developing smart energy grids and intelligent meters that will smooth out some of the energy peaks, and nanotechnology centers are looking at exciting new materials that could provide some answers for both efficient storage and transmission."

"While on this subject of efficiency, I have to talk about conservation," Scott continues. "The more efficient we get with energy systems, the more total energy we consume. That is one reason we introduced the energy life unit in our film, so that people could see they can make a difference. Unfortunately, there is also the rebound effect. Cars have become more efficient but now we have two or three and drive more miles. We also have several computers per household, bigger refrigerators, all using more energy. Ultimately, economics will drive us to make different choices and transition to other energy sources. But many efficiency gains can be made now, without changing our way of life."

### Boundless Energy

I asked Scott if he had a headline that would best describe him. He responded, "I would rather die living than live dying!" When asking about his exuberance and boundless energy, he responded with "My mother said that 'I came down the chute a runnin'." This sentiment is echoed by his coworkers and his busy schedule. Scott is traveling, in meetings, and working nearly non-stop week in and week out.

Scott has had a deep history with geology and the energy business. His father was a long-time geologist with Shell. Yet when it was time for college, Scott entered Trinity, a liberal arts university in San Antonio, Texas with no plan to go into geology. It was Professor Ed Roy's influence as educator and counselor at Trinity that got Scott excited about geology and he graduated magna cum laude, top of his class in both geology and business administration. Scott went on to get a M. S. in geology from the University of Michigan in Ann Arbor where his advisor and mentor was the prominent carbonate researcher and professor James Lee Wilson. This set Scott up later for a Ph. D. from the University of Colorado in Boulder.

Outside his work, Scott's other passion lies with his wife of 28 years and their four offspring, ranging from 21 down to 10 years. "Our big thing for family time is to travel," says Scott. "We will go on four to six week driving trips to different parts of the country, learning about the history, hiking, and enjoying what each area has to offer. We get books on tape to fit where we are going; we listened to Poe in the north-east and Killer Angels before visiting Gettysburg."

Scott on our future: "The big change happening globally is the flow of information. We cannot keep information from the young people of the world. Our job is to give kids the tools to bring change peacefully and with a global conscience. I am very optimistic about the future; we have the resources to do it and as I travel around I see young people with a sparkle in their eyes. Our kids will solve future energy problems and challenge us all to be better custodians of our planet." ■

## The Bureau of Economic Geology

Since Dr. Tinker took over the Bureau as Director in 2000, the organization has more than doubled in staff and quadrupled its research funding, as its importance to the State of Texas, the nation and the energy industry has grown. Over 200 people from 22 different countries work there.

"Scott gave strong leadership to the researchers here because he has also been a researcher (at Marathon's Research Center)," says Eric Potter, Program Director for the Energy Division at the Bureau. "A person can flourish in this environment where they can have a lot of independence. Here we have the leaders in several research communities working together."

"Scott is also a good analyst who can figure out what is important and how to achieve it," Mr. Potter continues. "We are committed to helping solve society's problems. From new cutting edge nanotechnology to carbon sequestration, our researchers are working on practical products and concepts useful to society."

*Dr. Tinker (front right) and Harry Lynch, director of Scott's documentary, are pictured in McKittrick Canyon (north-west Texas), one of the film's many and varied locations from around the world.*

Wilson Waggoner

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# Unlocking the Secrets of the Barents Sea

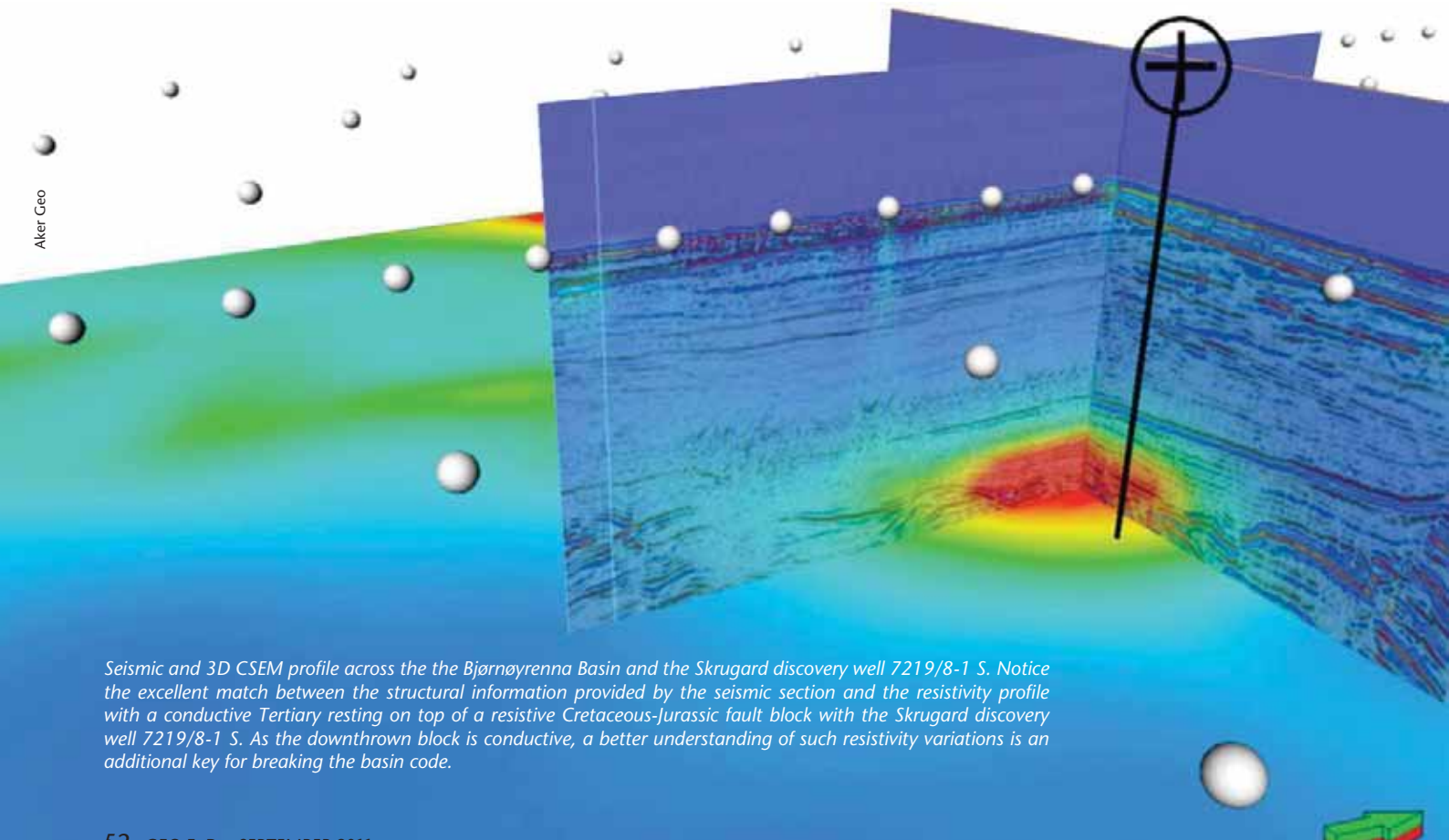
HALFDAN CARSTENS

The complexity of the Western Barents Sea necessitates the use of all available geological and geophysical data when undertaking regional interpretations, play fairway assessments and prospect definition.

Several recent oil and gas discoveries in the Western Barents Sea are now triggering an increased interest in this huge, largely unexplored petroleum province far beyond the Arctic Circle.

First, Statoil announced an oil and gas discovery with well 7220/8-1 – Skrugard – on April Fool's Day, in the Bjørnøyrenna Basin. It contains at least 250 MMboe, maybe up to 500 MMboe, within Jurassic sandstones. A 33m gas column and a 90m oil column were encountered (GEO ExPro Vol. 8, No. 3). Later, during late spring, Total drilled 7225/3-1 – Norvarg – far north on the Bjarmeland Platform. The well proved gas in three different layers within the Triassic. It has not been finished yet, but rumours say it may be a significant discovery.

Then Lundin Norway made another gas discovery in July with well 7120/2-3S – Skalle – further to the south, on the southern flank of the Loppa High, and only 25 km north of the producing



Aker Geo

*Seismic and 3D CSEM profile across the the Bjørnøyrenna Basin and the Skrugard discovery well 7219/8-1 S. Notice the excellent match between the structural information provided by the seismic section and the resistivity profile with a conductive Tertiary resting on top of a resistive Cretaceous-Jurassic fault block with the Skrugard discovery well 7219/8-1 S. As the downthrown block is conductive, a better understanding of such resistivity variations is an additional key for breaking the basin code.*

Snøhvit field, in the Hammerfest Basin. The well proved gas in three separate zones with a total column of 95m in Jurassic and Cretaceous sandstones.

The gas field Snøhvit has been producing since 2007 (1 Bboe recoverable gas and condensate), while the oil field Goliat (220 MMboe) is under development and is expected to start flowing in 2013.

"This follows 30 years of meagre results with only two commercial discoveries, in spite of close to 90 exploration and appraisal wells and hydrocarbons shows all around," says Bengt Larssen, President Exploration with Aker Geo.

## An Integrated Approach

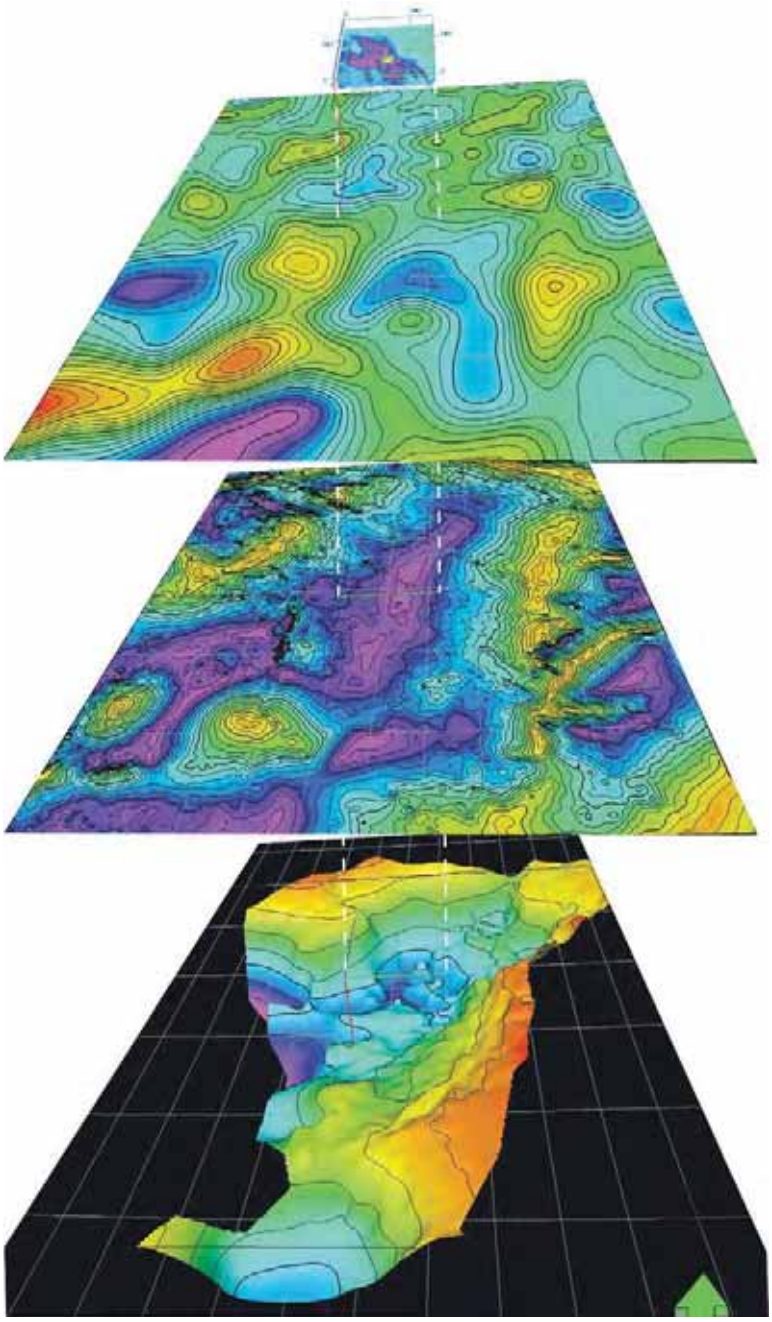
"It is well known within the Norwegian petroleum community that the Skrugard prospect is associated with a prominent flatspot. It has now also been confirmed by EMGS that the rumoured electromagnetic anomaly actually exists and has been used in de-risking the prospect. It is thus no big surprise that the structure contained hydrocarbons. The uncertainty was the type of hydrocarbons and volumes," he adds.

According to Larssen, the seismic data also shows widespread gas leakages in this area, meaning that there are – beyond any doubt – hydrocarbons in the system. The question is no longer "if", but "where" and "how much".

"The area needs to be better understood in order to unlock the values, both in terms of new play fairways and accumulations of hydrocarbons. One way of doing so is to use all available geological and geophysical information in an integrated study", Larssen claims.

The western half of the Barents Sea is considered very challenging. It is characterized by few wells (80 boreholes over 160,000 km$^2$, an area equivalent to the entire North Sea) and a variable quality of the seismic data, together with several highly tectonized basins and a complex uplift history. Recent 2D and 3D seismic surveys, with state of the art processing, do however effectively improve the quality of the seismic. Satellite gravity and airborne magnetic data supplement the seismic and geological data and serve to increase the overall understanding of the structural and basin development.

*Bjørnøyrenna Basin with the Skrugard discovery. Seismic structural map, Base Cretaceous (bottom) with the magnetic tilt derivative map, reduced to the pole, High Pass filter 15 km, gravity free air anomaly map, HP filter 15 km (middle) and (top) 3D CSEM (Controlled-Source Electromagnetics with a towed dipole transmitter and arrays of sea bottom dipole receivers) anomaly map showing a strong salt induced resistive anomaly close to sea bottom (cross section on page 56). The structural trend in the CSEM map corresponds to an offset in basin overall NNE-SSW trend.*



Aker Geo

In recent years, other geophysical data sets have penetrated the market, including Controlled Source ElectroMagnetics (CSEM) and Magnetotellurics (MT). The CSEM data is now extensively used by some companies to de-risk their prospects ahead of their license applications or drilling, while MT is still in its infancy offshore.

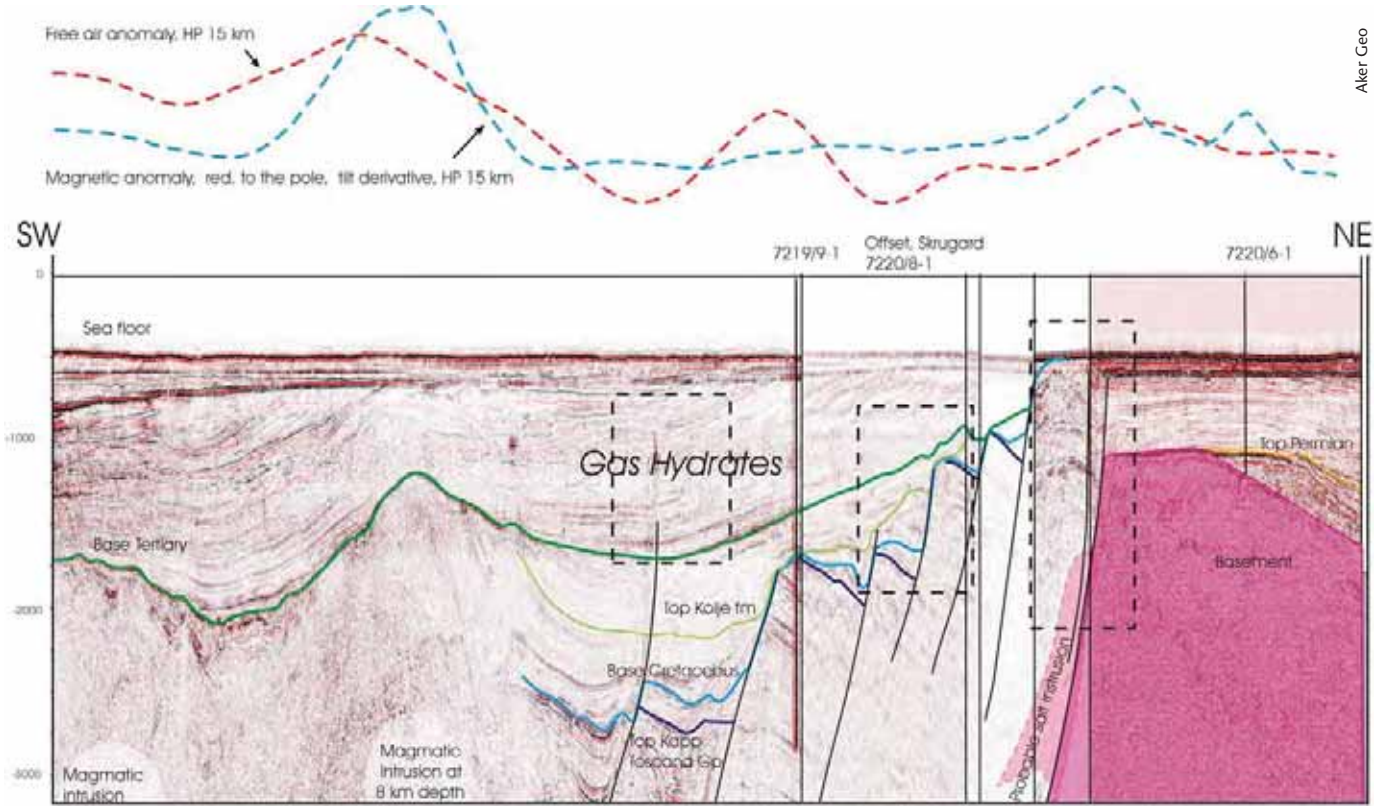
"We consider it very important that all these data sets should be an integral part of a regional assessment", says Guy de Caprona, senior geologist with Aker Geo.

"During the last decade Aker Geo has conducted comprehensive regional hydrocarbon potential studies on the Norwegian continental shelf, utilising mostly public domain data. The success of

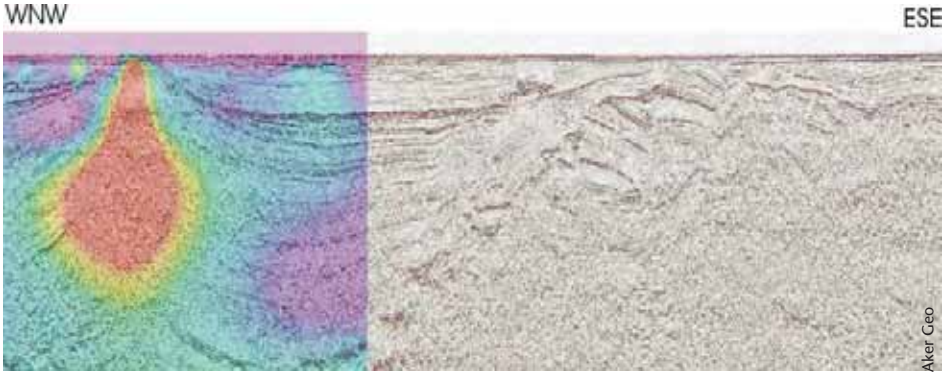
these reports has to do with integrating all available data resulting in the identification of play fairways," adds Larssen.

The company, based in Oslo and Stavanger, has – very timely – just finalised the most recent study in the Barents Sea, using all kinds of geological and geophysical information in addition to seismic and well data.

"The results are very promising," says Caprona, referring to the fact that gravmag and MT improve the understanding of structural and basin development, as the depth of imaging of these tools goes well beyond seismic. Gravity and EM help identify subtle structural features such as salt induced structures, while gravmag data anomalies




*Composite seismic line with gravity and magnetic profiles, with inserts, across the Loppa High and the Bjørnøyrenna Basin. The gravity data show that deep Carboniferous salt, identified on MT data, has used the Loppa High western bounding faults as migration conduit. A correct imaging of the geometry of the salt bodies is quintessential for the understanding of the plays. In this basin, the imaging capacity of seismic does not go beyond the middle Jurassic.*




*Seismic section and an inverted 2D MT profile (preliminary result): the resistive body in the center of the basin with low density is interpreted as a salt diapir. The naturally occurring electromagnetic field in the earth subsurface (magnetic field and its variations inducing electric or telluric fields) is recorded with the same dipole receivers as for CSEM data and at the same time. Beyond the depth of the seismic profile, not shown here, the MT data show an extensive, thick and highly resistive body interpreted as Carboniferous salt.*

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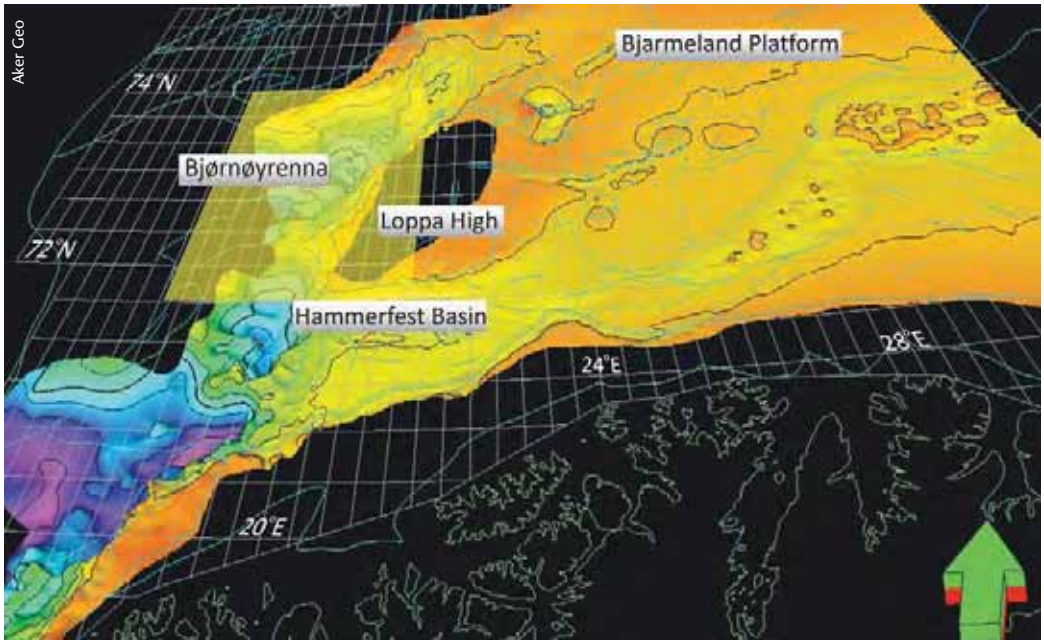
also pinpoint highs of possible magmatic origin.

Caprona adds that "developing play fairways is also improved by a multi-data approach. In addition, EM data can be used to de-risk prospects with respect to the content of hydrocarbons."

## Unique Systems

The western Barents Sea includes a number of different basins with their own unique petroleum systems and plays. Up to now, only two plays have been confirmed, but with the three recent discoveries this number has certainly increased.

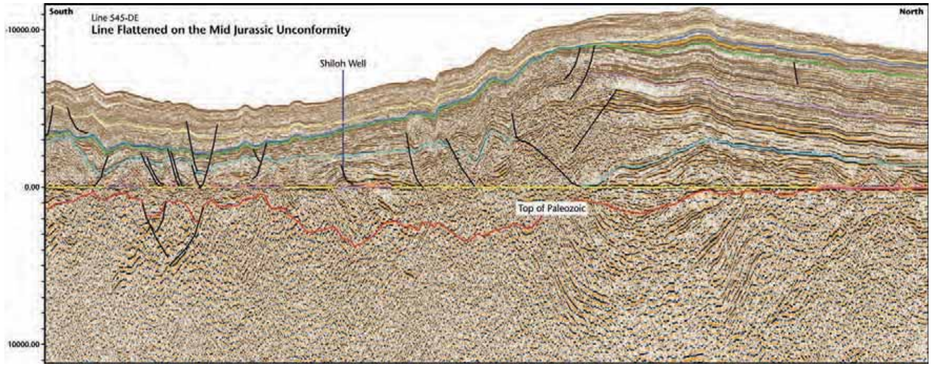
These recent discoveries will of great help to "break the code" and understand the petroleum systems of areas west of the Loppa High and, applying an integrated approach, to piece together the puzzle of hydrocarbon systems of the Barents Sea in general. ■



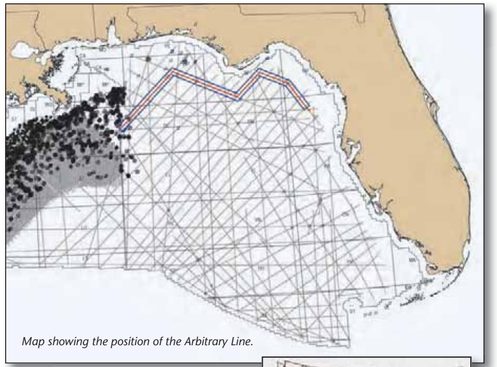

*Perspective view of the Base Cretaceous in the western Barents Sea. In yellow, the highlighted area shown on the expanded figure*

# Offshore Florida: Regional Perspective

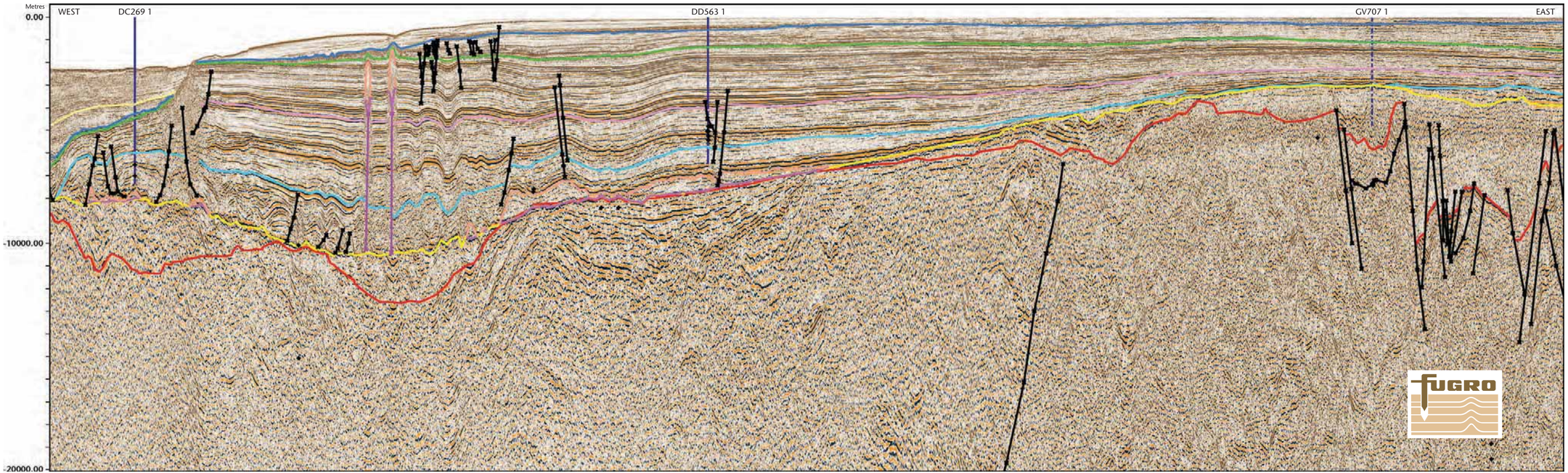
## New long offset seismic data provides insight into the petroleum potential and structure of the Eastern Gulf of Mexico




*Paleozoic sedimentary structures are more evident when the line is flattened on a horizon. This line is flattened on the Base of Jurassic, showing a better view of the Paleozoic section below the flattened horizon.*



*Map showing the position of the Arbitrary Line.*




*Arbitrary regional line across the Northern Florida Shelf and slope. The line traverses the Shiloh Well (DC 269) on the West end of the line, crosses into the Destin Salt Basin and across the shelf towards Tampa, Florida. Paleozoic structures are present on the shelf portion of this line. The red line is the Top of Paleozoic interpretation. The Pre Stack Depth Migrated line extends to a depth of 20 km.*

# What Lies Offshore Florida?

**Despite recent political events cooling interest in the area, newly acquired seismic shows that there remains considerable potential in the easternmost part of the Gulf of Mexico.**

KENNETH MOHN, FUGRO MULTI CLIENT SERVICES AND BRUCE E. BOWEN, CONSULTANT

In the Federal Waters offshore the West Coast of Florida and Alabama there has been a renewed interest in exploration, although recent political events had cooled interest in this region for a while. New regional long offset seismic data acquired by Fugro in 2009 and 2010 suggests that the Eastern Gulf of Mexico (EGOM) shelf and slope show potential for new oil and gas plays. Integration of this seismic with newly acquired gravity, magnetic and biostratigraphic data, together with well log information, is providing insight into the evolution of the Gulf of Mexico basin.

The new seismic data extends from the Florida coast westward to the central Gulf, tying previous surveys acquired by Fugro with three lines extending to the Texas shelf. The Deep East Survey is made up of over 35,000 km of 10 km offset seismic data along with gravity and magnetic data acquired across the shelf in various orientations, providing a comprehensive look at the deep structure. The Survey ties most of the exploration wells on the Florida shelf and incorporates the geological interpretation from those drilled on the slope.

## Eastern GOM Geology Revealed

Geological data from the EGOM indicates rocks range in age from Paleozoic to Recent. New regional seismic data suggests that folded Paleozoic age rocks extend under the Florida Shelf. The folds have been extensively modified by subsequent rifting in the Triassic and early Jurassic. The grabens created by this rifting are filled with clastic and evaporite sediments, which are distributed extensively across the shelf but are relatively thin. Deeper sediments that had been interpreted as Triassic basin fill on older data now appear to be folded Paleozoic rocks. Thick Paleozoic strata are also found in the southern part of the Eastern Gulf of Mexico along the border with Cuba where continental – transitional to oceanic crustal boundaries are not always clearly defined. Seismic data across the margin suggests there are early stages of rift that failed or translated to the Atlantic Margin at some point before or during the Permo-Triassic.

Jurassic Cotton Valley Group, Smackover, Norphlet Formations and the Louann Salt extend southward from the Florida panhandle onto the Florida shelf and slope. However, the area is at the Eastern Margin of the Gulf of Mexico Salt Basin, where less salt formed than in the central Gulf of Mexico. Salt was also deposited on the paleo-shelf in the Destin Salt Basin. The thickest parts of the salt basin are located around the base of the modern Florida Escarpment where paleo salt rafts were able to form.

## New Plays and Ideas

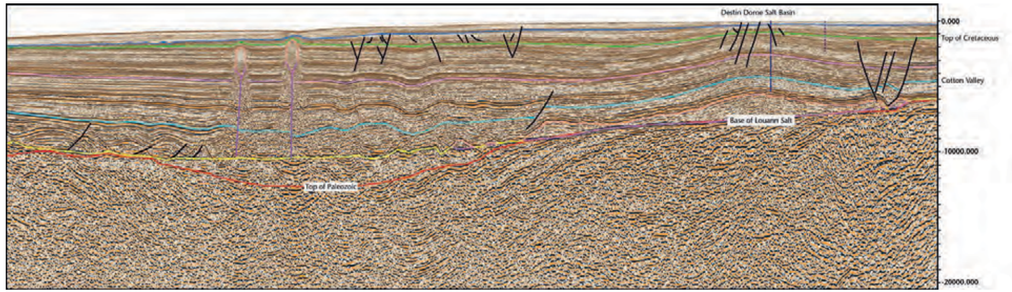
The Eastern Gulf of Mexico will be explored as an extension of current plays being made both onshore and offshore Louisiana and Alabama. Interpretation and integration of new data will help to develop new ideas for the region. One of the more recent plays in the EGOM is the Southern and Eastern extension of the Jurassic Norphlet Formation. Interest in this play increased with the results from the Shiloh Well, drilled in Desoto Canyon 269 by Shell and partners in 2003. This well, drilled to approximately 7,300m (24,000 ft), encountered hydrocarbons in the aeolian Norphlet aged Jurassic sands, with reported porosity readings that rivaled the Norphlet sands from wells drilled in the shallow waters offshore Alabama. Although described as a discovery well, it is still being evaluated by the operators. A second discovery in the Norphlet was made in 2007 in Desoto Canyon 353. This well also encountered hydrocarbons in Norphlet aeolian sands, where average porosity was reported at 20%. Possible solids in the hydrocarbon column may restrict permeability. The presence of aeolian sands in these wells suggests a much larger extent to the Norphlet Formation.

The eastern extension of the Jurassic Smackover Formation is another potential play. New seismic data shows there are several facies changes within the Jurassic as it is followed south and nearshore across Florida.

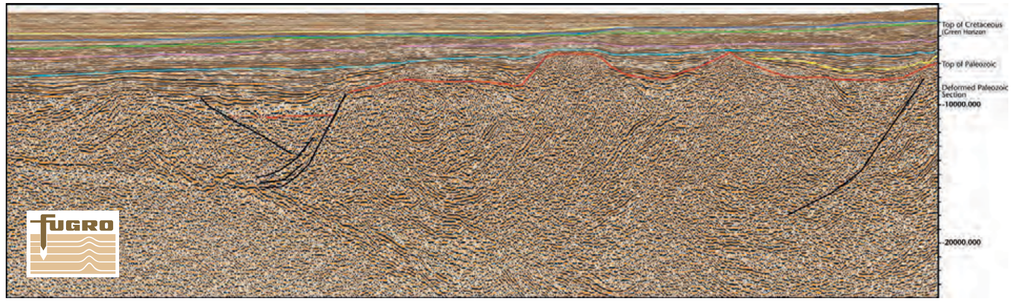
Cretaceous age sediments are found throughout the Eastern Gulf of Mexico. Some of the earlier plays made in the southern shelf area are Albian in age. Drilling activity in Cuba and Mexico suggests there could be good potential for these sediments in the Eastern Gulf of Mexico; however, to date the drilling is sparse, and with the lack of drilling, there is still a lot that needs to be understood about their prospectivity.

In the southern region of the Eastern Gulf of Mexico there are interesting structures found in the Paleozoic rocks along the southern boundary with Cuba. These sediments suggest a possible collision with Cuba from the south, forming large structures. In 1959, Gulf Oil produced live oil from a well drilled into Cretaceous age dolomites off the Marquessa Key. Several older wells that can be tied to the seismic data will provide some insight into the shallow regional geology. There are no deep penetrating wells offshore the southern coast of Florida to date.

Fugro is in the process of interpreting the regional data as well as integrating these data with new biostratigraphy from some of the historical wells drilled offshore Florida. This information should provide new insights into the petroleum systems and geology of the EGOM. Large 3-D surveys are also planned for this exciting offshore margin for the next phase of exploration. ■




*Line across the Destin Salt Basin. Destin Dome was an early gas discovery from the 1980s offshore Florida.*




*Seismic line that extends across the southern region near the border with Cuba. Note the Paleozoic structures in the deeper part of the section.*

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# Marine Seismic Sources

## PART IX: SEISMIC SURVEYS AND FISH

### What is known about the impact of seismic surveys on fish and fisheries?

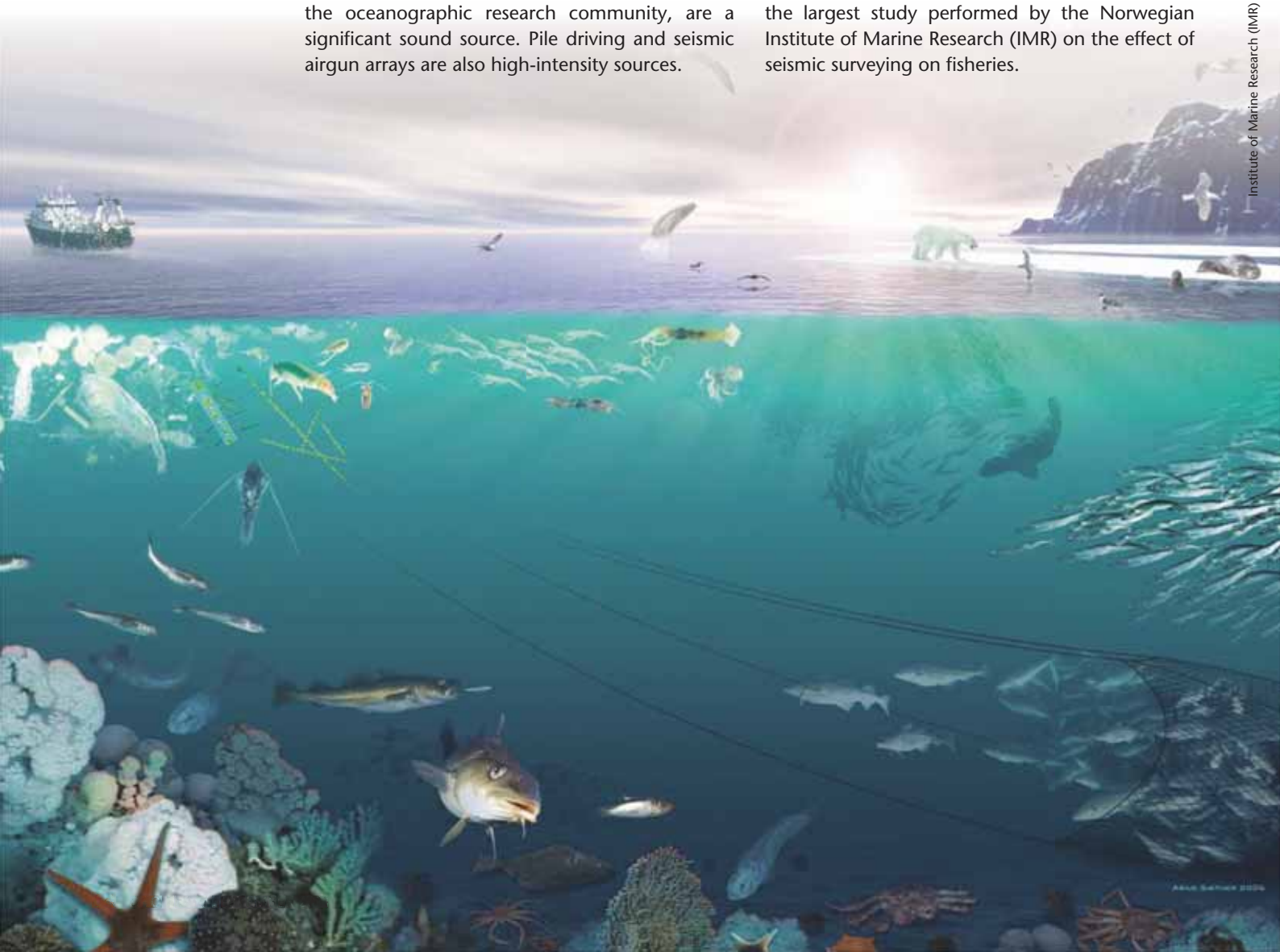
*"I know that the human being and the fish can coexist peacefully."*

**George W. Bush**
43rd U.S. President (1946- )
Saginaw, Michigan; September 29, 2000

MARTIN LANDRØ AND LASSE AMUNDSEN

There is growing interest in understanding the effects of human-generated sound on fish and other aquatic organisms. The sources of anthropogenic sounds are many. Boats and ships are a major source of noise, and sonars, not only used by navies but also by the shipping and fishing industries and the oceanographic research community, are a significant sound source. Pile driving and seismic airgun arrays are also high-intensity sources.

When a seismic survey is conducted, fish in the area hear the sound of the air guns and will often react to it, but how they react will depend on many factors, and it is difficult to conduct unambiguous studies in order to map the reaction patterns. Here, we summarize the most recent and, to date, the largest study performed by the Norwegian Institute of Marine Research (IMR) on the effect of seismic surveying on fisheries.



Institute of Marine Research (IMR)

## Studies on Fish and Fisheries

Many studies have been conducted on the effect of seismic signals on fish in all stages of life. These include studies of possible direct damage in the very early stages (eggs and fry), but since adult fish can move away from the sound source if they are disturbed, the studies for this group mostly concern behavioral effects.

Organisms can be damaged when exposed to sound pulses with a rapid rise time (i.e. rapidly increasing sound pressure) and a peak value of 230 dB or more. Sound pulses from air guns will often have a relatively slow rise time, and for this reason organisms can tolerate a higher peak pressure from these than from, for instance, underwater explosions. Sound pressures with a peak pressure of more than 230 dB will only occur in the immediate vicinity of the air guns, within a radius of just a few meters.

Dalen et al (1996) concluded that there is such a small amount of eggs and fry present within the danger zone that damage caused by air guns will have no negative consequences for the fish stocks. They calculated that the mortality caused by air guns might amount to an average of 0.0012% a day. In comparison to the natural mortality rate of 5–15% a day, the effects of seismic-induced damage seem insignificant.

The interaction between petroleum exploration and fish is a central issue in Norway, Australia and Brazil in particular. In Norway, the IMR executes an oil-fish programme with the objective of generating new knowledge about the acute and long-term effects on fish and other marine organisms of discharges of oil to the sea and chemicals used in drilling and production. It also seeks to obtain new knowledge about the effects of seismic shooting on fish and other marine organisms.

## The Lofoten and Vesterålen Survey

From 29 June to 6 August 2009 the Norwegian Petroleum Directorate (NPD) carried out a 3D seismic survey (approximately 15 x 85 km$^2$) outside Vesterålen in an area known as Nordland VII, about 250 km south-west of Tromsø in the Norwegian Sea. The period was chosen based on advice from the Directorate of Fisheries, the IMR and the fishermen's organisations, with the aim of conducting the survey during a period when the seismic acquisition activity would cause as little inconvenience as possible to the fishing industry, and avoiding spawning periods.

The seismic vessel was equipped with eight streamers and two seismic sources, each with a total volume of 3,500 cu.in. (57 l). The sources were fired alternatively in a "flip-flop" configuration at 138 bar (2,000 psi) every 10s. A total of 41 lines, around 85 km long and 400m apart, were shot.

At the same time, the NPD initiated and funded

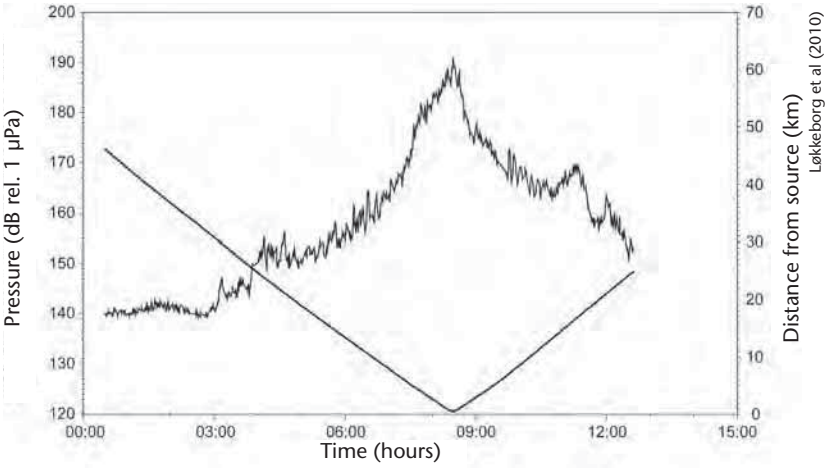

*Lumpfish larvae, a few weeks old. Fishing after Lumpfish dates back several hundred years. The eggs from the Lumpfish, found in the Atlantic between January and September, make an inexpensive caviar usually served as an appetizer.*

a NOK 25 million research project, one of the largest ever conducted, with the task of examining the consequences of seismic data acquisition on the presence of the fish species normally caught in this area: Greenland halibut, redfish, ling, pollack, haddock and saithe (all hearing generalists). The institute commenced its studies 12 days prior to the start-up of the seismic data acquisition, which took 38 days, and continued for 25 days after the activities stopped. As the chartered gillnet and longline vessels were fishing, a research vessel worked with another chartered fishing vessel to map the occurrence of fish and plankton in the area using echo sounders and sonar. In addition, stomach specimens were taken from the catches, and recordings were made of the sound from the air guns on the seismic vessel.

## Sound Levels Recorded

The airgun sound pressure was measured at the sea floor by deploying a hydrophone rig at various

*Sound pressure level (peak value) at hydrophone rig deployed at 184m depth as function of airgun distance. The closest distance is around 500m.*



## SEISMIC SURVEYS AND FISH

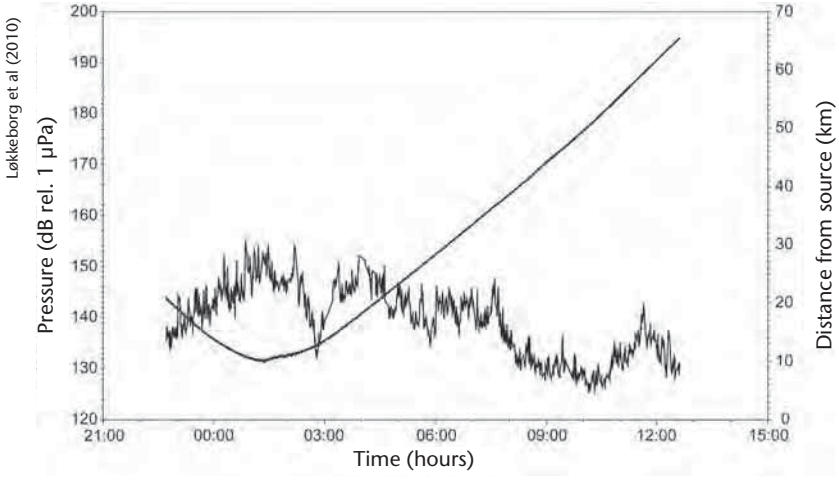
locations. The figure shows the sound pressure level from one seismic survey line relative to the distance from the airgun array. The hydrophone rig was at 184m depth. At the start of the line, about 46 km from the rig, the sound pressure level was measured at 140 dB re 1 µPa, and it kept almost constant until the vessel was at 30 km distance. As the vessel approached, the sound pressure level steadily increased up to 170 dB @ 6 km. Then the level increased more rapidly and the maximum at 191 dB was obtained when the vessel passed close at distance of 500m. The sound level turned out to be somewhat higher with distance after the vessel passed than that when it approached the rig, probably due to variation in water depth. (The shallower the water, the stronger will be the acoustic signal recorded in the water column).

The measurements show that the fish in the survey area were exposed to varying levels of sound pressures, depending on their distance from the seismic vessel. At 30 km distance from a fish field the sound pressure level was 140 dB, which is well above the hearing threshold of codfish but still below their threshold for behavioural change.

The highest sound level measured at the hydrophone rig at a depth of 184m was 191 dB, when the vessel passed at a distance of 500m. At this level, fish at this distance would be expected to react strongly if they have not already chosen to swim away, with known reactions including increased swimming activity, startle responses, changes in schooling behaviour, and vertical movement.

Sound measurements in the area of line catch of haddock showed a sound pressure level of maximum 155 dB @ 10 km. Fish can hear this level but it will probably not induce behavioural changes. For several weeks the seismic vessel operated many kilometres away from the haddock lines, so the fish were first exposed to low sound levels over a long time. Then the vessels approached the catch area, and the sound level gradually increased.

*Sound pressure level (peak value) at a hydrophone rig deployed at 73m depth as function of air gun distance. The closest distance is around 10.1 km when the maximum sound pressure level was 155 dB re 1 µPa.*




Fish are known to adjust to external influences. For instance, a novel sound in their environment, like seismic, may initially be distracting, but after becoming accustomed to it their response to it will diminish. This decrease in response to a stimulus after repeated presentations is called habituation.

Habituation may have led to the higher response levels for haddock. However, lower line catch rates for haddock as the seismic vessel approached the lines indicate that the haddock reacted to the seismic sound at closer distances.

### Effect of Seismic on Fisheries

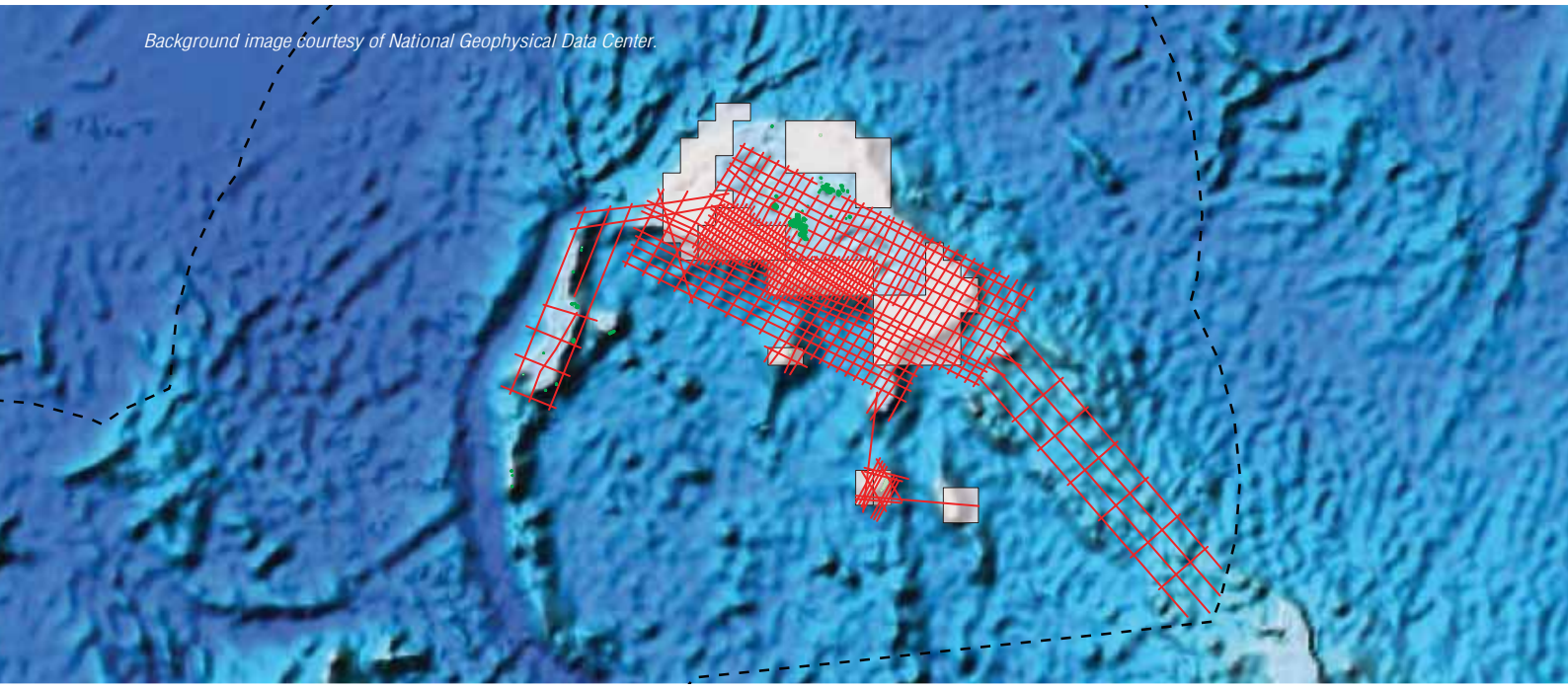
The survey clearly indicated that fish react to the sound from the seismic guns by changing their behavior, resulting in increased catches for some species and smaller catches for others. It appears that pollack and parts of the schools of saithe migrated out of the area, while other species seemed to remain. Analyses of the stomach contents in the fish caught did not reveal changes attributable to the seismic survey. Neither were any changes in the distribution of plankton proven during the seismic data acquisition.

The most probable explanation for both increased and reduced catches for the different species and types of fishing gear is that the sound from the air guns put the fish under some stress, causing increased swimming activity. This would, for example, explain why Greenland halibut, redfish and ling were more likely to go into the net, while long line catches of the same species declined.

However, the results of this study, showing few negative effects of seismic shooting, deviate from the results of previous studies, which demonstrated considerable reductions in the catch rates for trawl and line fishing. In research from the North Cape Bank in the Barents Sea in 1992, reported in Engås *et al* (1996, 2002), the seismic acquisition activity was concentrated within a smaller area, 81 km$^2$. The vessel was equipped with two streamers and one 5,012 cu.in. seismic source. There were 36 sail lines, around 18.5 km long, with a separation of 125m, compared to 450m for the Vesterålen survey, entailing a stronger and more continuous sound impact on the fish than in the Vesterålen study. In terms of the number of shots per square kilometer and hour, the sound influence was approximately 19 times higher in the 1992 survey than in the Vesterålen survey (Løkkeborg et al, 2010).

Seismic has been acquired offshore Norway for almost 50 years. The technology has become more sophisticated since the 1990s, largely as a result of the number of streamers that seismic vessels can tow. A high number of streamers implies that the

# NEW **SEYCHELLES**...




# ...NON-EXCLUSIVE **2D SEISMIC SURVEY**

**Fugro and Geomahakarsa have recently acquired ~20,000 km of 2D seismic data in the Seychelles.**

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## SEISMIC SURVEYS AND FISH

sail lines have larger spacing; thereby, the number of shots in the area is reduced. This is positive for fish and fisheries. In addition, the sensor systems in the seismic streamers are gradually being perfected, so that streamers can be towed at greater depths where ambient ocean noise is less, thereby perhaps accomplishing seismic shooting with lower decibels of sound.

We will discuss the issue of seismic and fish further in a later edition of GEO ExPro. ■


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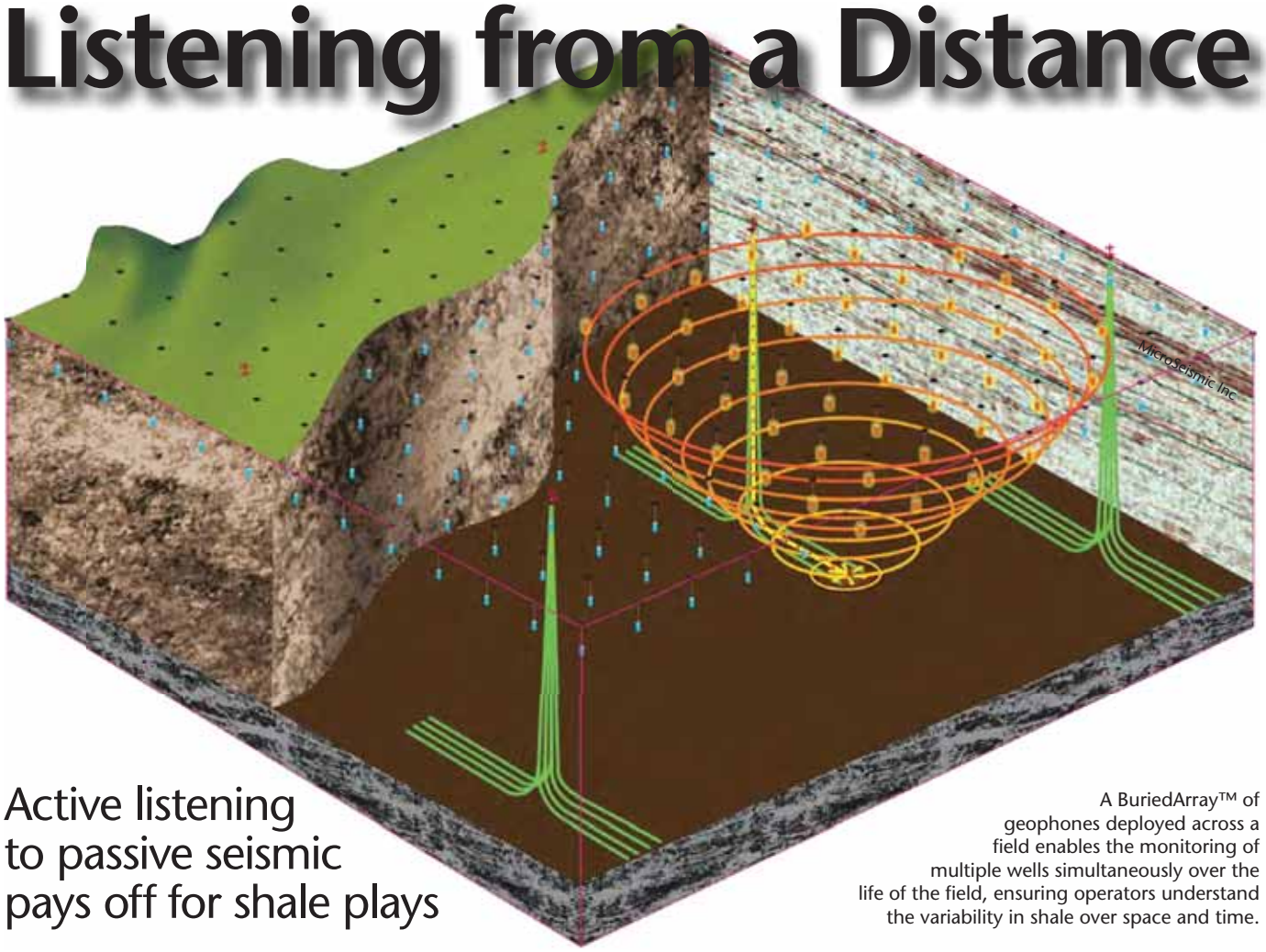
*Lasse Amundsen is adjunct professor at the Norwegian University of Science and Technology (NTNU) and at the University of Houston, Texas.*

*Martin Landrø is professor in Applied Geophysics at NTNU, Trondheim, Norway.*

*Fishing is a mainstay of life in Røst, one of the remote Lofoten Islands north of the Arctic Circle, near the test area chosen for the NPD survey.*

# Listening from a Distance




## Active listening to passive seismic pays off for shale plays

A BuriedArray™ of geophones deployed across a field enables the monitoring of multiple wells simultaneously over the life of the field, ensuring operators understand the variability in shale over space and time.

TED MOON

The past decade has seen a major transformation in gas production in the United States, driven mainly by the development of shale gas plays. According to the US Energy Information Administration (EIA), the proliferation of activity into new shale plays has increased shale gas production from 0.39 Tcf in 2000 to 4.87 Tcf in 2010, or 23% of US dry gas production. By 2035, EIA expects shale gas to represent 46% of US natural gas production.

This expansive growth in shale gas development, seen from the Barnett to the Marcellus, would not have been possible without the combined technology revolutions of advanced horizontal drilling techniques and hydraulic fracturing. These techniques have opened access to previously inaccessible, low-permeability shale gas reservoirs, allowing companies to profitably produce natural gas from these reservoirs for the first time.

However, this incredible opportunity has brought with it closer public scrutiny and increased environmental concerns, particularly the fear that hydraulic fracturing techniques, and the fracturing fluids used, may have long-term detrimental effects on the water table and nearby communities. Therefore, meeting the dual drivers of commercial and environmental sustainability has prompted the development of innovative techniques for monitoring and mapping fractures in the shale.

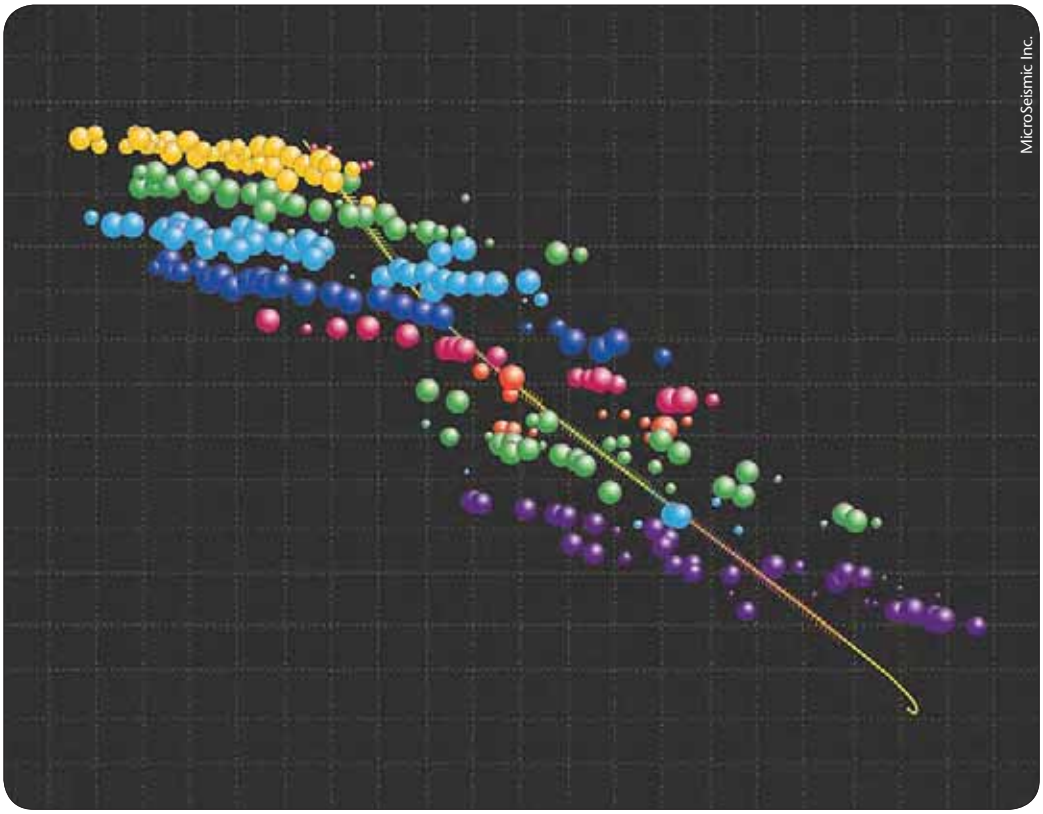
This is where MicroSeismic Inc. (MicroSeismic) has made a significant impact in a relatively short time. The company has pioneered a unique process in which the low-energy passive seismic, or microseismic, events that take place during drilling, stimulation and production are recorded and then analyzed for their impact on the reservoir. Armed with this information, reservoir engineers can optimize well placement and completions for maximum hydrocarbon recovery at reduced cost.

### Unique System

While microseismic monitoring methods are becoming more common, MicroSeismic's technique is unique in the way in which it is deployed, according to MicroSeismic President and CEO Peter Duncan. "Unlike conventional microseismic recording techniques that monitor from a single point downhole, our technique deploys an array of passive seismic monitoring instruments – geophones – laid out in a grid at or just below the surface. This data acquisition method not only delivers higher quality data, it avoids many of the monitoring difficulties common to downhole methods."

Drilling a dedicated monitoring well is expensive, costing some US$2–4 million per well. In addition, there are temperature limitations on the tools that can be deployed downhole, and the recording instruments can only map a relatively small area around the well. "Because of this, reservoir engineers do not gain the full picture of where fractures are occurring during stimulation, which hampers their ability to optimize completion and production strategies for the reservoir," Duncan says.

MicroSeismic's array of geophones placed on or near the surface dispenses with the need for most borehole monitoring and covers a much wider area. In addition, the seismic recording devices use subsurface noise from the production operation as the energy source, eliminating the need for separate sources such as dynamite or vibrators.

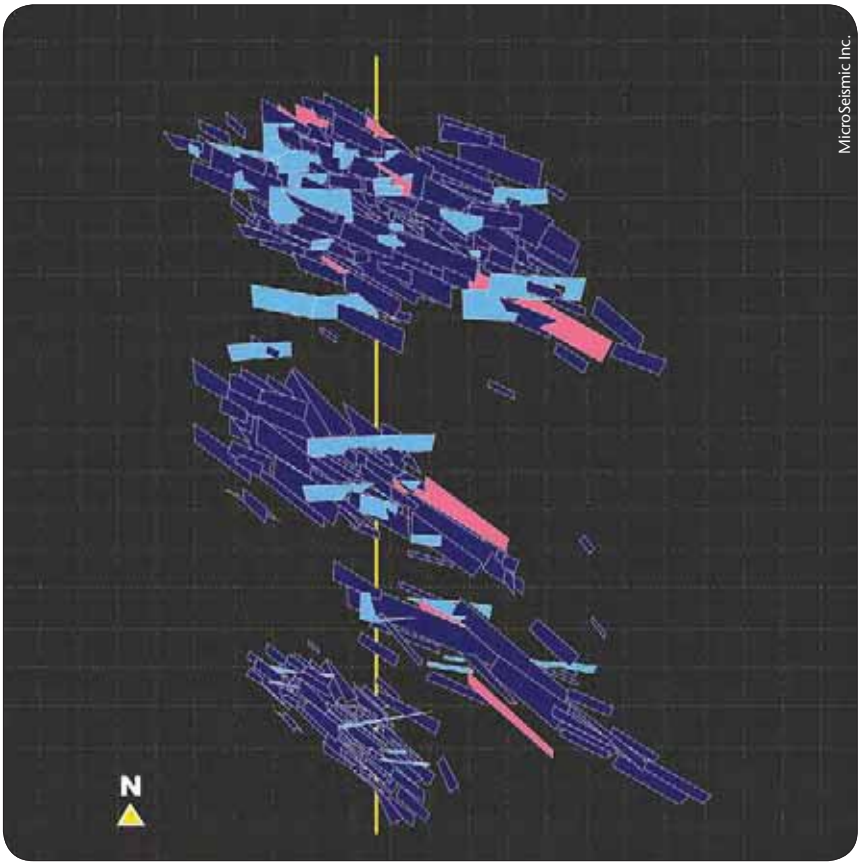



*Frac monitoring results using MicroSeismic's PSET® imaging technology indicate good wellbore azimuth and frac spacing. The spheres represent seismic events sized by amplitude and are colored by stage. Operators use this information to optimize well and frac spacing.*

Duncan admits that when MicroSeismic began in 2003, the concept of microseismic monitoring from a near-surface geophone array was met with a healthy dose of scepticism in the industry. "The conventional thinking was that the microseismic signals were too weak and our geophones were too far away from the source to be effective. However, we have proven that we don't need to be as close to the event as conventional monitoring, because we are using the collective listening power of an array of hundreds or thousands of geophones to create something akin to a parabolic dish microphone that can simultaneously detect multiple microseismic events over an entire field," he says.

The individual geophones are linked by MicroSeismic's Passive Seismic Emission Tomography (PSET) mapping and analysis program, which serves as a focusing algorithm that allows the engineer to use the dense array of geophones to 'beam steer', or sum the output of the entire array. In this way, microseismic events can be detected and located with a high degree of accuracy. PSET also overcomes the issue of signal attenuation by the overburden, which hinders the effectiveness

*Frac monitoring results are used to generate a Discrete Fracture Network (DFN) Model indicating the fracture paths back to the wellbore.*

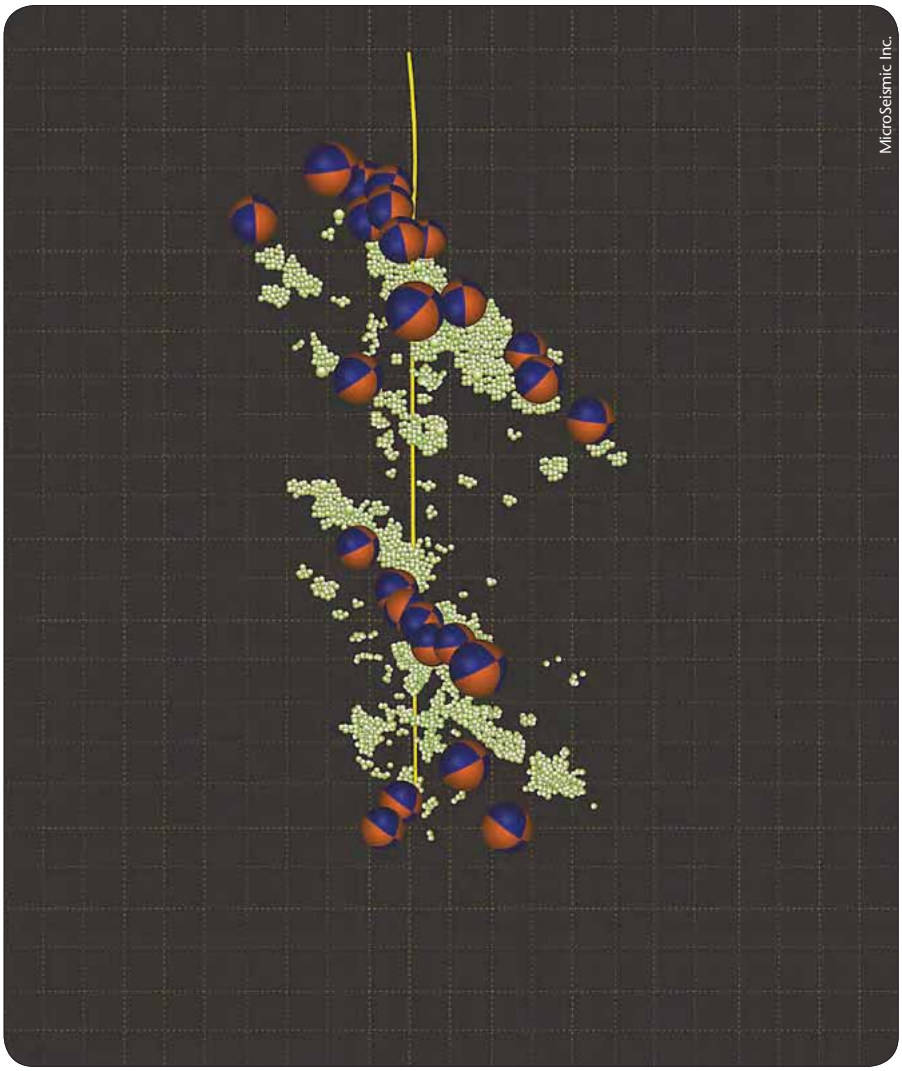


of conventional seismological earthquake location techniques.

Duncan likens his company's monitoring solution to a common medical procedure. "We are like doctors placing a stethoscope on a patient's chest. In our case, the patient is the reservoir. By listening for the almost imperceptible microseismic events and then diagnosing what these events might mean for the reservoir, engineers can take immediate steps to maintain the health of their production process."

The non-invasive monitoring technique helps ensure the long-term vitality of a shale gas reservoir by allowing operators to properly space their wells such that hydrocarbons are not bypassed and money is not wasted drilling unnecessary wells. In addition, mapping of a stimulation treatment helps ensure that the fracture path does not penetrate into environmentally sensitive subsurface areas such as water conduits.

The geophone array can also be used as an early-warning system for wellbore or casing stability problems. "Not only can we identify if there is an integrity problem downhole, but we can very accurately pinpoint the location and source, allowing for earlier and more effective intervention," Duncan says.




*PSET® processing and imaging technology identifies source mechanisms that help geologists understand how the rock is breaking during fraccing. Operators use this information to optimize their completions and field development strategies.*

## Real-time Monitoring

Over the past 7 years, MicroSeismic's monitoring technique has been steadily adopted by shale gas operators across North America, who are experiencing more efficient and increased production, while drilling fewer wells and with less impact on the environment. The company has advanced its monitoring expertise to the point that it is now monitoring multiple wells and simultaneous fracturing operations in real-time, from one installation over an area encompassing 1,300 km$^2$.

"Our technology gives operators a holistic view of their fields, allowing them to track interactions between wells and well-to-well variability over time," Duncan says. "This ability to monitor all wells over time is a powerful tool that lets operators adjust their completions and field-development strategies for enhanced long-term productivity."

MicroSeismic offers both temporary and life-of-field monitoring options. The company's FracStar design uses a removable surface-located array of geophones arranged in a hub-and-spoke pattern to monitor long laterals and pad drilling over a large area. The array's large 2D aperture and PSET-based microseismic monitoring images how the stimulation-induced fractures interact with a reservoir's natural fracture networks.

For longer term monitoring, MicroSeismic's BuriedArray system deploys an array of geophones permanently installed and buried at a depth of 100 m for those operators who need to monitor multiple wells over a long period of time for strategic planning and development purposes. This service drives down the cost of monitoring with each well drilled, making it a cost effective, long-term monitoring option. To date, MicroSeismic has installed 25 buried arrays and monitored over 3,000 frac stages for clients covering a total area of nearly 700 square miles. Another 3-4 projects are slated for installation before the end of the year.

"Whichever option is chosen, the bottom line is that companies can gather more real-time data for less cost and with a much smaller environmental footprint," Duncan says. "This adds up to better informed decisions about future stimulation to optimize field production and recovery."

Increasingly, operators that originally installed a monitoring array to detect microseismic only during a fracturing job have begun to see the array as a long-term, cost-effective way to monitor the movement of fluids out of their reservoir during production, or into their reservoir during enhanced oil recovery operations.

According to Duncan, this shift to using microseismic detection as a long-term production-monitoring tool is largely due to the growing influence of the Digital Oil Field concept. "One popular idea within the Digital Oil Field is to turn a field's production into a process that can be monitored and tuned in real time as conditions change," he says. "This can only be accomplished with information about the reservoir's status between the wells, in addition to the information at the wells. Our technique provides both."

## Further Applications Abound

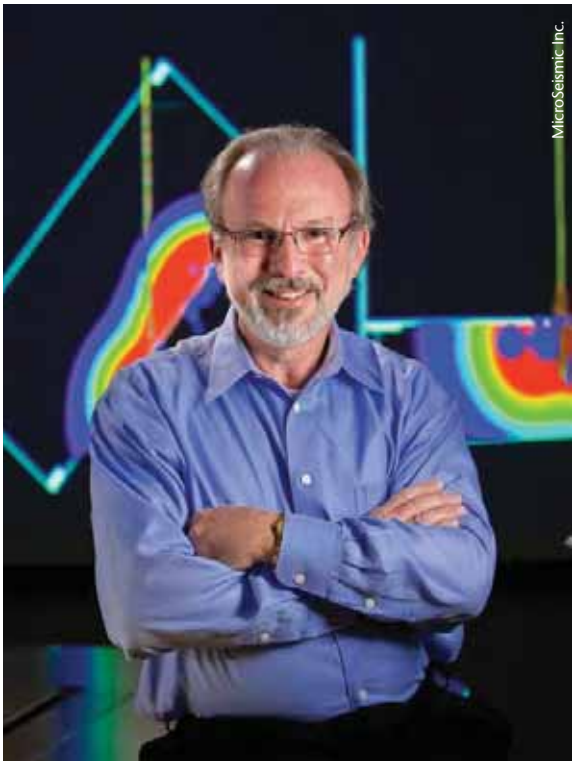
Going forward, Duncan sees Micro-Seismic's technique as an effective tool for monitoring everything from steam injection in oilsands projects in his native Canada to carbon sequestration and enhanced geothermal systems. For now, he is excited to be developing a technology that promises to hasten the emergence of efficient and environmentally sustainable production of unconventional gas around the world.

To that end, the company has used a recent capital investment of more than US$100 million to further develop its technology and expand its service internationally, including into Poland, where it has set up an office. An April 2011 report by the US EIA estimates Poland's potential shale gas reserves to be 792 Tcf of risked shale gas-in-place, from the Baltic Basin (514 Tcf), Lublin Basin (222 Tcf) and the Podlasie Basin (56 Tcf). If recovered, this sizable resource would keep the country supplied with natural gas for the next 200 years, delivering an enormous boost to the nation's economy and helping to reduce its dependence on imported gas from Russia.

The promise of such an economic windfall for Poland puts pressure on the geoscience and engineering communities to first verify that the shale gas resources exist in these quantities and are technically recoverable. This will be accomplished over the next 18 months with a series of 30–40 drill tests by various companies to more accurately determine the existence and commercial viability of Poland's shale gas.

If these tests confirm the potential, then operators will have to ensure that their exploration and production activities pose no risk to the safety or environment of local communities, and regulatory authorities will need to be satisfied that fears expressed over contamination to water supplies are unfounded.

These issues are mainly technical in nature, and Duncan is confident that MicroSeismic's technology is uniquely qualified to provide the answers. "Once they are familiar with the value our technology offers, we believe that governments and local communities in Poland and elsewhere will welcome the benefits it can bring in terms of responsible production and management of their unconventional oil and gas reservoirs." ■




*Dr. Peter Duncan began his career with Shell, and worked for a number of geophysical companies before becoming founding President of MicroSeismic in 2003. He was President of the Society of Exploration Geophysicists 2004 – 2004*

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# Exploring the Icelandic Frontiers

Brynjar Gunnarsson, Dreamstime.com

Iceland is renowned for its hot springs, geysers and active volcanoes that erupt from time to time, not world-class oil and gas production – but could basins close to this sparsely populated North Atlantic island be concealing significant hydrocarbon potential?

ALOZIE-DAVIES OKERE, CGGVERITAS

The Jan Mayen Ridge, situated some 400 km to the north-east of Iceland, is believed to have the potential for oil and gas accumulations because of its similarity to neighbouring North Atlantic sedimentary basins which are hydrocarbon-bearing. The More, Voring, Faroe-Shetland, Jan Mayen Ridge and East Greenland Basins were previously fused together as part of a continental mass prior to the opening of the North Atlantic Ocean Basin in the Late Palaeocene-Early Eocene.

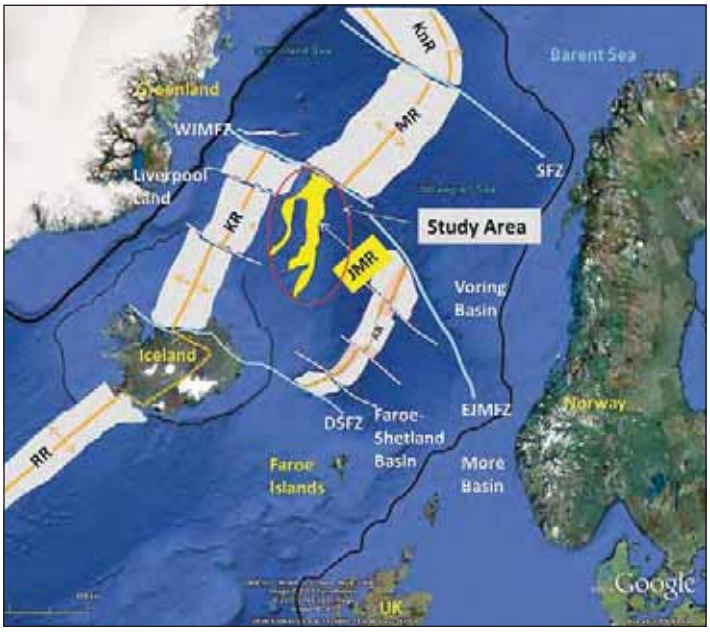
The Ridge is bordered by basalt provinces on both sides. Further to the east lies the Aegir Ridge, a non-active mid-oceanic ridge and, to the west is the Kolbeinsey Ridge, an active mid-oceanic ridge.

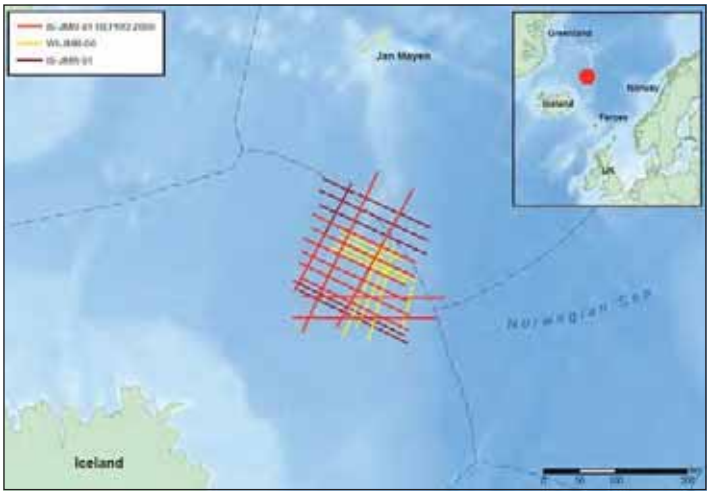
The microcontinent was formed in two tectonic phases: the opening of the Norway Basin in the Late Palaeocene/Early Eocene, and the rifting and final separation of the microcontinent from the Greenland margin in the Early Miocene. Both tectonic events culminated in the separation of Eurasia and Greenland. The eastern margin of the microcontinent developed as a volcanic passive margin and the western margin as a series of extensional fault blocks. From the northern part of the Jan Mayen Ridge to the south, there is progressive deepening of the basin and an increase in normal faulting and structural complexity.

Lundin et al, 1995 and Lundin and Dore, 2002, have established a significant plate re-organisation and change in extension direction during the development of the North Atlantic Ocean Basin. It begins with a sea-floor spreading phase which started during the Early Eocene (Ypresian) with the East Jan Mayen and Senja Fracture zones orientated in a north-west to south-east direction, as can be seen on the map. Between Late Eocene (Priabonian) and Early Oligocene (Rupelian), a northward propagating rift system developed within East Greenland between Liverpool Land and the Jan Mayen microcontinent. The Kolbeinsey Ridge then linked up with the Mohns Ridge through a newly formed fracture zone – the West Jan Mayen Fracture Zone – during Early Miocene (Aquitanian) times, while the previously formed Aegir Ridge became extinct. This resulted in the complete separation of the Jan Mayen microcontinent from East Greenland.

The North Atlantic region was then affected by post-break-up compressional events which re-shaped its structural grain. Lundin and Dore, 2002, Blystad et al, 1995, and Vagnes et al, 1998, have illustrated features attributable to the post-break-up compressional events, which include reverse movement of normal faults, broad basin inversion and various forms of stratal folding which occur in the More, Voring and Faroe-Shetland Basins. These features have been observed on the eastern margin of the Jan Mayen microcontinent, especially at the Ridge flank, and the authors propose

*A schematic map of the north-east Atlantic, modified from Google Earth, illustrating key regional tectonic elements. The Aegir Ridge and the ridge underlying the Iceland continental margin are all inactive mid-oceanic ridges. Abbreviations: AR=Aegir Ridge, KR=Kolbeinsey Ridge, KnR=Knipovich Ridge, MR=Mohns Ridge, RR=Reyknanes Ridge, EJMFZ=East Jan Mayen Fracture ZI can guess that the one, DSFZ=Denmark Strait Fracture Zone, SFZ= Senja Fracture Zone, WJMFZ=West Jan Mayen Fracture Zone.*




*CGGVeritas multi-client seismic database across the Jan Mayen Ridge.*

that they result from ridge-push forces, including sinistral reactivation of pre-existing, deep-seated, north-west trending crustal weaknesses.

## Seismic Insight

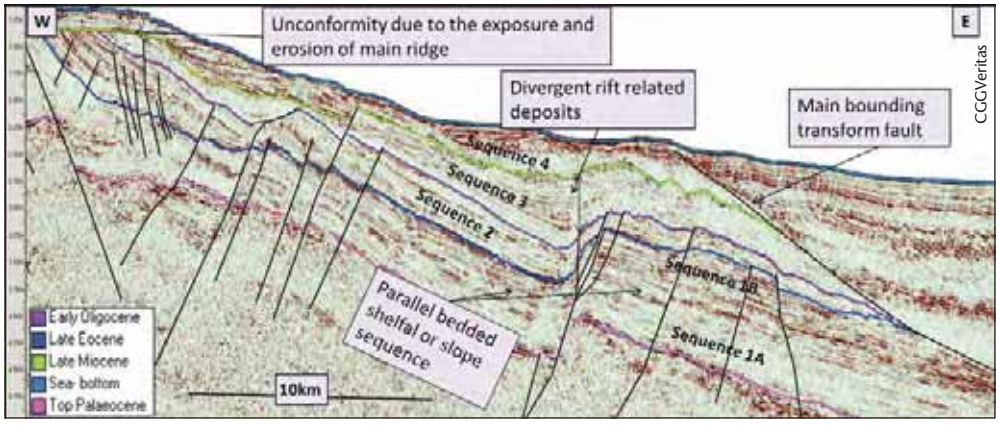
CGGVeritas has acquired and processed more than 3,600 km of 2D seismic lines over the Jan Mayen Ridge. The dataset was acquired in two phases: Phase 1, IS-JMR-01, consisting of more than 2,700 km of 10 km long-offset 2D seismic lines, was acquired in 2001. Phase 2, IS-JMR-08, with 859 km of long-offset (10.05 km) of 2D, was acquired in 2008 to infill the original 2001 dataset. In 2009, CGGVeritas reprocessed more than 1,700 km of key lines (IS-JMR-01-REPRO) from the 2001 survey, applying the latest techniques such as Fully Ray-Traced Kirchhoff Pre-stack Time Migration. The reprocessed dataset shows significant improvement in fault plane resolution, multiple removal and noise attenuation, enabling better imaging of structures and stratigraphy. The interpretation of the resulting high-quality dataset has led to a significant improvement in the understanding of this frontier area of the North Atlantic.

Four seismic horizons were interpreted across the data area. The deepest horizon interpreted is simply identified as Top Palaeocene and may represent the Palaeocene-Eocene boundary. It is widespread over the Jan Mayen Ridge, except where it is obscured by a thick sequence of volcanic rocks. It marks the top of high-amplitude reflections, that have been proven by the Deep-Sea Drilling Programme (DSDP) to comprise basalt and early Palaeogene sediments. The Top Palaeocene horizon is overlain by Sequence 1A: a set of homogenous, low-amplitude, parallel to sub-parallel bedded events. Sequence 1A is overlain by Sequence 1B, a set of parallel to sub-parallel high-amplitude reflections that may represent volcaniclastics and turbidites. Both sequences may have been deposited under low-energy shelf-slope environments.

The late Eocene horizon is not widespread across the Ridge. It is named according to published information on key tectonic events that affected the North Atlantic region. It is interpreted on the flanks of the Ridge and truncated on the top by a widespread, younger erosional unconformity. This horizon marks the top of Sequence 1B. It is overlain by Sequence 2, composed of homogenous, transparent and sub-parallel reflections that may represent deposition within more proximal depositional environments than the underlying Sequence 1B. The event marks what may be the end of a major extensional phase in the opening of the North Atlantic Basin.

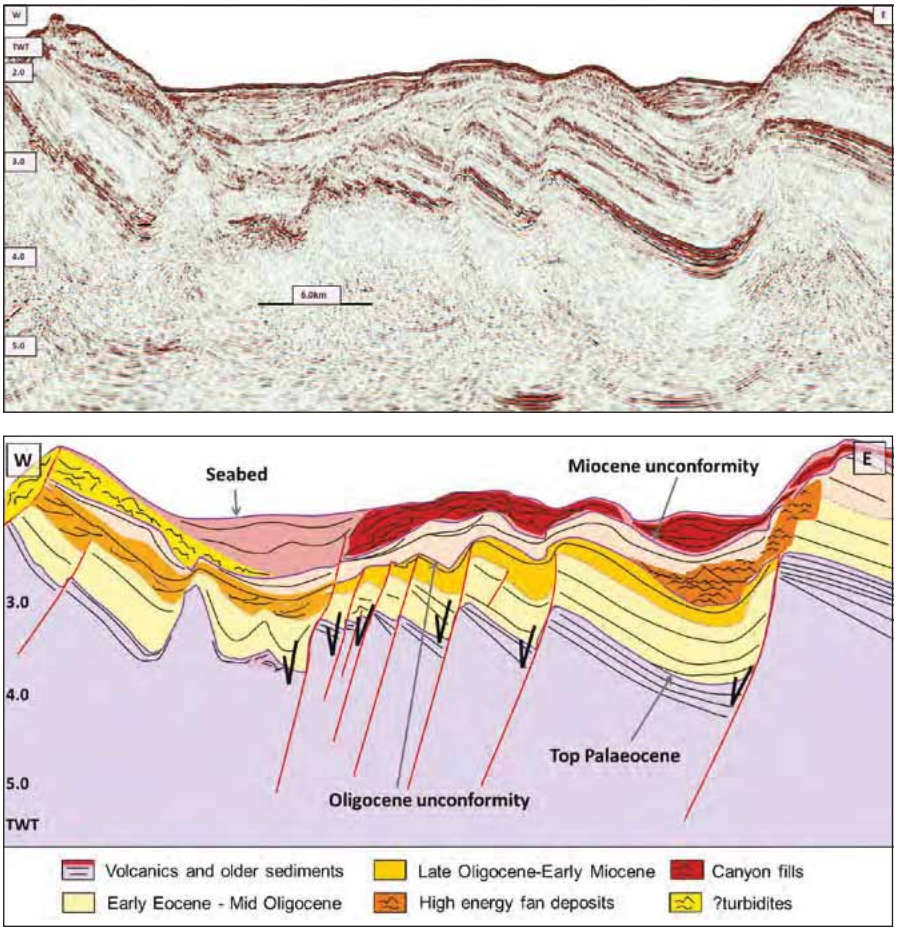
The Early Oligocene horizon is loosely named according to published information and may represent an event related to Eurasian and American plate re-adjustment terminating in local uplift. This

*Interpreted west-east seismic line illustrating key prospective structural targets within the Jan Mayen Ridge.*



erosional event also marks the top of a key compressional event that resulted in the reversal of normal faults adjacent to the Ridge. The horizon is widespread, except on top of the Ridge, where it is truncated by a younger erosional event. It is overlain by Sequence 3, composed of a diverging series of sediments that represent syn-rift deposits within high-energy depositional environments, which were deposited as a result of renewed extension in the region.

The late Miocene event is also loosely named, based on published information. The horizon is a key erosional event that is widespread within the mapped area. It is overlain by Sequence 4, which may be composed of variable facies. On the Ridge, the seismic facies are of higher amplitude and may be parallel to sub-parallel, representing deposition under low-energy conditions. On the flanks, deposition is more proximal and reflections are more chaotic and of lower amplitude.




*An uninterpreted W-E seismic line illustrating tilted fault blocks related to final separation of the Jan Mayen microcontinent from Greenland (above), with an interpretation of the section with key seismic facies identified (below).*

## Exploration Opportunities

The presence of layers of basalt within the Jan Mayen Ridge microcontinent makes imaging below them difficult. However, based on comparison with regional sedimentary basins which are hydrocarbon-bearing and which were formed and modified by similar tectonic processes, the sedimentary rocks are of sufficient thickness and age to potentially generate and store hydrocarbons.

A key risk to hydrocarbon generation in this basin is the presence of a mature source rock. The proven source rock for fields in the adjacent basins is Late Jurassic/Early Cretaceous, although there is some hypothesis that younger rocks could generate hydrocarbons within these basins. In the Jan Mayen Ridge, the presence of Late Jurassic/Early Cretaceous rocks has not been confirmed by drilling. However, within the Ridge itself, where imaging is better, there are indications of sedimentary sequences which may pre-date the late Palaeocene/Early Eocene opening of the Norwegian-Greenland Sea and these could offer the needed source potential.

In the western rifted margin, key hydrocarbon play elements have been identified on seismic. Possible reservoir rocks may include fluvio-deltaic sediments related to the initial separation of Eurasia and Greenland. Closures on tilted fault blocks within the rift margin could offer potential traps for hydrocarbons. For this play, potential hydrocarbon-sealing candidates have been identified on seismic as argillaceous facies which blanket the titled fault blocks within the rifted margin. These facies were possibly deposited during initial basin subsidence.

Additional play potential could be provided by four-way dip closures and reverse faults created by an early Palaeogene compressional event. These structures are present on the Ridge flank, inboard of the passive margin. The reservoir for this target could be provided by turbidites deposited within shelf-slope environments, with sealing provided by intra-formation shales.

Migration from the deep-seated mature source rocks (if present) into overlying structures is highly possible through a network of faults and fractures created by rifting and plate re-organisation. However, a key issue on migration, especially on structures adjacent to the Ridge, is timing of hydrocarbon generation and the compressional event, with the risk factor being whether the event has breached the structures, allowing leakage of hydrocarbons. ■

***References:***

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# A Truly Magical Place

JANE WHALEY

As you drive up towards the Ngorongoro Crater from the flat plains of the Serengeti, the searing heat begins to lift and the air gets cooler. The road becomes rougher and the scenery surprisingly mountainous, and it is easy to realise that you are climbing the steep sides of what was once a 5,000m high volcano. Small encampments of Maasai appear, with their tiny huts and bright red and purple cloths, and cows mingle with giraffes on the hillside.

Then you turn the final corner and spread out before you is one of the most famous yet still awe-inspiring and spectacular views in the world. About 600m below is the flat floor of the caldera, 20 km across and dramatically encircled by the steep crater walls. This natural enclosure is home to about 25,000 wild animals, the most densely packed concentration of wildlife in Africa. Nearly half a million tourists visit the Ngorongoro Conservation Area annually, most to view the astonishing microcosm of East African wildlife within its boundaries, but few probably realise just what a geologically unique area they are looking at.

**Extensive Rift System**

The Ngorongoro Conservation Area lies in the eastern branch of the East Africa Rift, part of the extensive rift system which resulted from the east - west separation of the Nubian and Somalian tectonic plates. Rifting started in the Early Miocene and is still continuing today, making the East African Rift system the most extensive active continental extension zone in the world. The history of the rift is discussed in greater detail on pages 20–24.

The two branches of the East African Rift system have very distinct features, the western one being characterised by high mountains and some of the deepest freshwater lakes in the world. The eastern branch, by contrast, is dominated by a number of dormant or extinct volcanoes, which include the famous Mounts Kenya, Elgon and Meru, not forgetting Kilamanjaro, at 5,895m the highest mountain in Africa and one of the most iconic sites on the continent.

This volcanic activity is also responsible for the basalts of the Crater Highlands. Lava erupted from a number of vents, including from a volcano which eventually exploded 2.5 million years ago and left behind a vast, 260 km$^2$, steep-sided basin: Ngorongoro Crater.

**Giant Caldera**

The crater is predominantly composed of basaltic (low silica) and trachytic (high silica content) lavas, all extruded between 2.1 and 2.8 million years ago. Flows attributed to the volcano have been identified 80 km away on the Serengeti Plains.

Ngorongoro, one of the largest unbroken calderas in the world, is especially remarkable because, unlike the majority of such features, it is not flooded. Its flat floor contains a small saline lake, the main water source for the animals living in the crater. It is also the daylight home to thousands of flamingos, their vibrant rosy hues, the result of grazing on algae from the lake floor, making the distant lake shimmer pinkly in the sunlight.

The majority of the animals living in Ngorongoro are ruminants, grazing on the rich grasslands of the crater floor, and include zebra, gazelles, eland and warthog, although giraffe, impala and topi are not found. There is also a herd of elderly bull elephants. The swamplands host hippos and many species of birds,

Jane Whaley

*Gazing down into the Ngorongoro caldera from the Crater rim is a 'must see' sight for the East Africa tourist.*

The Ngorongoro Conservation Area in Northern Tanzania is a World Heritage site renowned for its beauty and unique wildlife and one of the few places where active continental break-up and its attendant magmatism can be observed today.

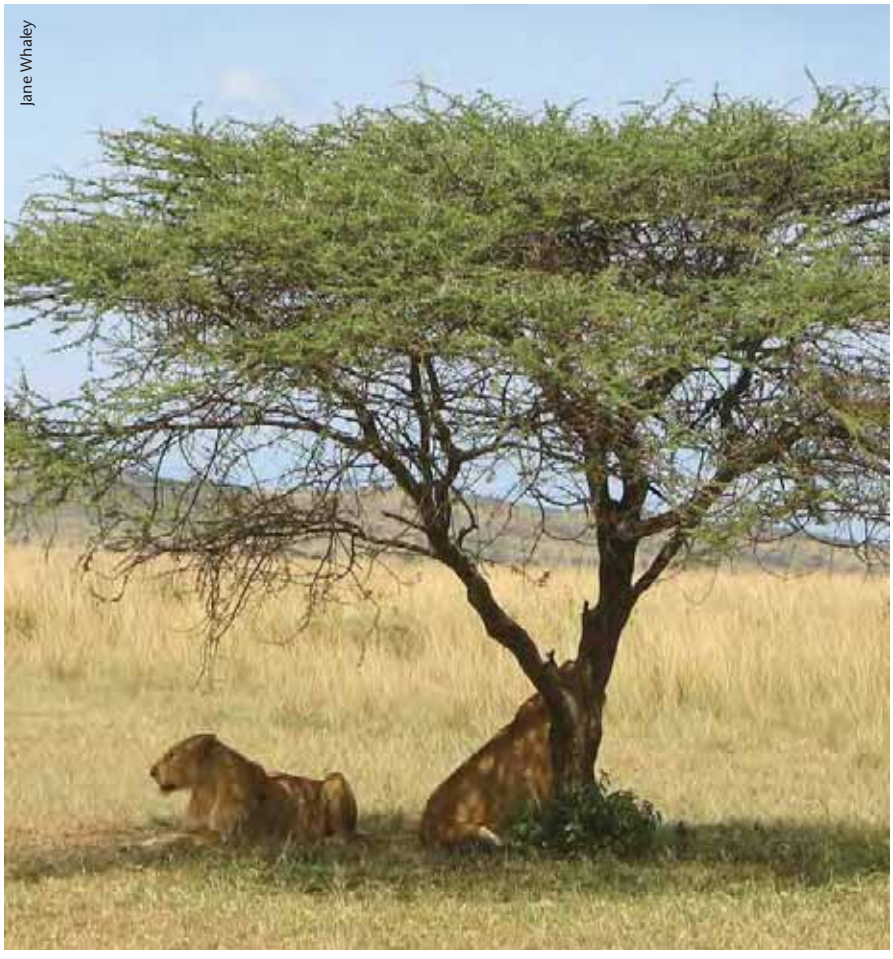
while baboons, monkeys, waterbucks and bushbucks are found in the rain forest on the southern and eastern slopes.

Ngorongoro is also one of the few places where it is possible to see wild black rhinos. Subject to intense hunting and poaching, these have declined from 100,000 in Africa in 1960 to a mere 2,400 in 1995, by which time Ngorongoro was one of the few pockets of rhino in Tanzania. With careful management and the use of armed guards to reduce poaching, numbers have slowly begun to rise, and there are now about 20 within the crater.

With all this tempting prey, there are many carnivores, including several of prides of lions. With plentiful food sources, they rarely leave the crater, and the dominant males, known for their long black manes, deter any would-be newcomers, so inbreeding is a potential threat. There are also leopards, cheetahs and serval cats, as well as many hyenas.

**Unique Oldoinyo Lengai**

Although many visitors are attracted to the scenery and wildlife of Ngorongoro and the Serengeti, not many make it to Oldoinyo Lengai, which is, in geological



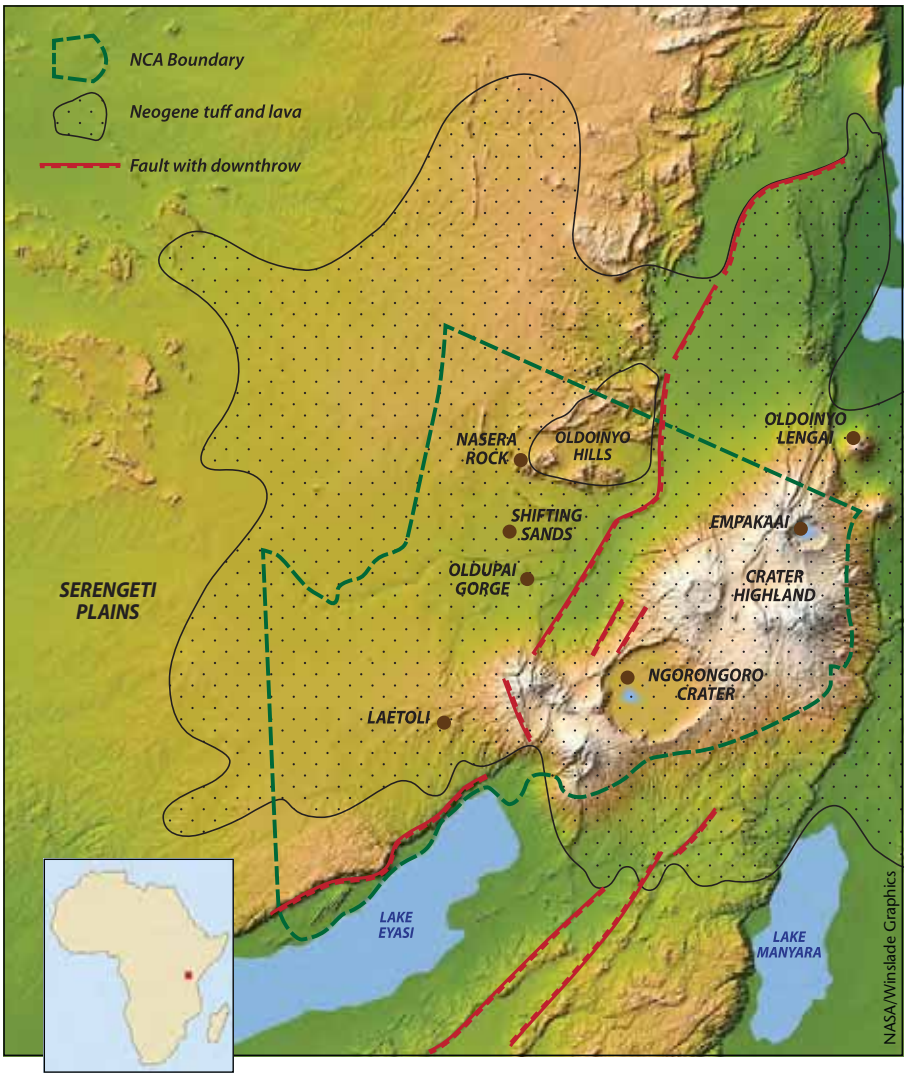
Jane Whaley

terms, an even greater wonder, as it is Earth's only active carbonatite volcano. This alkaline lava contains 50% carbonate ($CO^2$-bearing) minerals and less than 10% silica and are almost always found in continental rift-related tectonic settings.

Most carbonatite lava flows are unstable and react quickly in the atmosphere, which explains their relative rarity in the geological record. Uniquely in Africa, the Oldoinyo Lengai magmas also have an unusually high amount of sodium, up to about 35%, making the them solid rather than gaseous at the surface, so the lavas are very thin and flow like water. Carbonatite lava is also much cooler than other lavas, being only about 510°C (950°F), in comparison to basaltic lavas at over 1,100 °C (2,000°F). Contact with moisture rapidly turns it white, resulting in the apparent 'snow cap' of the volcano when seen from the air.

Recent studies based on gas emissions at Oldoinyo Lengai suggest that a very small amount of melting of the Earth's mantle from beneath mid-ocean ridges can produce carbonatites, and that the $CO^2$ probably comes directly from the upper mantle, just below the East African Rift.

Oldoinyo Lengai – 'Mountain of God' in Maasai – is the youngest volcano in this part of the Rift Valley and is less than 370,000 years old.




### Cradle of Mankind

The erupting volcanoes that formed the Ngorongoro Highlands may well have been watched by some of the earliest prehistoric men. About 40 km north-west of the crater is the world-famous Oldupai Gorge (also known as Olduvai), which contains some of the oldest evidence of hominoids, preserved by the abundance of volcanic ash. The lava layers have been subdivided into seven formations, ranging in age from two million to 15,000 years ago. These are underlain by volcanic tuff, probably derived from Ngorongoro, and then by the Precambrian metamorphic gneisses and quartzites which make up most of the African continent.

The climate in this part of Africa in the mid-Pliocene was wetter than it is now and Oldupai had springs, abundant vegetation

*The archaeological discoveries found in the lava at Oldupai established the African origin of humankind. The so-called 'monolith' on the right is an erosional remnant, coloured red by oxidised basalt washing into the basin from the lateritised Crater Highlands to the east.*


J. B. Dawson

*Weathered carbonatites give the appearance of snow from a distance on the flanks of Oldoinyo Lengai, the only active volcano in northern Tanzania.*

and a large freshwater lake, making it very attractive to grazing animals – and to the early upright hunters which preyed on them. Successive layers of ash rapidly buried and preserved the remains of both animals and hominoids, and also artefacts such as pebble choppers and scrapers, the oldest recognizable tools on earth. Pleistocene earth movements and faulting resulted in the diversion of a stream which eroded down through these sediments, creating a deep ravine and exposing a 90m cliff of lava layers filled with fossil and archaeological remains.

The most famous fossil found in Oldupai is probably the 1.8 million year old ape-like skull known as *Australopithecus boisei*, often referred to as 'nutcracker man', due to its large molars. However, it is thought that several hundred species of hominoids may have lived in this region two million years ago, including Homo erectus which eventually evolved into modern man.

About 45 km south of the Gorge is Laetoli, where in 1975 Mary Leakey found 3.75 million year old fossilized footprints, proving that hominids walked on two feet. Their preservation, one of the greatest palaeoanthropological discoveries ever made, is once again due to the abundant volcanic ash.

### Natural Wonders

We have barely touched on the many wonders of the Ngorongoro Conservation Area, which spans mountains, plains, woodlands and forests. There are the wide expanses of the Serengeti National Park, where the astonishing annual migration of nearly two million wildebeest can be followed; or the emerald green crater lake at Empakaai; Lake Eyasi, forming the faulted south-eastern edge of the NCA; the 'Shifting Sands', composed of fine black ash from Oldoinyo Lengai; or Nasera Rock, a granite monolith rising 80m above the plains and a meeting place for centuries.

All once again demonstrating that geology is not only responsible for shaping the earth around us, but also lies behind many of the natural and anthropological wonders of the world.

*Acknowledgement: Many thanks to Dr. Joe McCall and Prof J. B. Dawson for assistance with this article.* ■

## Wildlife and Mankind Together

The Ngorongoro Conservation Area (NCA) is not a National Park, but a conservation authority administered by the Government of Tanzania. It aims to maintain the balance of people and nature while guaranteeing the protection of the natural, cultural and archaeological resources for the wider global community. Originally part of the Serengeti National Park, it was established as a separate entity in 1959 as a multiple land use area, where wildlife could coexist with the Maasai pastoralists practicing traditional livestock grazing, whilst also allowing tourists space to enjoy one of the world's major wildlife localities. It covers 8,288 km$^2$, and was declared a World Heritage site in 1979.

As the oft-quoted 'Cradle of Mankind', man and his ancestors have lived in the Ngorongoro eco-system for more than three million years, but despite careful management, the fragile balance between the needs of humans and nature is hard to maintain. The number of Maasai in the NCA has expanded from about 10,000 when it was established to over 40,000 today, with 300,000 cattle. They are not allowed to live in the adjacent Serengeti National Park, nor in the Ngorongoro Crater itself, so pressure on the limited grazing is increasing, while the general wealth and health of the tribes people is declining.

The Tanzanian Government wants to increase revenues from tourism by building more luxury hotels along the Ngorongoro Crater rim, and may evict some Maasai to make way for this. Only time will tell if the admirable philosophy of the Ngorongoro Conservation Area 'to maintain the peaceful co-existence of human and wildlife in a natural and traditional setting' is ultimately achievable. ■


Andrew Quallington

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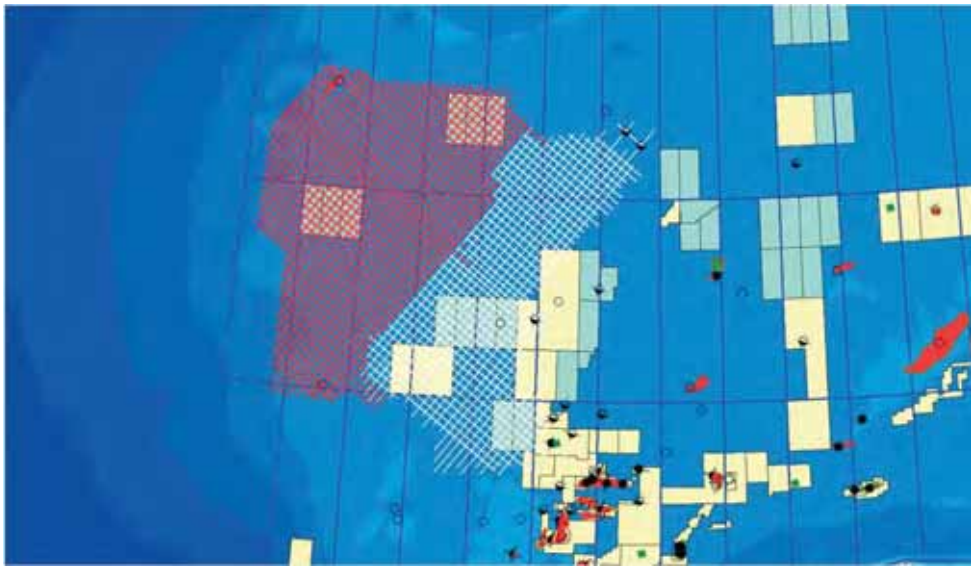

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# The Rise, Fall and Rise of The Standard Oil Company


*A view of the Standard Oil Refinery, Cleveland, Ohio, 1899*

RASOUL SORKHABI, Ph.D.

If one were to write the saga of the Standard Oil Company into a drama, it would have three major players: the "Gentleman" John D. Rockefeller (1839–1937) who co-founded and led the company from humble beginnings to a nation-wide trust; the "Lady Journalist" Ida Tarbell (1857–1944) whose "muckraking" (investigative journalist) work, *The History of the Standard Oil Company* in 1904, was largely responsible for the disintegration of the company in 1911 (now one hundred years ago) by the United States anti-trust law; and finally the "Company" itself. In the past two issues of *GEO ExPro*, we looked at the profiles of Rockefeller and Tarbell; in this final part of the article, we review the growth and fate of the Standard Oil Company, which, as we will see, remains the great-grandfather of the major US oil companies today.

## Rapid Expansion

In 1863, Rockefeller, aged 24, together with the Clark brothers and a chemist, Samuel Andrews, started an oil refinery in Cleveland, Ohio. Two years later, Rockefeller bought the Clark brothers' shares, and named the refinery Standard Works. As the oil business grew in the region, in 1870 Rockefeller and his brother William, along with Andrews, Henry Flagler, Oliver Burr Jennings (husband to the sister of William Rockefeller's wife), and Stephen Harkness formed a new company, the Standard Oil Company in Ohio (later Sohio). The name Standard was chosen to imply the standardization of oil refineries and products. Indeed, the oil barrel of 42 gallons was a design of Standard Oil in Pennsylvania in the 1860s; oil was stored in the wooden whiskey barrels and it was 40 plus 2 gallons per barrel because some oil was often lost during transportation.

The rise and expansion of Standard Oil occurred after the Civil War and during a period in the American history which has been dubbed as the Gilded Age, popularized in *Gilded Age: A Tale of Today* by Mark Twain and Charles Dudley in 1873 (in reference to the process of gilding an object with a surficial layer of gold). This was the period of rapid economic expansion, population growth, and rise of large enterprises and monopolies (over oil, tobacco, steel, beef and railroads) in the USA.

In his introduction to the abridged Norton's edition of Tarbell's *The History of the Standard Oil Company*, historian David Chalmers wrote: "John D. Rockefeller and his associates did not build the Standard Oil Company in the broad rooms of Wall Street banks and investment houses, water their stock and rig the market. They fought their way to control by rebate and drawback, bribe and blackmail, espionage and price cutting, and perhaps even more important, by ruthless, never slothful efficiency of organization and production."

Many of these methods were later disclosed and found to be unethical and in some cases illegal. Nevertheless, during the 1870s–1890s, Standard Oil absorbed many small and large oil companies and established regional companies across the USA. In 1882, Rockefeller and partners further consolidated their dominance by transforming Standard Oil into a trust with nine trustees managing the corporation on behalf of all shareholders. In 1885 the trust moved to New Jersey to take advantage

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of favorable regulations in that state, and another office in New York administered most of the Standard Oil's overseas activities.

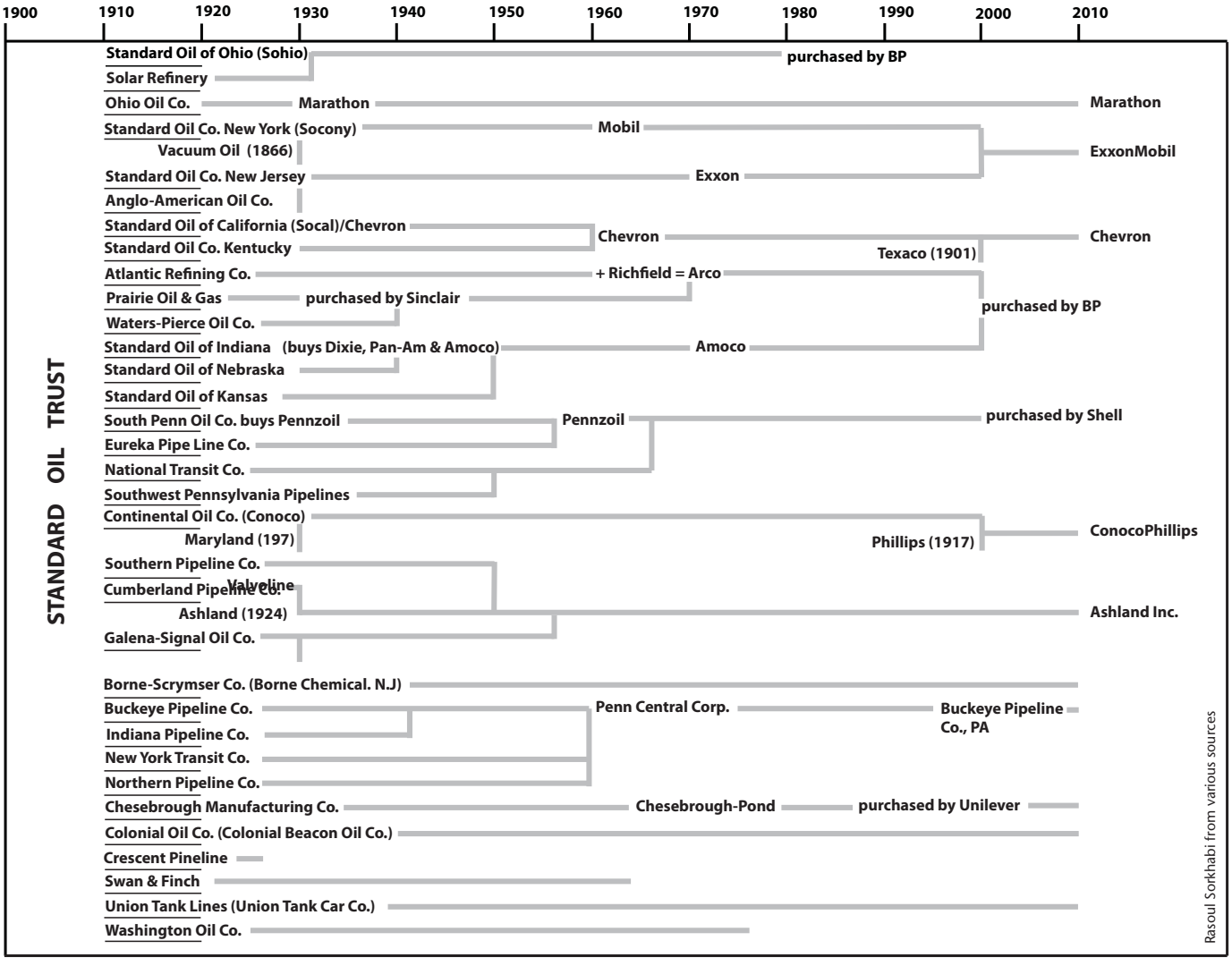
In 1890, Senator John Sherman of Ohio initiated an anti-trust law in Congress. Although US Presidents Grover Cleveland and William McKinley did not enforce the law in the 1890s, the Sherman Act became the source of American anti-trust policies a decade later. In response to this, the Standard Oil Trust changed its name to the Standard Oil Interests, with 20 companies, and made some cosmetic adjustments – but still the central power remained with a holding company first in New York and then in New Jersey.

## Progressive Era

Nevertheless, the 1893–97 depression, which hurt the middle and lower-income classes, and the rise of an intellectual movement against trusts and monopolies pushed the politicians to curb the economic power of corporations. It was in this ripe environment that Tarbell's book appeared and raised the public and political consciousness against the Standard Oil. The period 1890–1914 is sometimes called the Progressive Era in American history as it spoke for reforms in support of the middle-class, science and education, women's rights and social liberties, as well as anti-corruption and "trust-busting" policies. If Rockefeller was an icon of the Gilded Age, Tarbell and her work epitomized the Progressive Era.

President Theodore Roosevelt from the Republican Party was one of the strongest political leaders who pushed for Progressive reforms. A man of many achievements (the first American to win the Noble Peace Prize), he became President at 42 (the youngest US president ever) when President McKinley was assassinated. When Roosevelt ran for presidency in 1904, a highlight of his agenda was to limit the reign of monopolies over the American economy. Even though Standard Oil had contributed a large sum of money to the Republican Party campaign, Roosevelt ordered its return. His administration then started an investigation into the activities of Standard Oil. The company's top managers, John D. Archbold and Henry H. Roger (Rockefeller had retired in 1897) rushed to the White House in March 1906 to talk sense to Roosevelt, but apparently it did not work, for in November 1906 U.S. Attorney General Charles Bonaparte filed an antitrust law suit against Standard Oil in a St. Louis federal court. The company was under fire from various law suits and negative press coverage. A law suit against Standard Oil of Indiana eventually

*A time-line chart showing the history of the companies derived from the Standard Oil Company from 1911 up to the present.*



brought Rockefeller himself to a federal court in Chicago in July 1907. He played like someone suffering from memory loss. Although the court imposed fines, the company remained intact. Ida Tarbell, who was then editor of *The American Magazine*, wrote articles titled "Roosevelt versus Rockefeller" in 1907–1908. Rockefeller, who always tried to keep a low profile, responded by publishing his memoir *Random Reminiscences of Men and Events* in 1909.

After three years of court proceedings, which involved 14,495 pages of documents and the testimony of 444 witnesses, in 1909 a four-judge federal court panel ruled for the Attorney General's suit and against Standard Oil. The Sherman Anti-Trust Act was to be implemented. Roosevelt was then out of office (he had declined to re-run for presidency) but rejoiced at the news. Standard Oil appealed the case. The next stop was the Supreme Court, which on 15 May 1911 upheld the federal court ruling. Chief Justice Edward White gave Standard Oil six months to dissolve itself as a single entity and be split into several companies with independent boards of management.

## New Thirst for Oil

At that time, Standard Oil operated on a huge scale: It refined nearly 75% of all US crude and marketed over 80% of domestic kerosene. In July 1911, Standard Oil announced its new structure: It would split into 33 companies, some large and some small. In doing so, it made sure that the new companies shared the market rather than competed with one another, which was to be expected – as Financier J. P. Morgan commented, "How in hell is any court going to compel a man to compete with himself?"

The stock shares in the 'baby' Standards were distributed in proportion to the original shares to the shareholders of Standard Oil. Rockefeller himself owned about one-fourth of Standard Oil stock. Some people thought he would sell his shares as the company's value would decline. But Rockefeller knew his business far better.

When oil production began in the 1860s, oil was mainly used for kerosene lamps. Thomas Edison's invention of electric bulbs in the 1880s seemed to eclipse the oil industry. However, Henry Ford's design of automobiles in the 1900s generated a new thirst for oil in the form of gasoline. Therefore, within a year of the dissolution of Standard Oil, the stock market value of its spin-off companies doubled. Rockefeller soon became the first American billionaire. In 1912, when Roosevelt was trying for another term of presidency (this time as the leader of the new, short-lived Progressive Party, a spinoff from the Republican Party) he remarked, "No wonder that Wall Street's prayer now is: Oh Merciful Providence, give us another dissolution."

Despite the dominance of Standard Oil over the American market from the 1880s through the 1900s, one important fact should not be ignored: Oil prices throughout this period remained at about $1 per barrel, lower than the prices before or after this period. It seems that it was the expansion of markets (cheap oil) rather than high oil prices that financially fueled the growth of Standard Oil. Or as Rockefeller would tell his colleagues, "Give the poor man his cheap light, gentlemen."

While the name Standard Oil is part of history, its godfatherly figure remains, as many of the US major oil companies operating today trace their origin to that enormous oil enterprise. ■


*Logos of several important Standard Oil companies formed in the nineteenth century but which continued to dominate the oil industry in the twentieth century. (NB: These logos are shown only for the informational purpose of this article, and are not meant as trade use.)*

# Mighty Thoughts of Small: Nanotechnology for Upstream Applications

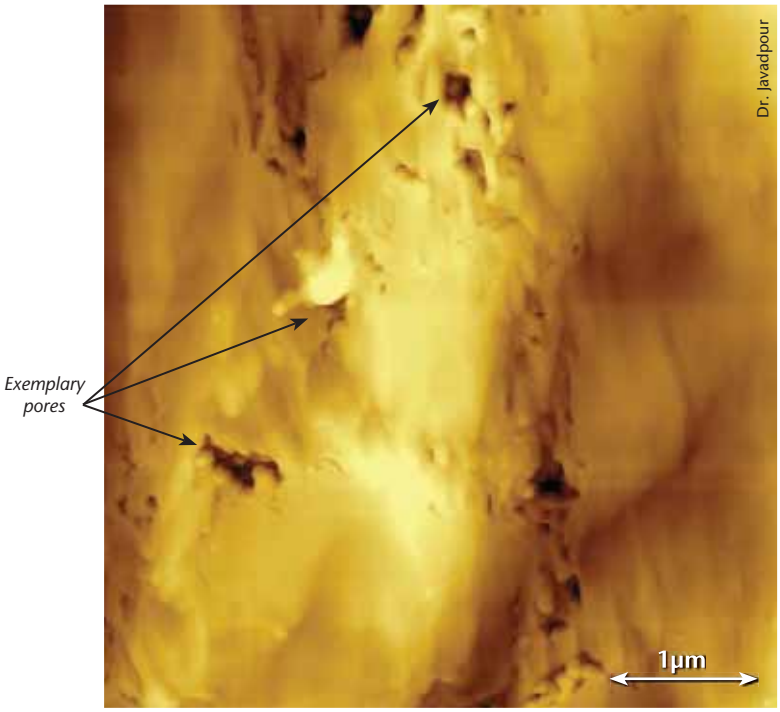
From opening new doors in the understanding of gas flow in low permeability shale packages to reservoir monitoring and enhanced recovery, nanotechnology's potential is huge.

THOMAS SMITH

## Atomic Force Microscopy

Nanoparticles and nanopore spaces are just too small to see even with the best optical microscopes. Scanning electron microscopes (SEM) can obtain two-dimensional topography and mineralogy images on finished surfaces. However, rocks contain many discontinuities and their properties can be heterogeneous, even at nanoscale. Atomic force microscopy (AFM) is a unique tool for nanoscale characterization because it can provide high-resolution topography images that show both mechanical and physicochemical properties.

AFM uses a stylus tip to scan a sample in a way resembling our sense of touch which allows direct measurement of interactive forces between surfaces or molecules. AFM can measure the topography of surfaces for an examination of the geometry of the pore network at the nanoscale. Direct measurement of surface forces, such as van der Waals, and electrostatic forces between molecules of interest and mineral rocks are also possible with this instrument.




*A topography image taken by an atomic force microscope (AFM) showing nanopores in a shale sample. The entire image is approximately five micrometers across or about 1/10th of a human hair diameter.*

Something that we are all familiar with, a human hair, is about 50,000 nanometers (nm) in diameter. Over 1,000 times smaller than the human hair, nanoscale materials occur naturally in the environment. Now, scientists and engineers are arranging collections of tens to thousands of atoms to create nanoparticles that can range from 1 to 100 nm in diameter. The important point here is that these nanoparticles can be built to specific sizes and for specific purposes as well as be assembled to perform specific functions.

**Simply put, nanotechnology is the engineering of functional systems at the molecular scale.**

## Big Differences

One of the exciting and challenging aspects of nanoscale particles is that the behavior can be very different from classical physics, following the much more different rules of quantum mechanics. For example, you cannot walk up to a wall and be teleported to the other side, but, at the nanoscale an electron can. Insulators (substances that cannot conduct an electric charge) can become semiconductors when reduced to the nanoscale. Thermal conductivity and other physical properties can change drastically at the nanoscale.

With particle attributes changing at the nanoscale, scientists are experimenting to learn more about their properties and ways to take advantage of them in various applications. We already use many products that employ nanotechnology such as nanoparticles of zinc oxide or titanium oxide in our sunscreens or as a coating on clothing for better UV protection, in scratch-resistant

coatings on our cars and eyeglass lenses, and in making tennis rackets lighter and stronger. The oil and gas industry is also embracing this new and exciting technology.

"Nanotechnology is helping in two key aspects of upstream oil and gas production," says Dr. Farzam Javadpour, a key researcher in nanotechnology at the Bureau of Economic Geology in Austin, Texas. "One aspect that has become very important for the production of oil and gas from very tight formations such as shale is that this technology gives us a new look and understanding of the reservoir itself and how fluids flow through very small pore space. The second aspect deals with new ways to monitor and enhance the reservoir performance."

### Shale Gas Reservoirs

Hardly a day goes by without news of a shale gas or shale oil play discovery. New drilling and fraccing technology has helped unlock these resources, but what we lack is an understanding of where all these resources are coming from. The mudrocks are composed of very fine grain particles with very small pores, so the traditional Darcy permeability equation cannot explain or describe fluid flow from such small pores. For the first time, technology is now imaging these tiny pores and enabling researchers to unlock some of their secrets.

"The physics of gas flow in tiny pores is different from large pores," says Dr. Javadpour. "The interaction of gas molecules and the pore inner wall become important, hence molecular interactions should be considered. AFM can measure these force interactions. We are using the measured interactive forces to understand how flow occurs in these very small pores and develop new flow models that will yield better reserve estimation and ultimate recovery."

### Reservoir Performance

Along with all the new shale plays, oil companies are trying to squeeze every drop out of the conventional reservoir that they can. The latest secondary and tertiary recovery methods, drilling muds, and ways of connecting pore space over great distances are yielding good results. Nanotechnology is playing a key role and will be ever-present in the future oil or gas field.

"Nanoparticles have a very large surface area relative to their volume," says Dr. Javadpour. "The interaction of nanoparticles and mineral grains or fluid interfaces in the reservoir is a new field of research. We can inject a certain volume of nanoparticles with specific characteristics into a well and by analyzing the nanoparticle concentration from an observation well, we learn about the geology and reservoir characteristics. In this case, the nanoparticles act as tracers. We can also make nanoparticles smart and perhaps bring specific information about pressure or even a fluid sample. Another example is that ferromagnetic nanoparticles can be injected into the well bore prior to petrophysical well logging. The injected particles enhance well-log readings and yield better measurements about the reservoir properties. Because of their large surface area to volume ratio, new nanoparticle-surfaced proppants are being developed that could enhance the effectiveness of hydraulic fracturing treatments."

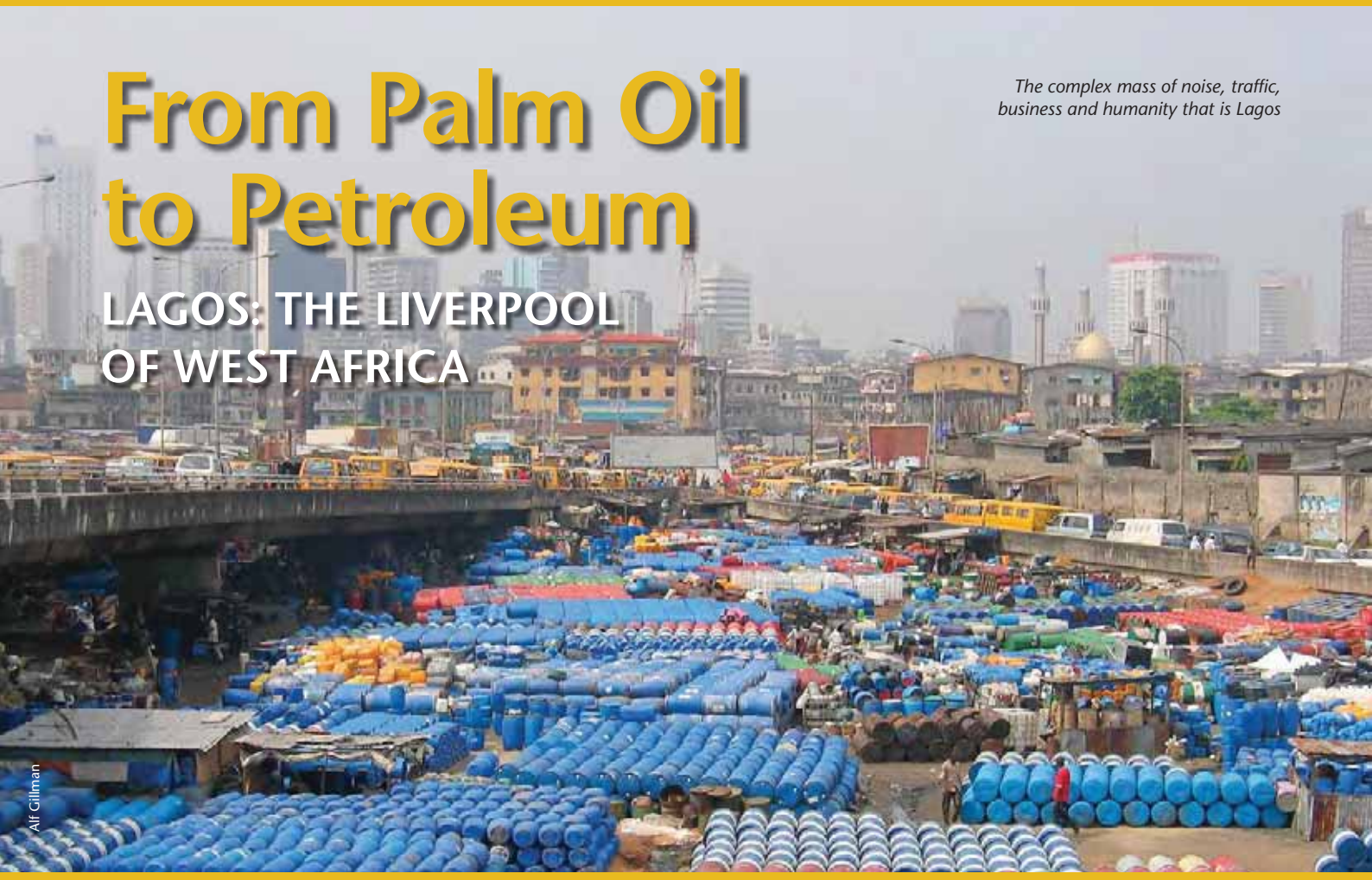
Dr. Javadpour is the principal investigator on a project examining particle transport in porous media, one of many projects supported by 10 major international oil companies through the Advanced Energy Consortium (AEC). The AEC was the brainchild of Dr. Scott Tinker, Texas State Geologist and Director of the Bureau of Economic Geology at the University of Texas at Austin (see GeoProfile, pages 48-50), and opened in January 2008 with Dr. Tinker serving as Director.

"The AEC funds research projects of particular value to the industry at universities, labs, and companies around the world," says Dr. Tinker. "The primary goal is to develop intelligent subsurface micro and nanosensors that can be injected into oil and gas reservoirs to help characterize these reservoirs and improve recovery." ■

*(Editor's note: This article is a brief introduction into nanotechnology. A more comprehensive article will appear in our issue on new technologies next year.)*

# From Palm Oil to Petroleum

## LAGOS: THE LIVERPOOL OF WEST AFRICA



*The complex mass of noise, traffic, business and humanity that is Lagos*

Alf Gillman

ELEANOR ARCHER

Lagos is famous for its teeming crowds and chaotic traffic jams, full to the brim with noise, pollution and crime. As the commercial centre of Nigeria, it is home to at least 10 million citizens, a number predicted to grow to 25 million by 2015, which will make it the third largest city in the world. Before oil was discovered in Nigeria in 1956, there were less than 300,000 people living in Lagos, but as the economy grew, the population swelled rapidly as Nigerians were drawn towards their financial centre.

However, Lagos was a central trading station within Africa long before oil was discovered. Being situated on the Bight of Benin, it became a popular trading spot for European ships, which were drawn to the large lagoon behind Lagos island where there was the opportunity to access the rivers flowing in from the north. By the 1500s, Portuguese sailors began trading across the lagoon, naming the area 'lagos', meaning 'lakes', and buying ivory, slaves and cloth from the local inhabitants. Before that, it had been called called Eko, which stems from either Oko (Yoruba: "cassava farm") or Eko ("war camp").

Lagos was settled at various times by hunters and fishermen from the Awori sub-nationality, the southernmost of the Yoruba-speaking peoples. Yorubaland, of which Lagos is part, was involved in long-running wars which pushed the original settlers further and further south towards the sea in search of refuge, where the natural topography of the islands served to protect those seeking shelter from the internecine wars.

### Leading Slave Port

However, this same shelter provided far less security for its people in the latter part of the eighteenth centuries. Although Lagos originally played a comparatively small part in the slave trade, the rising power and regulations of Dahomey (the Republic of Benin) combined with the abolition of the slave-trade in France (1794) and England (1807) forced the slavers to seek cover and abandon the exposed beaches of Dahomey and Bagadry for the camouflage of the Lagos lagoon. Additionally, proximity to the prolonged warfare and disruption to the north of Lagos in the first half of the nineteenth century created a vast supply of slaves for export, making it West Africa's leading slave port at the time. The Trans-Atlantic slave voyage database put the number of slave exports between 1776 and 1850 at 308,800, with only 24,000 slaves shipped before 1801. The Lagos lagoon facilitated easy and quick movement as it was the only outlet to the sea in the Yoruba region.

Slaving operations continued in Lagos until 1851 in spite of the British anti-slavery patrols. In 1841 Oba Akitoye ascended on to the throne in Lagos and tried to end the trade, but Lagos merchants, most notably Madam Tinubu (after whom Tinubu Square in Lagos is still named) resisted the ban, deposed the king and installed his brother Oba Kosoko. The British, however, supported Oba Akitoye, and aided him in regaining his throne in 1851. A decade

later, these close connections helped Britain annex the kingdom, which had the dual effect of crushing the slave trade and allowing the British to control trade.

When the Liverpool and Bristol slave traders were faced with abolition, they searched for new exports from Africa. Industrialisation in Britain and Europe created a new market for palm oil as a lubricant for machinery, in medicines and for soap and candle-making. Palm oil produced in the interior of Lagos was believed to be of the best quality in West Africa. The oil, along with other commodities such as ivory, led Lagos to become one of the centres of European commerce in West Africa, giving it the nickname 'the Liverpool of West Africa'. In 1887, the remainder of modern-day Nigeria was seized by Britain, and Lagos was declared its capital. Ex-slaves, known as Creoles, returned from Sierra Leone, Brazil and the West Indies to Lagos, contributing to the Portuguese architecture on Lagos Island.

Nigeria ultimately obtained independence in 1960.

## Wealth Floods In

After the oil boom of the 1970s, Lagos expanded considerably, as wealth flooded into the nation. Where once a variety of goods such as palm oil and cacao beans had made up Nigeria's exports, oil now accounts for between 95 and 99% of the country's merchandise exports and 80% of its revenue. A member of the Organization of the Petroleum Exporting Countries (OPEC), Nigeria has proven oil reserves of 37.2 billion barrels, the tenth largest reserves in the world, most of which are located in the Niger River Delta. Nigeria ranks as the world's eighth largest exporter of oil and the United States' fifth largest source of imported oil.

Reportedly, about 80% of Nigeria's energy revenues flow to the government, a further 16% covers operational costs, and the remaining 4% go to investors. However, the World Bank has estimated that, as a result of corruption, 80% of the energy revenues benefit only 1% of the population. In a city where the nation's wealth and economic activity is concentrated, with the headquarters of most of the country's commercial banks and major corporations, two-thirds of the population live in slums, with up to 65% of the city living below the poverty line. With a population density averaging 18,150 people per square kilometer (2007), the city cannot keep up with its frantic population growth. A 2006 report estimated that less than 1% of households in Lagos were linked to any closed sewerage system.

However, in recent years, Lagos has become involved in an on-going rehabilitation of the infrastructure in the heart of the city. At the centre of this stands Eko Atlantic, an artificial island the size of Mahattan, being built from scratch to house 250,000 people, which it is hoped will ease the exhausted infrastructure and overpopulation. ■

*Lagos expects to be home to 25 million people by 2015*

Alf Gillman

# IRAN: Huge Gas Discovery

Although first found in May this year, a recent announcement by the Iranian oil Ministry has upgraded the volume of reserves in the Madar discovery to 17.5 Tcfg (495 $Bm^3$). The field lies in southern Iran, within the Nayband Bay National Park, a few kilometres south-east of Assalouyeh in the coastal Bushehr province. The well, which TD'd at 4,430, tested 7.5 MMcfgd on a 1/2" choke from the Permian Upper Dalan Formation, but the main target was thought to be the Dehram Group. Deputy Oil Minister Ahmad Qalebani, who made the announcement, said that they estimated that 80% of the gas is recoverable, and that the field also contains 1.5 Bb of gas-condensate, from which 658 MMbc is recoverable.

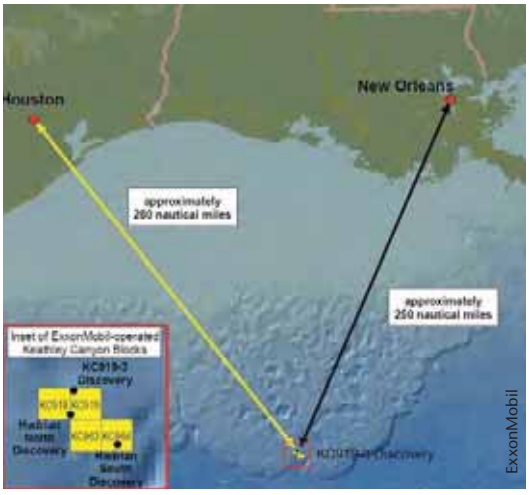
The port of Assalouyeh, 270 km south-east of the provincial capital of Bushehr, is the site of the huge Pars Special Energy Economic Zone facilities, which include a deep water port and an airport, built to develop Iran's offshore South Pars field, which the country shares with Qatar.

# GOM: 1st Post-Moratorium Discovery

ExxonMobil's Hadrian discovery was confirmed in July this year as one of the biggest Gulf of Mexico finds of the last decade, after the KC919-3 wildcat well confirmed the presence of a second oil accumulation in the same block. The original 2010 discovery well, KC 919 2S0B0, had encountered a 168m net oil pay and a minor amount of gas in high quality Pliocene and Upper Miocene sandstone reservoirs in the Keathley Canyon area, approximately 386 km off the Louisiana coastline, south of Lafayette. The recent KC919-3 wildcat confirmed the presence of the accumulation with 145m net oil pay in Pliocene sandstone, which is the shallow secondary target. The well is continuing in order to reach the main Miocene target, expected to be at a depth of about 2,000m. The water depth in the area is about 2,100m.

The accumulation is thought to spread from Block KC919 into the adjacent Block KC918 to the west. In addition, in 2009 ExxonMobil encountered 60m of natural gas pay in Pliocene sandstone reservoirs at its Hadrian South prospect in Keathley Canyon Block 964 to the south-east of the most recent discovery. The company therefore estimates that there is a recoverable resource of more than 700 Bboe in its combined Keathley Canyon acreage, more than 85% of which is oil. ExxonMobil is the operator with 50% interest and is partnered by Eni Petroleum US and Petrobras.

Prior to the Deepwater Horizon oil spill, ExxonMobil had a rig on location and an approved permit to drill, when activities were suspended. The permit was renewed in March this year and this is the company's first post-moratorium deepwater exploration well.





Repsol

# BRAZIL: Campos Basin Pre-Salt Discovery

Repsol Sinopec have announced what they describe as a 'most significant' oil discovery at their Gávea pre-salt prospect, which is in the Campos Basin, rather than the Santos Basin where the majority of such fields have been found. The well, 1-REPF-11A-RJS, is located about 300 km east of Rio de Janeiro, in waters over 2,700m deep. It has been drilling since before March 2011 and reported two oil accumulations earlier in the year, but the significance of the discovery has only now been confirmed. The consortium, which also includes Statoil (35%) and Petrobras (30%), is currently analyzing the results of the well before continuing with exploration and evaluation work in the area.

*The Stena DrillMAX drilling the Gávea discovery well in the Campos Basin*

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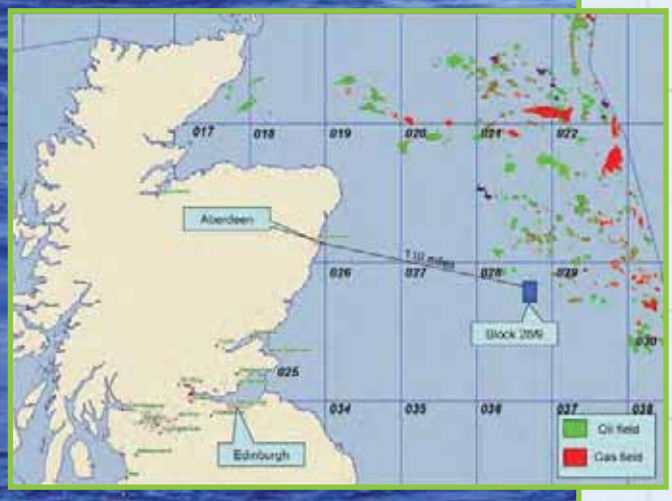



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# New Digital Africa Maps

New digital maps, based on ones originally produced by Africa specialist Ed Purdy, should shed new light on the exploration of the continent

Ed Purdy was an explorationist, academician and teacher. To many he is best remembered as a pioneer in the field of carbonate sedimentology but Ed also made significant contributions to the understanding of African geology. In 1989, Ed authored maps showing the Exploration Fabric of Africa, and African Basins. Using data from a variety of sources he compiled regional geology, tectonic framework and a range of exploration-oriented information. The maps were published at scales of 1:5,000,000 and 1:10,000,000 and were accompanied by a set of explanatory notes. They were well received and over 1,000 copies were produced and distributed.

Sadly, Ed died in October 2009, and as a tribute to the contribution he made to geology, friends and former colleagues decided that his Africa maps should be updated to reflect significant recent developments in oil and gas exploration in Africa, including deep water West Africa, Nile Delta, the Transform Margin and the Ugandan Rift Valley.

The Exploration Fabric of Africa Project (EFA) has been sponsored by 23 companies with interest in Africa and their contributions are being used to prepare an exploration GIS using ESRI ArcGIS software. Hardcopy maps and other digital output will be published by the American Association of Petroleum Geologists. Currently, two beta versions have been released and a final version will be available in 2012.

## Wide Range of Data

Digital geological datasets included in the project are a version of Ed Purdy's surface geology, the USGS 1997 data and a digital geological dataset derived in part from UNESCO maps of Africa. Outcrop geology is constructed as a series of polygons each of which is attributed with chrono-stratigraphic and lithostratigraphic information.

Public domain gravity and magnetic data have been reprocessed and new grids showing isostatic gravity, Bouguer gravity and total magnetic intensity have been produced Other grids have been prepared to show bathymetry, based on Gebco data, and relief, from SRTM 90m data.

Depth-to-basement and total sediment thickness maps have been prepared from inversions of the gravity and magnetic data, calibrated to a variety of G&G data (wells, seismic etc).

Over 1,200 fields and significant discoveries are included in the GIS, together with information on hydrocarbon types, seeps and play fairways.

The AAPG group of layers all contain hyperlinks which allow searching of AAPG Datapages publications. The AAPG Seismic Atlas layer contains links to over 600 published seismic images in and around Africa, and AAPG burial histories for Africa can be displayed through the hyperlink. Users can also search for AAPG and associated publications based on field name, country or basin.

In addition to seismic images from AAPG, there are four regional offshore seismic lines which have been made available by ION from the BasinSPANS project. It is anticipated that more seismic images will be included from other seismic acquisition companies. The project also includes the location of African Deep Sea Drilling (DSDP) and Ocean Drilling (ODP) sites with hyperlinks to NOAA and TAMU archives.

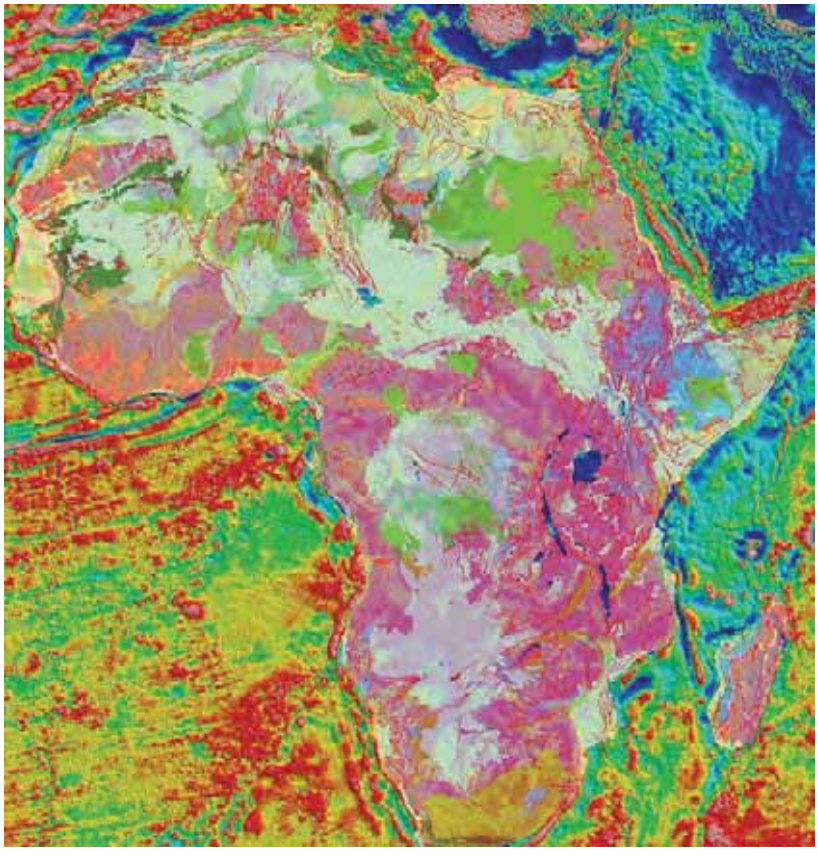
A spatial index of geological maps of Africa has been kindly provided by The Geological Society. This index, shown at various scales, allows users to search for geological maps held by The Geological Society based on a variety of search criteria.

For users not wishing to use ArcMap, the GIS project can also be visualised through a browser-based Java Script viewer (ArgGIS Server application), and via Google Earth (kmz files).

The EFA Project team are contributing their service on a pro bono basis and a proportion of the funding from sponsors has been donated to Africa Now, a charity supporting farmers and small businesses in Africa. EFA has a new website at http://www.efafrica.com where further information can be found.

**PETER WIGLEY**

*Map from EFA version 1.2 beta showing reprocessed isostatic gravity with a semi-transparent overlay of onshore outcrop geology.*

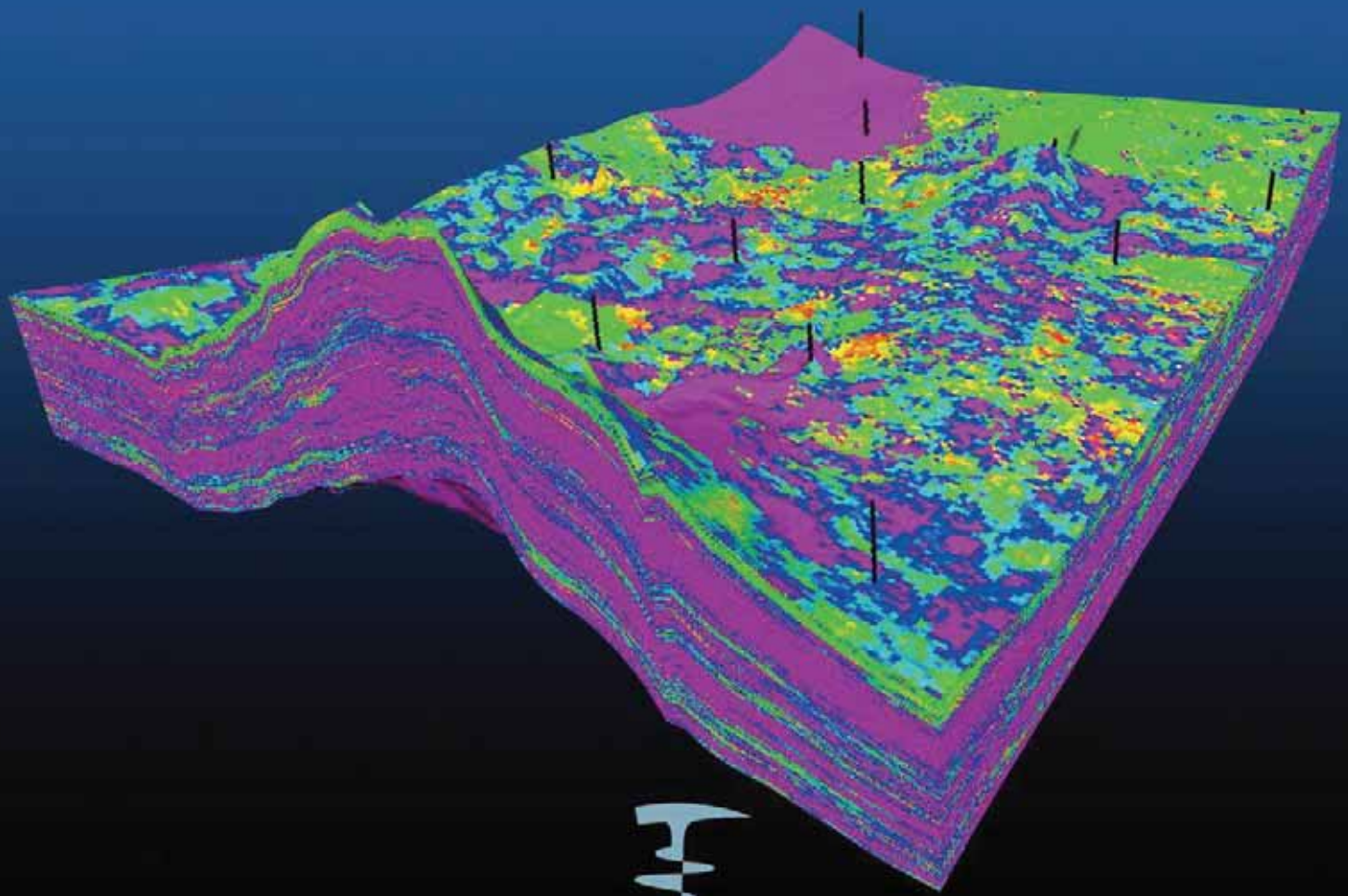


# Production Geoscience 2011

## Geology, resource potential and production strategy of marginal and challenging developments

Stavanger, November 1-2, 2011

www.geologi.no/pg2011



GEOLOGICAL SOCIETY
OF NORWAY

# Do We Need Another Seismic Company?

New kid on the offshore seismic block, **Dolphin Geophysical**, started trading in 2010 and has been growing steadily ever since. But with a few notable exceptions, seismic companies seems to come and go with great rapidity, so does the industry need yet another? We ask **Atle Jacobsen, Chief Executive Officer of Dolphin**, to answer this question.

***So why does the industry needed another seismic company?***
During the last two years the seismic industry has seen two significant bankruptcies and a take-over, so by bringing a new player to the table we are increasing competition. Increased competition pushes the market to strive for the best results for clients in the most economical way, thus an improvement in processes is necessary. As a new company we intend to innovate in both technologies and processes.

***Is there room for even more companies?***
The demand for high end 3D vessels is increasing and I believe it will continue to improve into 2012 and beyond. All indications point to a rebound in the market and in the space of 6 months we have already expanded from zero to four vessels, all of which are generating revenue. In early 2012 we expect to take delivery of Polar Duke's sister ship, increasing our presence in the high end segment. We have already shown that we are opportunistic and will continue to look for growth opportunities both organically and through market consolidation.

***What important factors does a new company bring to the oil industry?***
Competition, new vessels, new processes and improvements in already established relationships.

***Have you identified a particular niche market, or are you looking at the whole business?***
Dolphin's strategy is to provide a vessel for each area of the market, whilst focusing on high-end 3D vessels and Multi-Client projects as well.

***What do you think makes a successful seismic company?***
Operational efficiency, powered by people; handpicked teams, with unquestionable experience and drive and a strong QHSE ethic; all these are essential.

Everyone in our management has a minimum of 10 years' experience in the seismic industry, and our team as a whole has a tremendous track record in building solid enterprises. Although a technology driven company, our focus on human resources and creativity is important – our business is all about acting together to recognise and create business opportunities.

Robust QHSE performance is vital when competing in today's offshore industry – that's why our very first Purchase Order was for the procurement of the best risk and compliance system available; Integrum, which connects all work sites in real time to provide an inclusive system that is both transparent and flexible.

We believe we have created in Dolphin is a very competitive alternative; fit and ready for hard, efficient work, lean and keen, geared for performance and with a healthy appetite for the next challenge. This combined with stability and foresight are the keys to a successful seismic company.

***Why did you decide to base yourselves in Bergen, Norway?***
Bergen is a main pool of expertise for both the shipping and seismic industries – having an office in Bergen puts us closer to our shipowners and also gives us access to an extremely knowledgeable local workforce. Plus, we like the rain!

***What advantages does a small company have over its larger competitors?***
Dolphin is a streamlined organisation which gives us the ability to act on and react quickly to both the challenges and opportunities we are faced with.

As a new, seismic company we have had the opportunity to hand pick our staff, and the driving force of any successful company is its people.

***How do you see the marine seismic industry developing in the future?***
I see two main channels of development: increasing demand for high-end 3D vessels, and the uncovering of new unexplored territories using the Multi-Client business model. ■


Dolphin Geophysical

*Alte Jacobsen, CEO of Dolphin Geophysical, has 17 years experience in the offshore E&P industry, having worked for a number of companies, including PGS, Stolt Offshore, Multiwave and Wavefield Inseis. He holds an MSc in Nautical Engineering from NHT in Trondheim.*

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# Pre-Salt Exploration Trends in the Kwanza Basin

The continued application of new technologies is opening up a new exploration frontier in the deepwater Kwanza Basin

JOHN BALCH, DI INTERNATIONAL

Since the discovery of the Girassol field by Elf in 1996, most deepwater exploration in Angola has focussed on post-salt Tertiary fans in the Lower Congo Basin. The application of modern seismic imaging has meant that nearly four out of five exploratory wells drilled in 2009-2010 were successful and two-thirds of Angola's oil production is derived from deepwater fields.

The pre-salt plays off Brazil have generated some of the largest discoveries in recent history, with over 14 Bboe found since 2007, and the US Geological Survey has estimated that pre-salt formations in Angola could contain up to 30 Bbo, equivalent to the resources of Nigeria or Qatar.

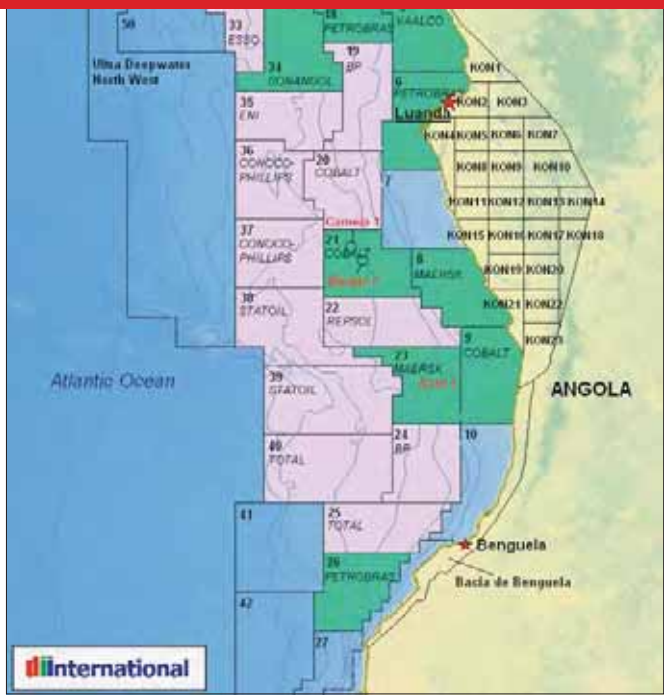
The National Oil Company, Sociedade Nacional de Combustíveis de Angola (Sonangol) has been working in conjunction with Petrobras to gain a better understanding and promote the pre-salt potential and in January 2011, Carlos Saturnino, Sonangol's Director of Negotiations, stated that exploration in Angola was entering a new phase which will require greater investment and have greater technological complexities.

## Potential On and Offshore

Unlike the pre-salt basins of Brazil, which lie offshore, around 20% (25,000 km$^2$) of the Kwanza Basin lies onshore, although the prospective sub-salt formations can lie around 4,000m below ground level onshore and are even deeper offshore. There has been no active exploration in the onshore area for over 20-years, but there is still the potential for new discoveries in this proven oil producing region.

The risks in deepwater areas are greater and the accumulation of high quality modern seismic data with leading edge processing/velocity modeling is becoming critical to accurately identifying leads and prospects. The nature of the salt is a primary control and varies across the Kwanza Basin. Blocks 36-40 appear to have thicker but shallower salt horizons, whilst inboard of Blocks 19-24, thick diapiric salts appear to be more common. Extensional rift tectonics dominate in the pre-salt section, with a fault induced relief that exhibits both tilted and folded sections. Potential pre-salt plays could include tilted fault blocks with sands and carbonate mounds providing potential reservoirs for oil sourced from adjacent lacustrine shales.

BP successfully used conventional narrow-azimuth 3D seismic data to identify many of its five pre-salt discoveries on Block 31 in the Lower Congo Basin and in 2008-2009 shot the first wide-azimuth towed streamer (WATS) seismic survey outside the Gulf of Mexico over the western part of the block to refine its model and provide data with sufficient resolution for the appraisal and development of sub-salt discoveries.



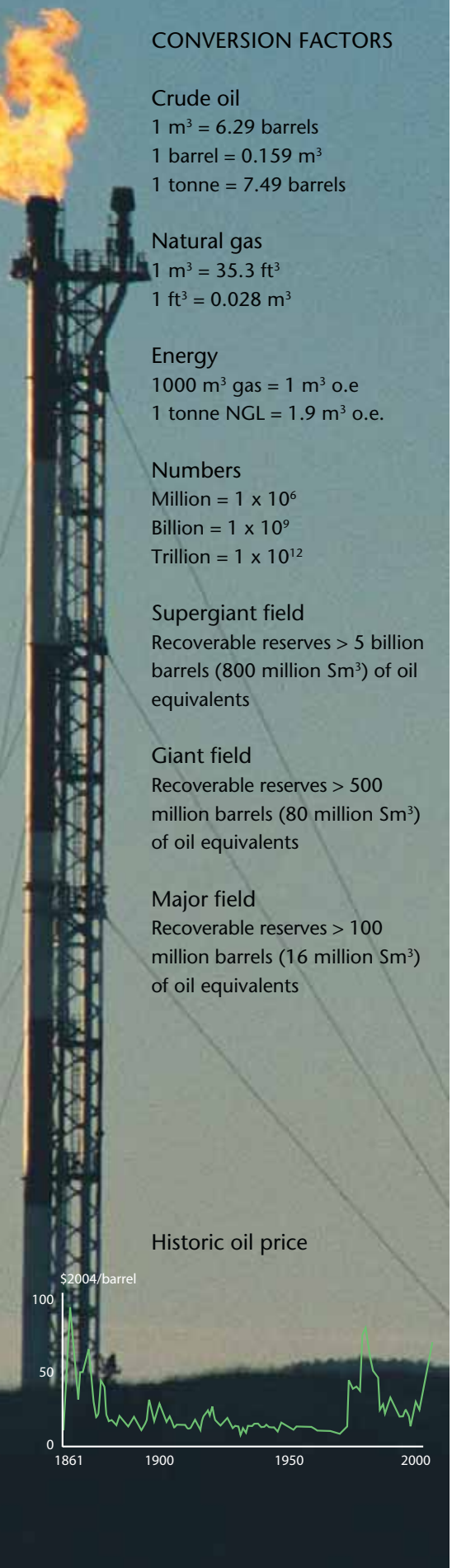

*In January this year provisional awards in the pre-salt of the Kwanza Basin were made to operating groups led by BP, Cobalt, ConocoPhillips, Eni, Repsol, Statoil and Total.*

## Ongoing Exploration

Relatively few wells have been drilled offshore Kwanza Basin and many of the historical wells were apparently drilled off structure. Drilling operations, however, are ongoing. Maersk is thought to have spudded exploration well Azul 1 on Block 23 in the southern Kwanza Basin in June 2011, with a pre-salt target over 5,000m deep. Cobalt Energy International spudded and then abandoned its first well (Bicaur 1) on Block 21, after encountering an overpressured water sand, with limited quantities of natural gas. It is reviewing its shallow drilling hazards before either spudding a new well, Cameia 1, or returning to a location near Bicaur 1. Further south, Petrobras is planning to drill its first pre-salt wildcat in the Benguela Basin on Block 26 in Q3/Q4 2011 to investigate the deepwater Ogonga prospect. BP is understood to have released a deepwater drilling rig for the well and may farm into the block.

On the northern margins of the basin, Vaalco may also drill an exploration well on Block 5 during the second half of 2011. The US based independent has identified many prospects and leads with up to 350 MMboe of recoverable resources in multiple plays, including pre-salt opportunities.

Sonangol remains committed to exploring the pre-salt and frontier plays and continues to gather data across all open areas in Angola. The next licensing round is not expected before 2012 and is will probably comprise open areas both onshore and offshore Kwanza, as well as areas in the Benguela and Namibe Basins. ■



## 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

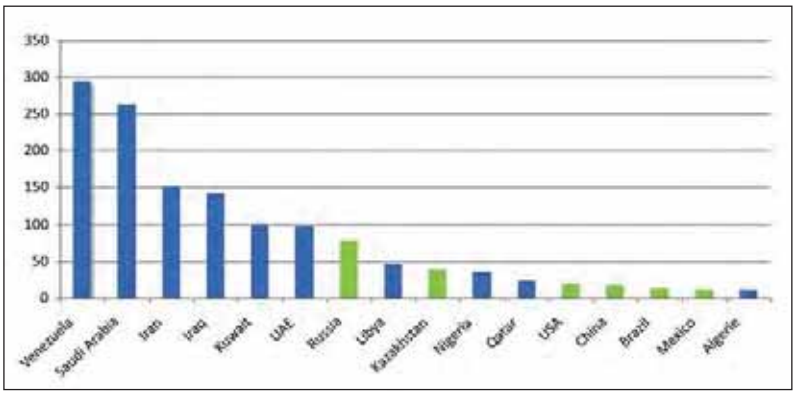
### Historic oil price




# Venezuela in First Place

*Halfdan Carstens*

According to figures recently published by OPEC, Venezuela has passed Saudi Arabia and now has more producible oil in the ground than any other country. Huge reserves of heavy oil are the explanation.




*Oil reserves in Bbo by country as given by the OPEC Annual Statistical Bulletin. OPEC countries in blue.*

World oil production may not have peaked yet.

OPEC has published the 46th edition of its Annual Statistical Bulletin (ASB). The most striking figure is the estimate of Venezuela's oil reserves. This has now reached 296 billion barrels, up from 211 billion barrels last year, an increase of more than 40%. Looking back over the last five years, the figure has more than tripled – that is remarkable, to say the least. It is also in agreement with the statement made by President Hugo Chavez earlier this year, when he claimed that the proven oil reserves in Venezuela are the largest in the world.

In comparison, Saudi Arabia's oil reserves have been constant for the last five years according to the same report. The OPEC estimate is 264 billion barrels. Both countries are members of OPEC.

The BP Statistical Review of World Energy 2011, also published this summer, does not agree with ASB, as the estimate for Venezuela is "only" 211 billion barrels of oil, as opposed to 264 billion barrels of oil for Saudi Arabia. But the BP review agrees with ASB in that Venezuela's oil reserves have increased considerably since 2000. In fact, the reserves have increased almost threefold, according to the BP experts.

ASB, published later than the BP report, does not give a reason for the discrepancy between the two estimates.

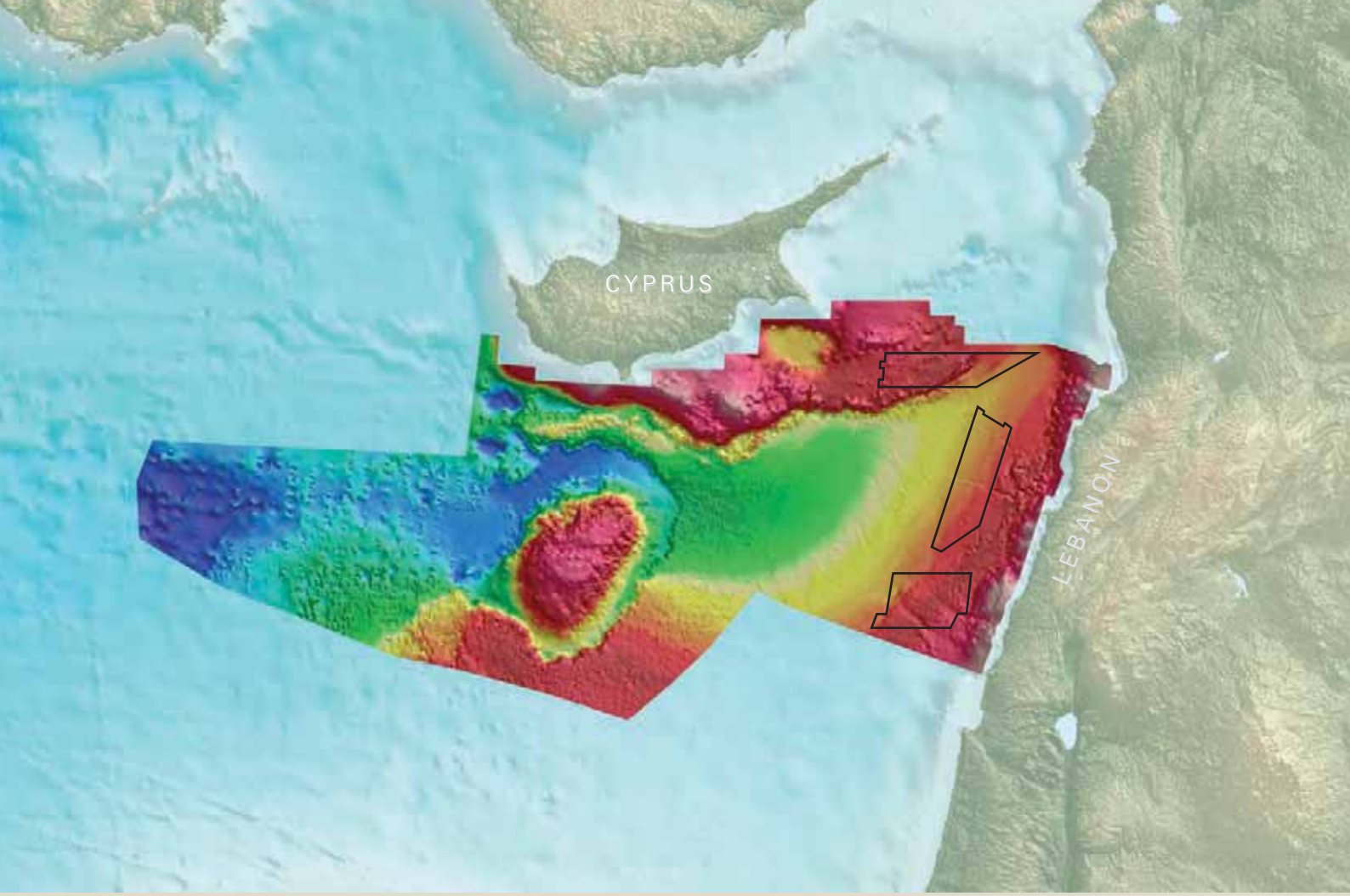
Regardless, it is interesting that Venezuela now considers its heavy oil in the Orinoco Belt to be recoverable with today's technology and price of oil, as it is well known that this petroleum province has vast resources of untapped oil.

The U.S. Geological Survey has previously estimated a mean volume of 513 billion barrels of technically recoverable heavy oil in the Orinoco Oil Belt. Their range is 380 to 652 billion barrels, of which the lower estimate – as we can see – is still less than the ASB reserve estimate. With great confidence it can thus be stated that the Orinoco Oil Belt contains one of the largest recoverable oil accumulations in the world. The USGS also says that the Orinoco Belt is estimated to contain 900–1400 billion barrels of heavy crude in proven and unproven deposits.

The Orinoco Oil Belt covers some 50,000 $km^2$ (equivalent to some 8 North Sea quadrants), and the heavy oil is largely contained within fluvial, nearshore marine and tidal sandstone reservoirs of the Miocene Oficina Formation. Sandstone reservoirs range in depth from 150 to 1,400m, and they contain heavy oil with a range of gravities from 4° to 16° API. Viscosities are thus generally low.

OPEC consists of 12 countries: Algeria, Angola, Ecuador, the Islamic Republic of Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela. The total OPEC output was 34.234 MMbopd in 2010, according to BP, while Venezuela had a daily production of 2.471MMbopd last year.

**HALFDAN CARSTENS**




# MegaSurveys

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# Nigeria-Sao Tome and Principe
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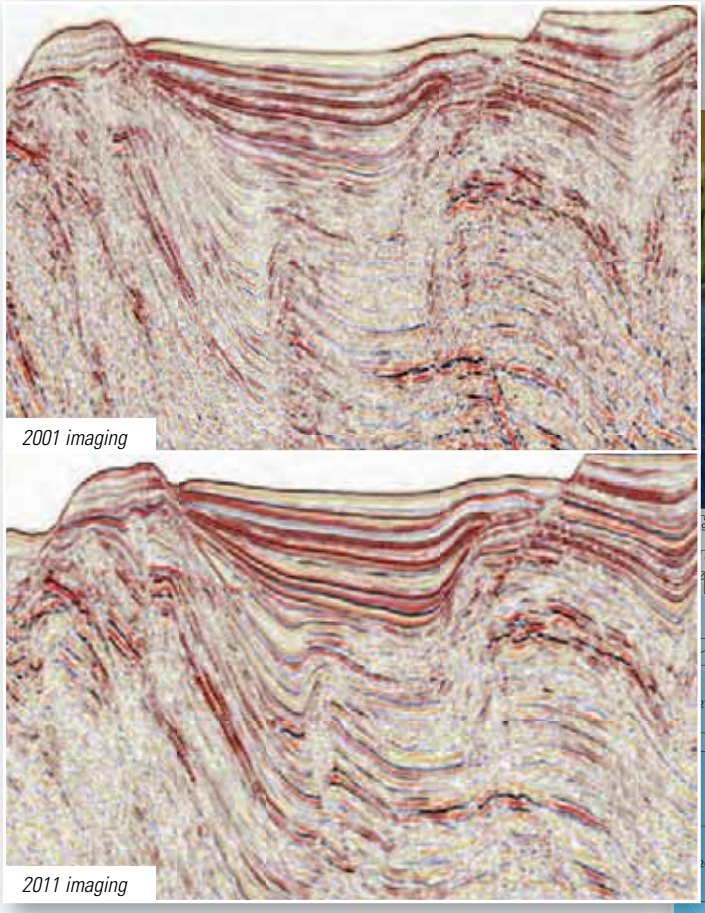


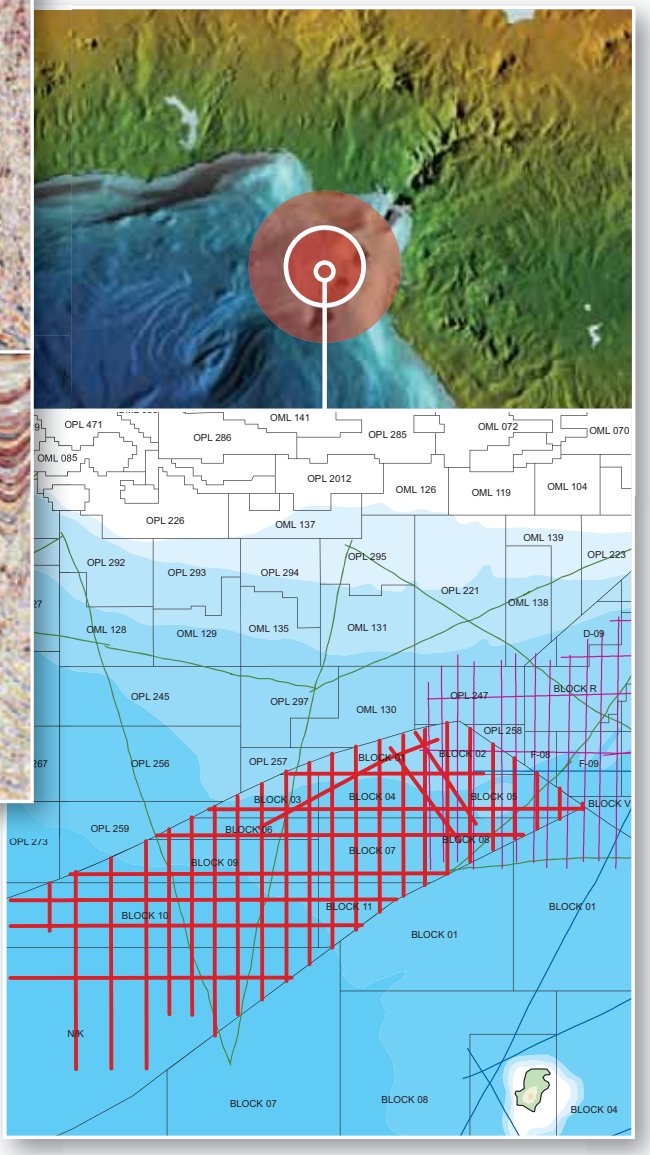


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