GEO ExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED

VOL. 8, NO. 6 – 2011

geoexpro.com

COUNTRY PROFILE

# Libya:
## The Next Chapter

**GEO Cities:**
**The Making of Modern Dubai**

## GEOPHYSICS
Emphasizing Vibrations

## GEOTOURISM
The Wonders of Yellowstone

GEO ExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED


*Can crabs hear seismic sources?*

# CONTENTS

**This edition of GEO ExPro Magazine focuses on North and South America and Frontier Exploration**

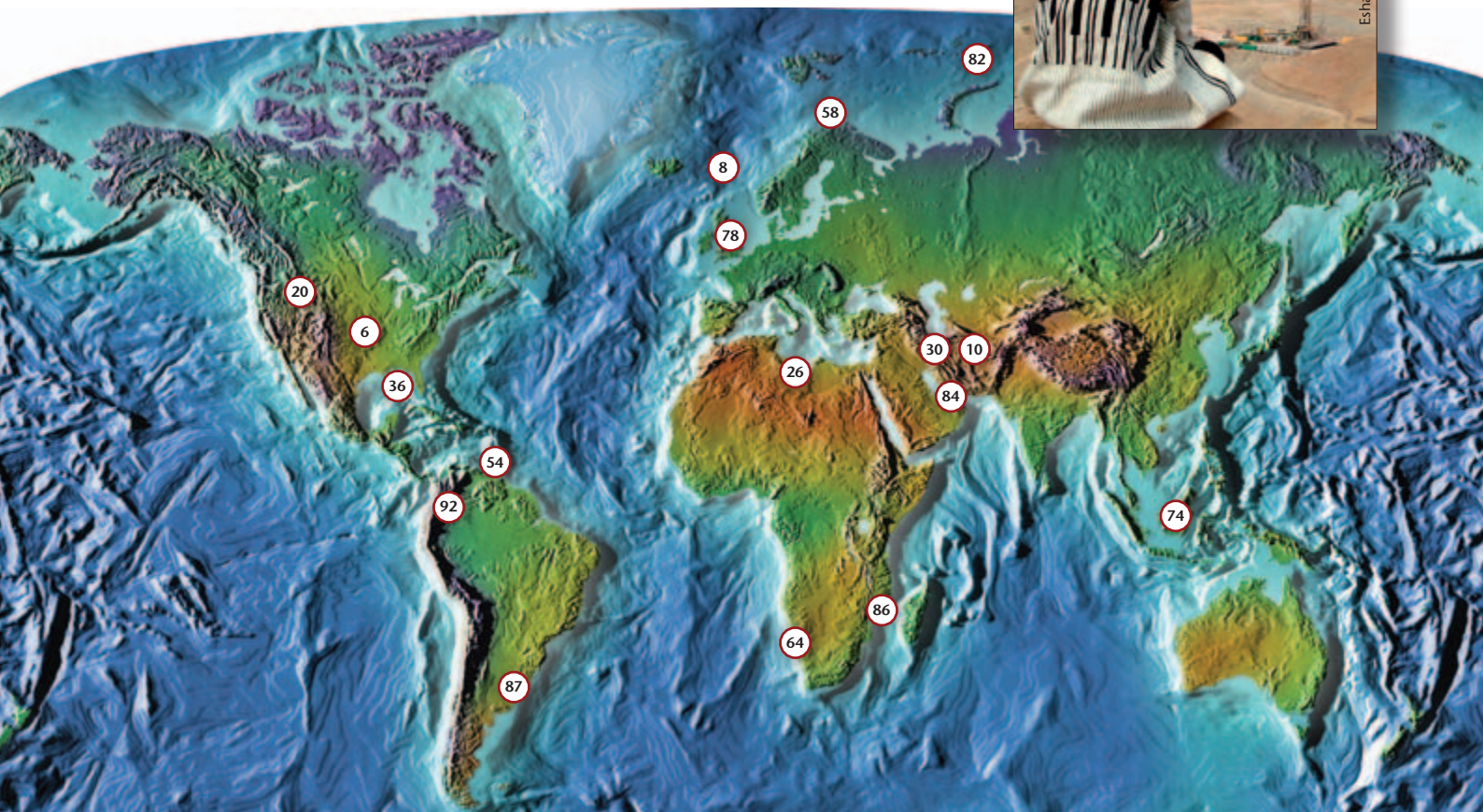
## COLUMNS



## FEATURES




*Iran holds 10% of the world's proven oil reserves of oil and 16% of the gas – and it started here, at the Masjid Sulaiman oil field.*

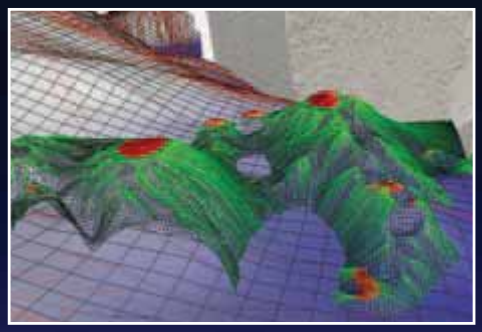


# Petrel 2011

E&P SOFTWARE PLATFORM



# Deliver **confident** prospect selections



Capture prospect uncertainty from the start; assess seal capacity and charge timing as you interpret seismic, make maps, and calculate volumes—in one application.

Deliver confident decisions—with Petrel.

**www.slb.com/petrel2011**

Global Expertise | **Innovative Technology** | Measurable Impact

Schlumberger

# Time for a Little Education


*Cuadrilla rig at Preese Hall near Blackpool, north-west England, where drilling is believed to have caused minor earth tremors.*

Shale gas has been a game changer for the energy industry in the United States – but things look a bit different in Europe. Drilling by Cuadrilla Resources at a shale gas well in the north-west of England was stopped when minor earth tremors were felt, and an independent report concluded that pressure changes due to water injection during the fraccing process were to blame. One good thing to come out of this is that the average person in the UK, at least, is now a lot more knowledgeable about the process – but also a lot more concerned. Headlines in the newspapers such as 'we caused 50 tremors in Blackpool – but we're not going to stop' do not really help the industry. A group of protesters calling themselves 'Frack Off' occupied another Cuadrilla site, causing operations to stop for a day. Questions are also being raised over an increase in seismic activity in an area of Oklahoma which has over 100 injection wells. In France the government banned hydraulic fracturing in May this year due to concerns about the technique's impact on the environment.

Cuadrilla have said that they estimate that there is more than 200 trillion cubic feet of gas in its license area in north-west England, and that the development could create over 5,000 jobs in the UK. And as European gas prices continue to rise, the development of a European shale gas industry could begin to reduce those costs, as it has in the United States.

The British Geological Survey, among others, has pointed out the lack of peer-reviewed research into fraccing and associated issues like potential water contamination. The French ban on fraccing, and by default on shale gas exploitation, was made before any serious assessment of the potential of the resource in the country had been undertaken. If the petroleum industry thinks this is a key resource for the future, it is time to start spreading the word by encouraging research and educating the general public so they can be informed by all sides of the debate.

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

## YELLOWSTONE NATIONAL PARK

At morning's first light, views across steam rising from the West Thumb Geyser Basin located on the west shore of Yellowstone Lake can take you back to when the earth was in a more primordial state. "The Wonders of Yellowstone" in this issue will introduce the reader to the world's first national park, which started a new trend in protecting special places for future generations.

*Inset:* From Pirates to Prada: As the United Arab Emirates celebrates its 40th anniversary, we take a look at the making of the modern Dubai.




GEO ExPro

www.geoexpro.com

**GeoPublishing Ltd**
15 Palace Place Mansion
Kensington Court
London W8 5BB, U.K.
+44 20 7937 2224

**Managing Director**
Tore Karlsson

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

**Contributing Editors**
Thomas Smith
Thomas.smith@geoexpro.com

Halfdan Carstens
halfdan@geo365.no

Rasoul Sorkhabi
rsorkhabi@egi.utah.edu

Paul Wood
sciwrite@btinternet.com

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

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

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

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

**Cover Illustrations:**
*Cover picture: Thomas Smith*
*Inset: Phil Magor*

**Layout:** Bookcraft Ltd.
**Print:** NXT Oslo Reklamebyrå

issn 1744-8743

# Paradigm Shift for US Oil Production

*THINA MARGARETHE SALTVELT, PH.D*

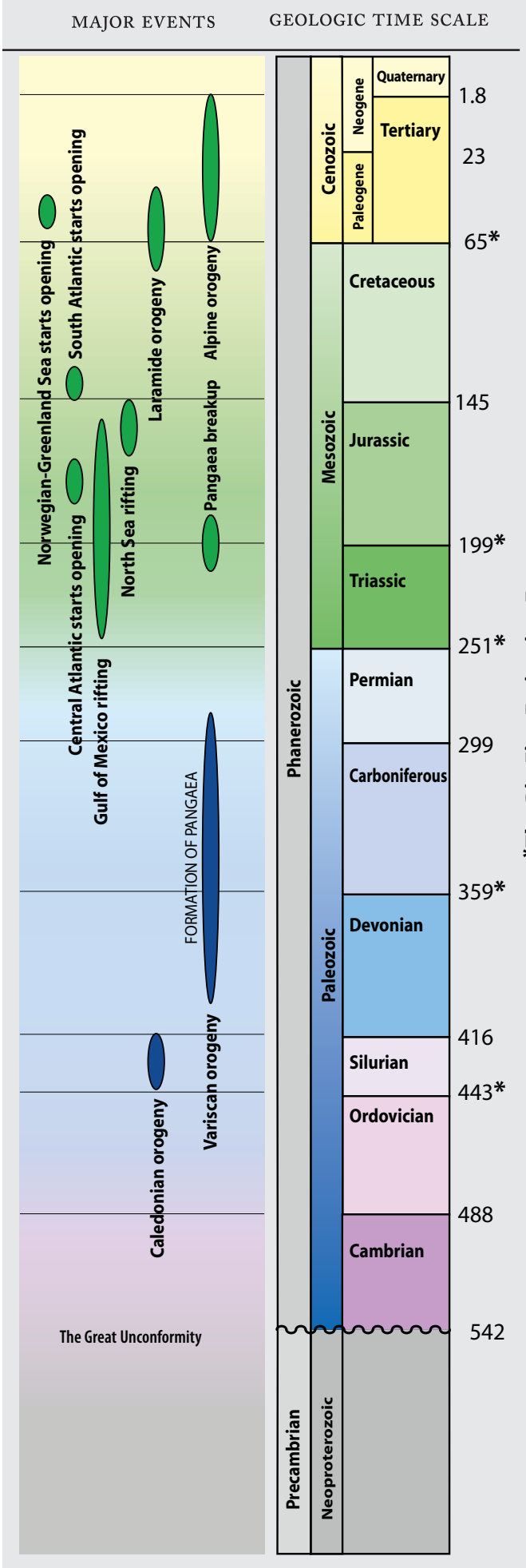
The last time that the oil weapon was used was during the oil crisis in 1973. The US no longer had an oil buffer for the West to lean on and was thus unable to defend itself against OPEC's oil supply cut. Does shale oil mean the US could once again become self-sufficient in oil?

A technological breakthrough has made shale gas production profitable and transformed the US gas market. At today's production level the total gas reserves of the US are now large enough to cover consumption for the next ten years. The same technique can be used to extract oil from shale, so we could therefore be facing a paradigm shift also in the oil market.

Ever since the oil crisis in 1973, the US has had an ambition to become self-sufficient in oil again. New extraction methods and high oil prices have made production of oil from shale formations lucrative. There is still little available information on the overall size of extractable oil reserves. According to the United States Geological Survey, the extractable shale oil reserves of the US could be more than 24 Bbo. The US is assumed to have about half of the world's known reserves. Shale oil production is expected to increase six-fold over the coming ten years from the current level of around 400,000 bopd. Together with increased NGL production (natural gas liquids) and larger extraction from existing fields, shale oil could take the US one step closer to oil self-sufficiency.

Until the early 1970s the US rather than the Arab countries was seen as the oil industry's last resort. Oil producers in Texas, Louisiana and Oklahoma could always swiftly turn on the taps and transport more oil to the global market if the need arose. But US oil production peaked as early as 1970 and has since fallen by over 30%. During the same period overall oil consumption rose by a hefty 41%. This has made the US very dependent on oil imports from politically unstable countries such as Nigeria, Venezuela and Iraq. The growing dependency of the US on imported oil has made the country more economically and politically vulnerable. Oil-exporting countries have on a number of occasions used oil to exert political power. The last time that the oil weapon was used was during the oil crisis in 1973. The US no longer had an oil buffer for the West to lean on and was thus unable to defend itself against OPEC's oil supply cut. Since then, Venezuela's Hugo Chavez has several times threatened to cut oil supplies to the US. The president of Iran has threatened to use the oil weapon if the US and the West step up the pressure to stop the country's uranium enrichment program. The sharp rise in oil prices in recent years has therefore been a growing worry for the president. In value terms oil makes up around 20% of the country's imports of goods and more than half of the US trade deficit. Increased shale oil production, stricter energy efficiency requirements, notably in the transport sector, and increased usage of biofuels could slash the oil imports bill and significantly improve the US trade balance versus other countries.

Shale oil production also offers major environmental challenges. There is growing concern that the manufacturing process may pollute the ground water, and the US authorities are considering limiting drilling activity near water reservoirs. Stricter environmental requirements could put a major damper on the extraction of shale gas and oil. ■




km

and counting...

# The World's Second Largest 2D Multi-Client Seismic Library*

*In July Spectrum added more than 500,000 km to its Marine 2D Multi-Client library making it the world's 2nd largest. The library includes some of the best regional Multi-Client datasets available in the Mediterranean, Eastern Gulf of Mexico, N.W. Australia and N.W. Europe.

The newly enhanced Spectrum library now exceeds one million km of seismic data covering all major sedimentary basins worldwide.

Spectrum

For more details please contact:
+44 1483 730201
mc-uk@spectrumasa.com
www.spectrum**asa**.com

# Collaboration is the Future

## A new atlas of the North East Atlantic region is the outcome of collaboration between national survey organizations.

In the present straitened times, finances are tight for all research organizations, and geological institutes are no exception. This realization has prompted the national geological surveys of many of the countries bordering the North East Atlantic – a key petroleum province – to form an alliance with the aim of furthering geoscience understanding in their joint region. The resulting North East Atlantic Geoscience (NAG) cooperation framework was agreed to by the chief executives of the British, Norwegian, German, Icelandic, Netherlands, Irish, Northern Irish, Danish and Greenland national geological surveys or institutes.

The idea behind this venture is to identify projects and areas of research which can be more effectively furthered through collaboration. One of the first projects to be put forward is an initiative centered around the tectonic development of the North Atlantic, with particular emphasis on continental margin evolution and increased understanding of the deep water basins along the continental margins. In the spring of 2009, representatives of the surveys formed the NAG-TEC Group with the remit to define and carry out this project.

From the outset, a key emphasis was to identify and compare important conjugate margin pairs to understand the full rift system across the entire North Atlantic basin, but it was quickly realized that there were a number of barriers that prevented optimal design of possible new projects. These included a lack of regional compilations of key geological and geophysical information, which together with local nomenclature differences resulted in difficulties in establishing regional correlations, while large areas with sparse data made it difficult to prioritize which data gaps were most important in terms of regional understanding.

As the group looked at these issues, it became readily apparent that a new comprehensive and up-to-date Tectonostratigraphic Atlas of the North East Atlantic Region was necessary, from which it will be possible to develop an understanding of the evolution of the area on a regional scale. The Atlas will be an A3 publication and GIS digital atlas, comprising maps, charts, analyses, metadata of all known geophysical and geological investigations and summary chapters describing and analysing the key outcomes from the project.

### De-risking Exploration Frontiers

As NAG-TEC project leader John Hopper from GEUS (Geological Survey of Denmark and Greenland), explains; "This Atlas will be an important asset to the oil and gas industry, as the search for hydrocarbons moves into the more remote corners of the Atlantic. It will de-risk frontier exploration areas and deep water basins by providing a quantitative analysis of basin parameters and regional correlations of key stratigraphic units and geologic formations and an understanding of the basin response to magmatic seafloor spreading. It will be critical for exploration in undrilled frontier areas by highlighting connectivity between them and known prospective areas, and will develop new models for the tectonic and stratigraphic evolution of the conjugate margin system, leading to more accurate reconstructions of sediment sources and sinks through time.

"As we believe that the outcome of the project will form the essential knowledge base for setting regional exploration priorities for the next decade and beyond, we have asked the petroleum industry for sponsorship, and already have a number of companies involved. Sponsors join the project on a non-exclusive basis and contribute €200,000. They gain access to the confidential project web site and participate in the steering committee meetings and in regular workshops."

"This is an exciting development and we hope it will be the precursor to a number of other collaborative schemes," John Ludden, Director of the British Geological Survey, adds. "In the future the European geological surveys could form consortia of, for example, paleontologists or geochemists, sharing knowledge and expertise, and running joint projects. The European geological surveys working together has to be good for future research." ■

GEUS

## ABBREVIATIONS

**Numbers**
(US and scientific community)

| | |
|---|---|
| M: thousand | = 1 x $10^3$ |
| MM: million | = 1 x $10^6$ |
| B: billion | = 1 x $10^9$ |
| T: trillion | = 1 x $10^{12}$ |

**Liquids**
barrel = bbl = 159 litre

| | |
|---|---|
| boe: | barrels of oil equivalent |
| bopd: | barrels (bbls) of oil per day |
| bcpd: | bbls of condensate per day |
| bwpd: | bbls of water per day |

**Gas**

| | |
|---|---|
| MMscfg: | million $ft^3$ gas |
| MMscmg: | million $m^3$ gas |
| Tcfg: | trillion cubic feet of gas |

Ma: Million years ago

**LNG**
Liquified Natural Gas (LNG) is natural gas (primarily methane) cooled to a temperature of approximately -260 °C.

**NGL**
Natural gas liquids (NGL) include propane, butane, pentane, hexane and heptane, but not methane and ethane.

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

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

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

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

# COMPLEXITY SIMPLIFIED

**HPVA** High-Productivity Vibroseis Acquisition

**V1** Point-Source Acquisition

**EmphaSeis** Broadband Vibroseis

## Better Technology for Better Imaging

Realize the true potential of vibroseis using the proprietary technology and acquisition expertise of CGGVeritas. Utilized worldwide, CGGVeritas advanced vibroseis techniques enhance signal quality, boost productivity and empower high-density wide-azimuth acquisition:

- **EmphaSeis** – Customized broadband sweep for better imaging of shallow and deeper targets
- **V1** – High-performance point-source operations with real-time QC for better reservoir delineation and characterization
- **HPVA** – Patented noise removal for higher-quality data from slip-sweep operations

CGGVERITAS

Safer, Finer, Better

**Get to Know Our SeisAble Benefits**

cggveritas.com/land

# Afghanistan Taking Off?

## CNPC becomes first international player to secure Afghanistan acreage

NASA/GSFC

Ravaged by years of war, geographically disadvantaged, landlocked and mountainous and carrying genuine fears of political instability; hardly incentives to attract investors. However, state-owned China National Petroleum Corp (CNPC), well accustomed to such obstacles internationally and on a quest to secure future energy supplies, has accepted the odds and won the first acreage to be awarded in Afghanistan through a tender process. CNPC beat off competition from four other bidders for a contract to explore for and produce oil in three blocks in north-west Afghanistan. The Kashkari, Bazarkhami and Zamarudsay blocks contain an estimated 80 MMbo in a remote part of the country thought to hold a total of about 1.6 Bbo and 16 Tcf gas.

The three blocks are in the southern edge of the Amu Darya Basin, a prolific hydrocarbon-bearing region found in portions of Turkmenistan, Uzbekistan and northern Afghanistan. The basin has a Paleozoic to Triassic basement complex of igneous and metamorphic rocks, overlain by Jurassic to Paleogene terrigeneous sedimentary rocks, with a cover of Neogene to Holocene orogenic clastics. The most important reservoir rock in these three blocks is Lower Cretaceous Hauterivian sandstone, found at depths of 1,000 to 1,500m. Productive Lower Cretaceous Albian and Aptian sandstones also may be encountered at shallower depths.

The geology of Afghanistan is structurally complicated, consisting essentially of a succession of narrow north-east trending terrains of continental fragments of Paleozoic to Tertiary age. Oil and gas exploration commenced in Afghanistan in 1956 and the first oil field, Angoat, was discovered in 1959. Subsequently, the Yatimtaq gas field was discovered in 1960 followed by Khwaja Gogerdaq gas field in 1961 and Khwaja Bulan gas field in 1964. Despite the concentration of exploration activity in the Amu Darya Basin, the part of the basin in Afghanistan is relatively underexplored when compared to the Turkmenistan and Uzbekistan counterparts. CNPC is already producing oil from the basin across the border in Turkmenistan, so winning Afghanistan's first exploration license to be tendered internationally in four decades gives the company a strong foothold in the country.

Afghanistan signed a Memorandum of Understanding on cooperation in the petroleum sector with Norway in 2007, covering the development of a legal framework, the provision of consultancy for a tendering process and organizational capacity building. The passing of The Hydrocarbon Law by the Parliament in January 2009 was a milestone in the Afghan petroleum sector. Even so, the challenges for any company attempting large-scale investment in Afghanistan are many, typified by the admission that there is almost no oil infrastructure in the country. The difficulties were revealed in a licensing round question-and-answer sheet on the Ministry of Mines website that stated: "No oil pipeline exists in Afghanistan other than the 3 km, 6" line from Angoat to the bottom of the hill nearby." The size of the task facing a new investor is supported by the fact that "no true full-fledged development plan has ever been implemented." The first Afghan Hydrocarbon Bidding Round was a failure, with one bid received in February 2010 for the three blocks on offer and that bid was rejected. Against this background Kabul, perhaps rather optimistically at this time, believes with the right exploration company the Amu Darya region can become a "successful" oil and gas province. With this in mind, the Ministry of Mines has indicated it is formulating plans to auction two further oil field contracts, one near Mazar-e-Sharif in northern Afghanistan and another at Herat in the north-west.


Whether Afghanistan can ever support a real oil and gas industry remains to be seen. Its geology is structurally complicated and, although the blocks on offer are in the relatively peaceful north, these challenges are compounded by potential security risks and by problems determining whose consent is required for a particular resource to be accessed. Though major progress has been made in the technical expertise of the Ministry of Mines, members of parliament have limited knowledge about oil and gas bidding procedures, as well as the larger issues of managing hydrocarbon revenues effectively. There is no up-to-date master plan for the energy sector. As a result, there is a risk that the internal-external coordination of hydrocarbon projects could be driven by the interests of single actors, either Afghan or international, rather than by a clearly defined and agreed set of goals.

**KEN WHITE, IHS**

# Change the Way You Analyze Mud Gas

## Weatherford's GC-TRACER™ surface gas detector reinvents formation gas analysis to provide vital intelligence for reservoir characterization



With precise composition in a wider spectrum of gas measurements, you can now

- identify fluid types, hydrocarbon maturity and degradation, sweet spots, fractures and faults;
- receive early indications of net pay, fluid mobility, porosity and relative permeability;
- improve fluid-sampling programs, pick casing points, geosteer horizontal wells and optimize frac design.

The *GC-TRACER* detector is **Tactical Technology™** that helps you make drilling, evaluation and completion decisions with greater certainty than ever before. Contact us at sls@weatherford.com or visit **weatherford.com/surfacelogging.**

Drilling
Evaluation
Completion
Production
Intervention

**Surface Logging Systems**

- **Data management**
  - Integrated data systems
  - Real-time operations
- **Drilling optimization**
  - Electronic drilling recorders
  - Geopressure consulting services
  - $H_2S$ detection
  - Hole-stability monitoring
  - Kick detection
  - Underbalanced drilling
  - Vibration detection
- **Formation evaluation**
  - Advanced formation gas analysis
  - Formation cuttings analysis
  - Geoscience consulting services
  - Source rock analysis
  - Wellsite geochemical analysis

**The *change* will do you good℠**

Weatherford®

**weatherford.com**

# An Excellent Reservoir

## The Aldous/Avaldsnes prospect has grown into one of the largest discoveries in the North Sea ever, largely due to excellent reservoir properties.

The **Aldous/Avaldsnes** discovery (see *GEO ExPro* Vol. 8 No. 5) is set to become the largest oil field in the entire North Sea. While Statoil is operating License 265, including Aldous, Lundin Norway is in charge of License 501 where Avaldsnes is located.

The huge structure used to be considered as two different prospects, but the Statoil discovery published in August, following the Lundin discovery well last year, made it clear that a common oil/water contact between the Aldous and Avaldsnes structures had been established. The uncertainty for a large part lay in the existence of a saddle between Aldous and Avaldsnes, as can be seen on the cross section.

The latest reserve figures were presented by Statoil in October. While the low estimate for the entire structure is 1.7 Bbo, the high estimate has now risen to 3.3 Bbo. The latter figure compares with reserves figures from Ekofisk and Statfjord that are 3.5 Bbo. Both Statoil and Lundin leave the impression, however, that the reserve figures could continue to grow as the appraisal program continues. Regardless, this is the largest discovery in the world this year.

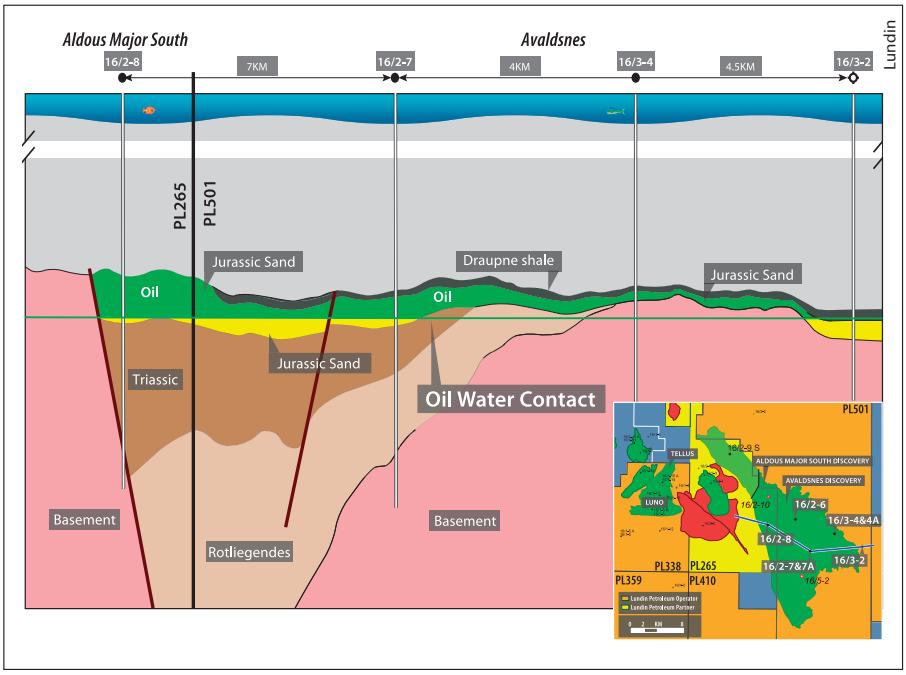
"Aldous/Avaldsnes is a giant, and one of the largest finds ever on the Norwegian continental shelf. Volume estimates have now increased further because the appraisal well confirms a continuous, very good and thick reservoir," says Tim Dodson, Executive Vice President for Exploration in Statoil.

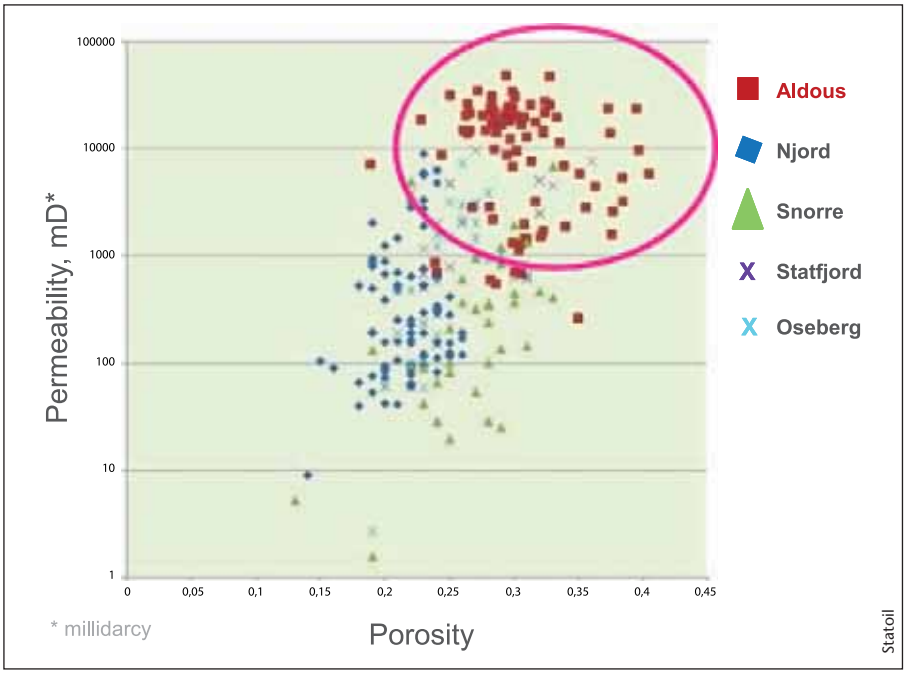
Good indeed! As evident from the diagram, porosities in the Jurassic sandstones are typically above 30%, often approaching 40%, with a few samples with porosities even above that figure. Lundin has previously said that the net to gross ratio in the reservoir is close to 100%. Permeabilities are also excellent. It is not often we see values exceed 1 Darcy, let alone 10 Darcy.

Contrary to what has been claimed by pessimists, it will be a long time before the sun sets on the Norwegian oil industry.

**HALFDAN CARSTENS**

*An oily core sample from the giant discovery*

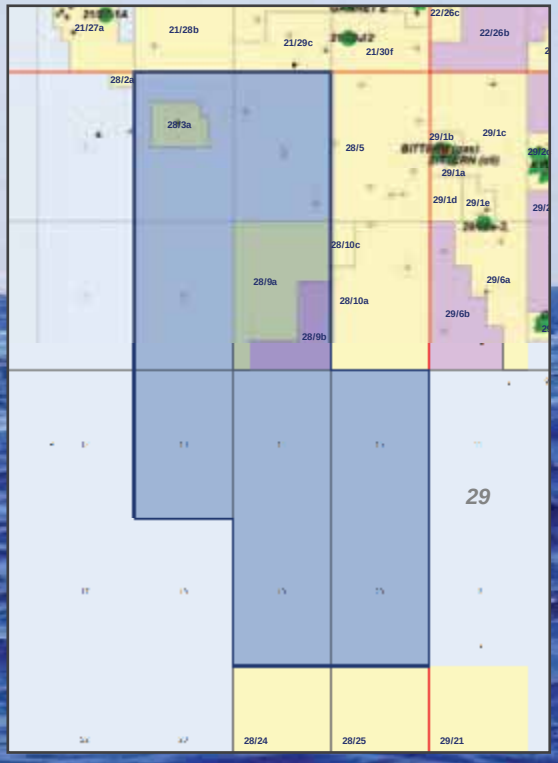



# UK Quad 28

## New Multi-Client 3D Data

Polarcus has acquired ~2,000 sq. km of high-density multi-client 3D data over and adjacent to the UK Block 28/9 Catcher discoveries.

Fast-track processing is now available for UK 27th round evaluations.





**For further information contact:**

**Iain Buchan**
iain.buchan@polarcus.com
+971 50 554 0420

**Elwyn Jones**
elwyn.jones@geopartnersltd.com
+44 1342 870761


***Visit us at PROSPEX in London***
***13-14 December, Booth # 111***

www.polarcus.com

To view data sheet for the Catcher survey please scan.

Polarcus®

# Standing on the Shoulders of Giants

The recent Bath Discoveries Conference was devised as a celebration of the 30th birthday of the Geological Society of London's Petroleum Group. The opportunity to celebrate such an auspicious occasion in style and focus on a topic which lies at the heart of the Petroleum Group's *raison d'être* and at the same time to return to the magnificent Meeting Rooms and Pump Room at Bath, venue of the inaugural meeting, was just too good to miss. The focus of the conference was on Major Discoveries of the 21st Century – 'Standing on the Shoulders of Giants' – reflecting on Isaac Newton's words of wisdom and insight.

The convenors arranged an impressive array of 22 talks over two and a half days, predominantly from industry and covering many of the key discoveries of the last 10 years, together with reviews of some of the principal technologies that have enabled them. Keynote talks took a broad ranging retrospective and forward look at the industry, its performance and challenges. Each day was completed with a lively panel-based debate focusing on various aspects of how we might learn better and truly build on the 'Shoulders of Giants' that have preceded us. In his welcoming note to the conference Jim Brooks, one of the creators of the Petroleum Group, reflected not just on the success of the Group but also some of the great explorers and geoscientists who have paved the way for our industry today.

Over 165 people attended, most from industry, covering all dimensions of the business from super majors and majors to large and small independents, consultants and service groups – a truly diverse array. Only a few of the academic community were able to attend, possibly due to the start of a new academic year; a disappointment as the meeting provided a unique window into global exploration, its successes and challenges. There are or have been few such focused events in the conference calendar globally. The participants were mostly more senior technical leaders and managers, posing a question about how we can better engage and inform less experienced staff without in any way compromising the impact of such an event. Nevertheless, it was a very successful meeting: lots of high quality talks and discussion, great networking and a unique window into the industry today.

## Wide Ranging Discussions

Day one focused on exploration success enjoyed by the majors and some of the technologies involved. A consistent theme permeating the whole day was the value of high quality integrated geoscience, the need for a deep understanding of the whole petroleum system and the value of determination to succeed despite adversity. The final panel discussion was wide ranging and thought provoking, with capability and the need to replenish our workforce a recurring theme.

The second day looked at what the majors have missed in both new and mature basins, to the benefit of the independents – here imaging, petroleum systems, uncertainty and risk management were core themes, together with better drilling and completion technology. Talks covered some of the key discoveries in new basins that had slipped under the radar screen of the majors, including offshore Ghana, deep-water Sabah and Rajasthan. Another lively panel discussion focused on what distinguishes the different players and their various attitudes to risk and uncertainty. Challenging paradigms, determination and courage under adversity, integrated petroleum system understanding and informed risk taking were all part of what was a lively and energized discussion session.

The meeting concluded on the third day with a look ahead, analyzing what we had discussed in the first two days to examine how we might truly build on the shoulders of giants. The final panel session reflected on the three days and what we had seen and learned, in which the challenge of future technology and accessing future resources figured prominently.

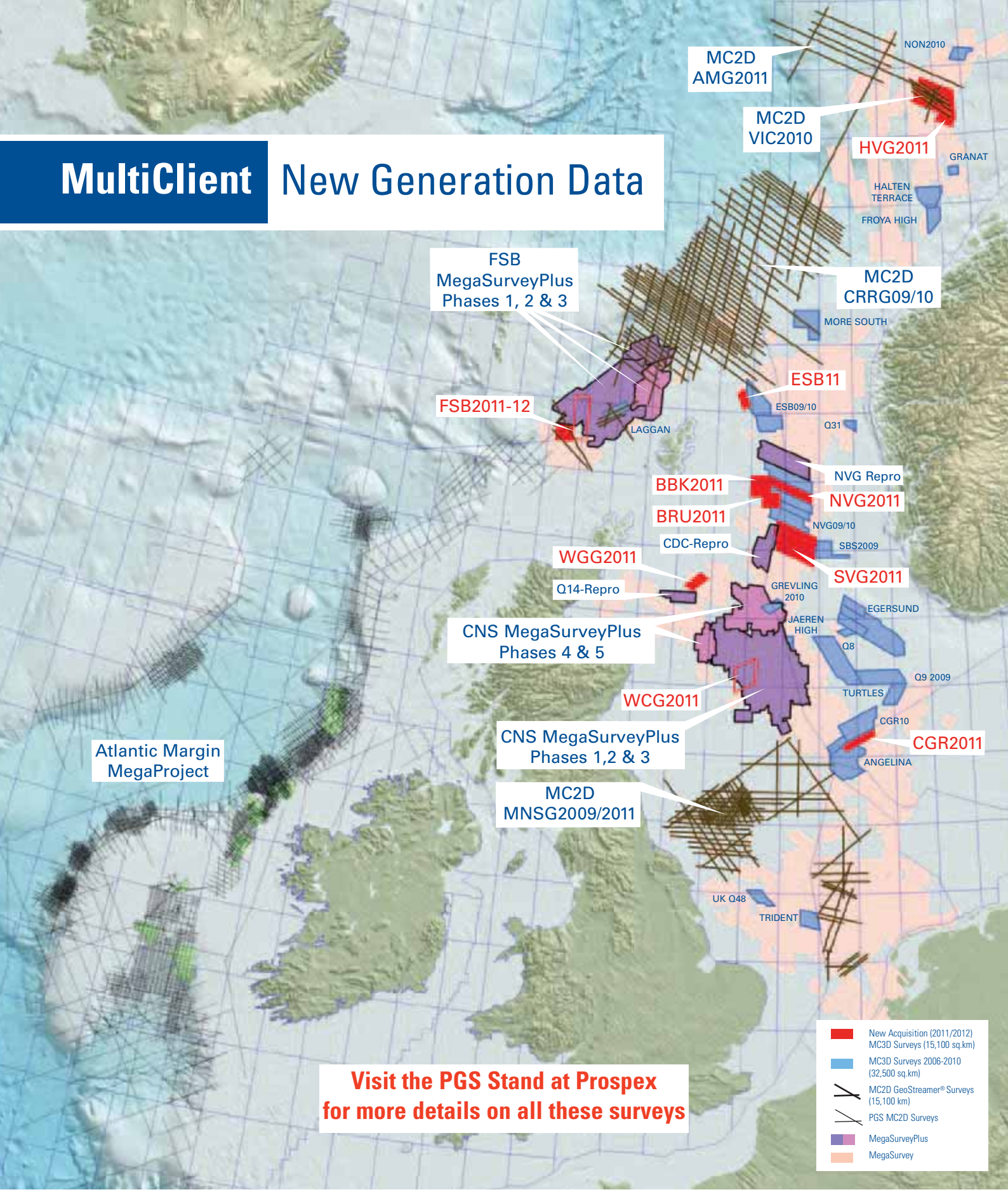
Overall, when we reflect back on the meeting and its highlights, I am sure that many will recognize what a unique opportunity it offered to learn and network with many of the key players in the industry. The constant hum and energy of discussion at the breaks, the thoughtful debates and the high quality presentations and discussions all contributed to a highly successful event. Very rarely do we get the opportunity to focus, share and discuss in such a collaborative way. It left many of us thinking deeply about how we can continue to build on the shoulders of the giants who preceded us and also create a great legacy for those who will follow us.

**MIKE BOWMAN**

*The conference dinner in the magnificent Georgian Pump Rooms in Bath, where discussion and networking spilled on through the evening and the venue was enjoyed by all.*

Neil Meneer/Bath Tourism Plus

# MultiClient New Generation Data




**Visit the PGS Stand at Prospex for more details on all these surveys**


**Mike Keaveny**
**Tel: +44 1932 376577**
**michael.keaveny@pgs.com**

**Joanna Lumley**
**Tel: +44 1932 376549**
**joanna.lumley@pgs.com**

**mceurope@pgs.com**


**A Clearer Image**
**www.pgs.com**

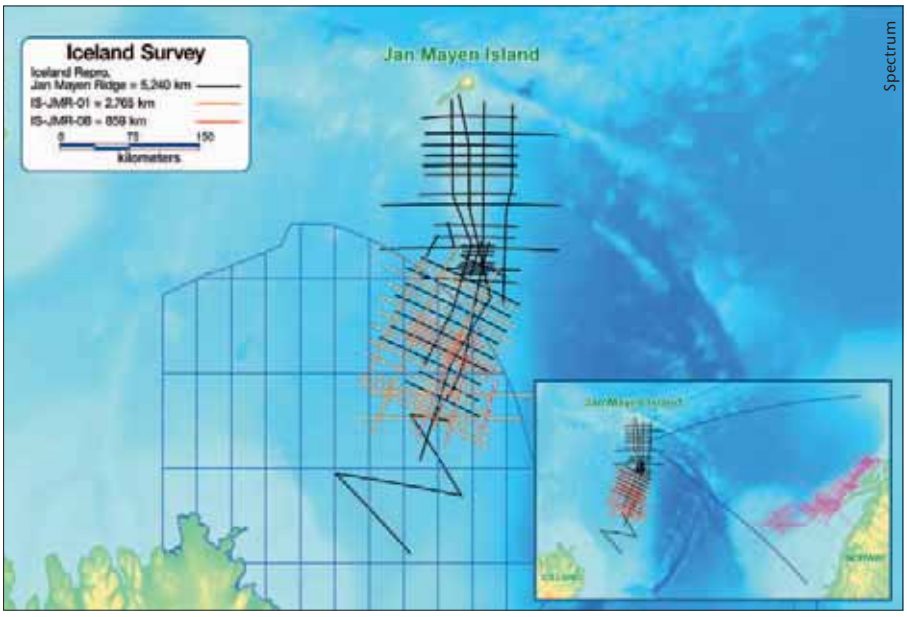
PGS

# Data for Icelandic Licensing Round

On October 3 the National Energy Authority of Iceland opened the Second Licensing Round for hydrocarbon exploration and production licenses on the Icelandic Continental Shelf, offering acreage over the **Dreki/Jan Mayen Ridge** (JMR) area offshore the north-eastern coast of Iceland. To coincide with this, multi-client specialist seismic company, Spectrum, has released details of over 10,000 km of 2D multi-client seismic data covering this interesting but unexplored area, which is believed to have similarities to the hydrocarbon basins in Norway and East Greenland.

The presence of layered basalt sequences within the Jan Mayen Ridge and adjoining basins has historically made deep seismic imaging difficult, but Spectrum's experience of sub-basalt processing has enabled it to improve the imaging in the area. As a result, pre-Tertiary basalt sequences have been identified and a number of seismic anomalies indicating the possible presence of hydrocarbons can be recognized. All the elements of a potential working hydrocarbon system have been identified within the area in both structural and stratigraphic play types. The datasets used were acquired between 1985 and 2008 and have been reprocessed using the latest techniques.

Two regional tie lines also link the Jan Mayen Ridge through the Lofoten Basin towards the prospective Barents Sea margin and the proven petroleum system offshore northern Norway. The round closes on April 2, 2012. ■





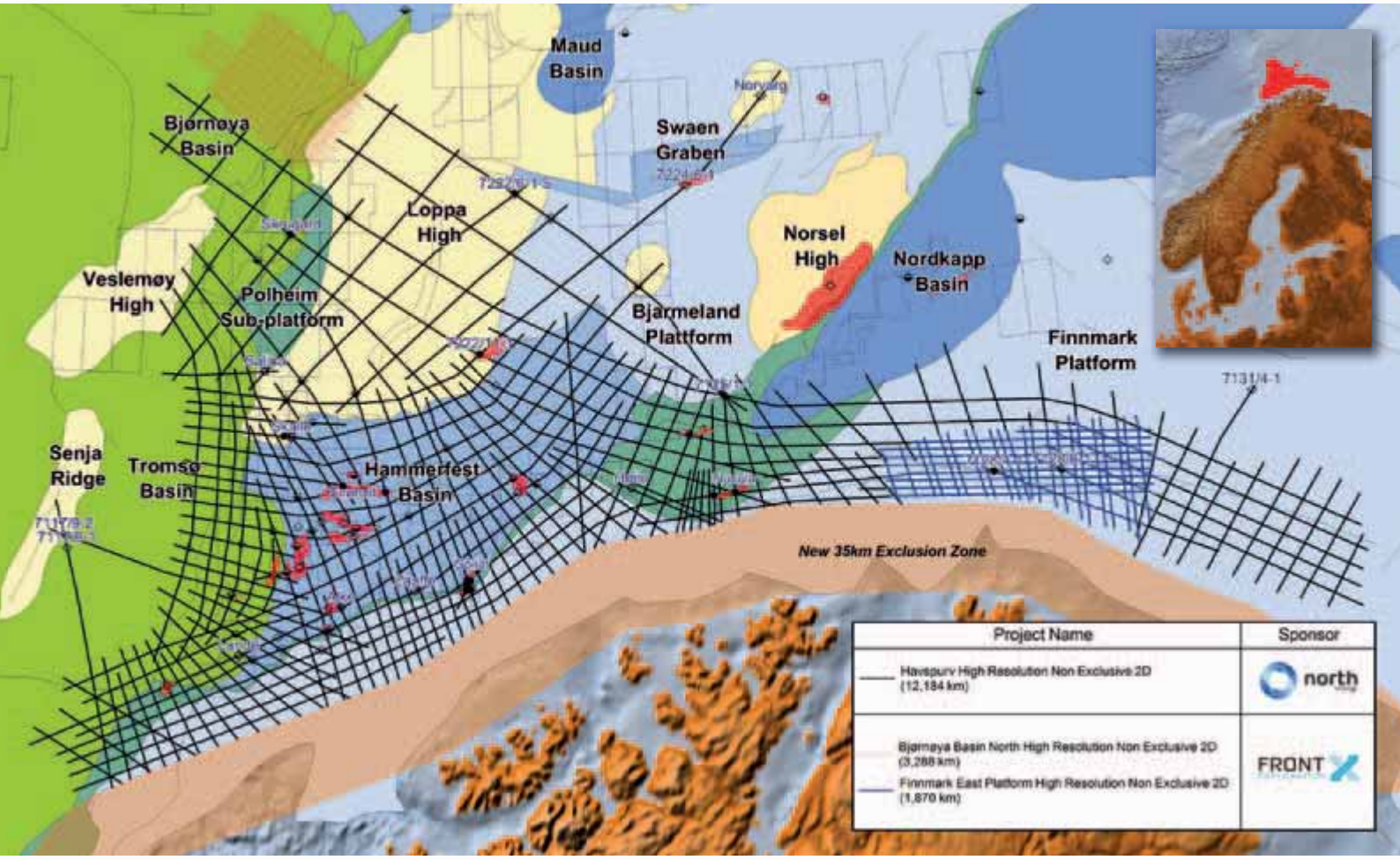
*Blackpool in north-west England is better known as a holiday destination than for earth tremors*

# Fraccing Caused Tremors

After minor earth tremors were felt in May 2011 in Blackpool in the usually seismically inactive area of Lancashire in north-west England, fingers were pointed at drilling for shale gas which was being undertaken at the time. The company who were doing the exploration, **Cuadrilla Resources**, the UK's leading unconventional oil and gas explorer, immediately ceased all operations and commissioned an independent review by a European team of independent seismic experts, all leading authorities on the subject.

The resulting report concluded that it was highly probable that the fraccing being undertaken at the well, Preese Hall-1, did trigger a number of minor seismic events, which recorded a maximum of 2.3 the Richter scale. It suggests that they were due to an unusual combination of geology at the well site coupled with the pressure exerted by water injection as part of operations, which was an extremely rare coincidence and would be unlikely to occur together again at future well sites. It also concluded that since Cuadrilla's water injection operations were being conducted at considerable depth it was thought any seismic event that did occur would not be expected to have any impact on the surface. Cuadrilla will now install additional highly sensitive monitoring equipment and has stated that if a seismic event of more than 1.7 is encountered in any of its wells, it will stop water injection and release pressure in the well. It has yet to resume drilling at Preece Hall-1. ■

# BARENTS SEA HIGH-RESOLUTION 2D SEISMIC SURVEYS
## NORWAY




The Havspurv, Bjørnøya Basin North and Finnmark Platform East seismic 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.
- High Resolution 2D coverage outside the new 35km exclusion zone.
- Well-ties to all recent significant discoveries, including Skrugard, Skalle & Norvarg fields.
- Phase 1 now complete.
- Data is available from Q4 2011.


Email: sales@searcherseismic.com
Web: searcherseismic.com


MAGE
Project Partner

SEARCHER SEISMIC

# Deepest Well Ever

Shell have set a record in the oil industry by drilling and completing a subsea well at a water depth of **2,934m** (9,627 ft). The well is located in the Perdido Development, in an ultra-deep sector of the Gulf of Mexico, 320 km south-west of Houston. Drilling is on the Tobago field, one of three fields spread over 70 km² which are producing through the Perdido drilling and production platform. The record was previously held by another field in the Perdido Development, Silvertip, with a well drilled in 2,852m (9,356 ft) of water. The third field accessed by Perdido is Great White, representing about 80% of total production from the development. Perdido produced its first oil and gas on March 31, 2010, which was also the first commercial production from the Lower Tertiary reservoir in the Gulf of Mexico, the oldest producing reservoir in the area.

The **Perdido** platform is jointly owned by Shell, BP and Chevron and is the deepest drilling and production facility in the world, capable of handling 100,000 bo and 200 MMcfg per day. Development of the fields commenced in July 2007. The platform sits on top of a giant floating steel cylinder or spar, and it is held in place by nine mooring lines each more than three km long. It took a multinational effort to complete the project; the spar was designed in the USA and built by workers from Finland, Latvia and Estonia; mooring equipment came from Britain and Poland; a Dutch company towed it 13,200 km from the shipyard in Finland, and other equipment came from Mexico. ■


Shell Oil Company

*The Perdido platform in the ultra-deep Gulf of Mexico*

# Joint Conference in Marrakech

The AAPG European Region joined with the Moroccan Association of Petroleum Geologists in holding the 2nd International Joint MAPG and AAPG Conference and Exhibition in Marrakech in early October. The conference theme, "North West Africa: Building on Past Success to Unlock Future Potential," attracted more than two hundred delegates and ten exhibitors to the Mansour Eddahbi Palais des Congress for a comprehensive program of oral and poster presentations. Delegates on a pre-conference field trip to the Ourika valley also investigated the relationship between active tectonics and sedimentation in the High Atlas.

The first MAPG-AAPG conference took place in Marrakech in 2007. Since then, exploration activity has gathered pace both onshore and offshore. As a result of technological improvements, new exploration concepts have led to notable gas discoveries in Morocco and Mauritania. Despite this surge of activity, the sedimentary basins of North West Africa remain generally underexplored and further potential exists for both conventional and unconventional resources.

The conference addressed regional geology, tectonics, stratigraphy, sedimentology and magmatism, as well as structural geology, including salt and shale tectonics, and exploration methods and technologies. On the final evening, participants attended a Moroccan dinner where they were entertained by traditional Moroccan dancers and a display of horsemanship.

The AAPG European Region thanks the Conference Co-Chairs, Gabor Tari and Haddou Jabour, and the Advisory and Scientific Committees for creating an excellent technical program. Thanks also go to the patron, the Ministry of Energy, Mines, Water and Environment of Morocco, and sponsors ONHYM, Circle Oil, Prospectiuni and Kosmos Energy. The AAPG European Region looks forward to further co-operation with the MAPG in the future. ■

**DAVE COOK**
*European Region Past President*

*The famous souk in Marrakech*


Jane Whaley

# Prospect Assessment Solution

Oslo based company **GeoKnowledge** aims to assist petroleum companies, governments and industry suppliers worldwide to evaluate the risks, resources and economic value of inherent in their exploration and exploitation projects through the use of its decision support and asset management solutions. Recently French supermajor Total has rolled out a new prospect assessment solution based on the **GeoX** system from GeoKnowledge. This replaces the present in-house system and the existing Total prospect database will be moved onto the system, so all exploration prospects are now assessed using GeoX.

More than 200 Total explorationists were trained over a five month period in offices as far apart as Paris, Stavanger, Balikpapan in Indonesia, Buenos Aires, Luanda and Dubai. Initial reactions from users are reported to have been very positive.

Total made the decision to move to GeoX because it needed a single common secure database for its prospect inventory which also had the potential for additional integrated applications such as assessment of shale gas opportunities. All Total's prospect classification, risk model and post drill analyses are preserved within the system. ■

# Software Entrepreneurs Sought

**SURGE Accelerator**, a Houston-based incubator for energy industry technology software start-ups, is seeking software entrepreneurs to solve energy problems with innovative technologies. It is offering a 12-week program open to entrepreneurs from all over the world. Designed to help start-ups transition into capitalizing companies, this 'boot camp' offers mentorship by industry experts and resources from leading service providers such as Silicon Valley Bank and Houston Technology Center, as well as connection to the world's energy ecosystem and $30,000 in cash.

Essentially, Surge is looking for companies with software that unifies information technology with the energy industry. The three key areas that need technology solutions are smart grid applications; energy trading and risk management; and the digital oilfield. Companies need to be able to scale in an efficient manner and have a working model or an existing prototype of their product.

The 25 selected Surge companies will participate in the program and have the chance to attend more than 40 sessions with a curriculum specifically formulated to prepare businesses for the industry. Finalists are expected to relocate part or all of their team to Houston from March to the end of May 2012, and visa support will be provided for international applicants. The final application deadline is January 2, 2012. For additional information program visit www.surgeaccelerator.com ■

# Monitoring and Modeling Hydraulic Fracturing

**MicroSeismic** is a global geophysical service company providing real-time monitoring and mapping of hydraulic fracture operations for developing unconventional oil and gas plays. **SI Technologies** is a global technology company providing software, training and engineering solutions for the design and analysis of well stimulation programs. So it is no surprise that they have decided to combine their expertise to develop integrated monitoring and modeling solutions for hydraulic fracturing. As a result of this collaboration, operators will be able to integrate their completions engineering, production modeling and microseismic monitoring data in order to optimize their completions programs to ultimately de-risk the prospects and significantly enhance recovery. It will help increase production and recovery on a well-by-well, multi-well and life-of-field basis, while providing oil and gas companies with a better understanding of the hydraulic fracturing process to optimize well performance in unconventional resources. ■

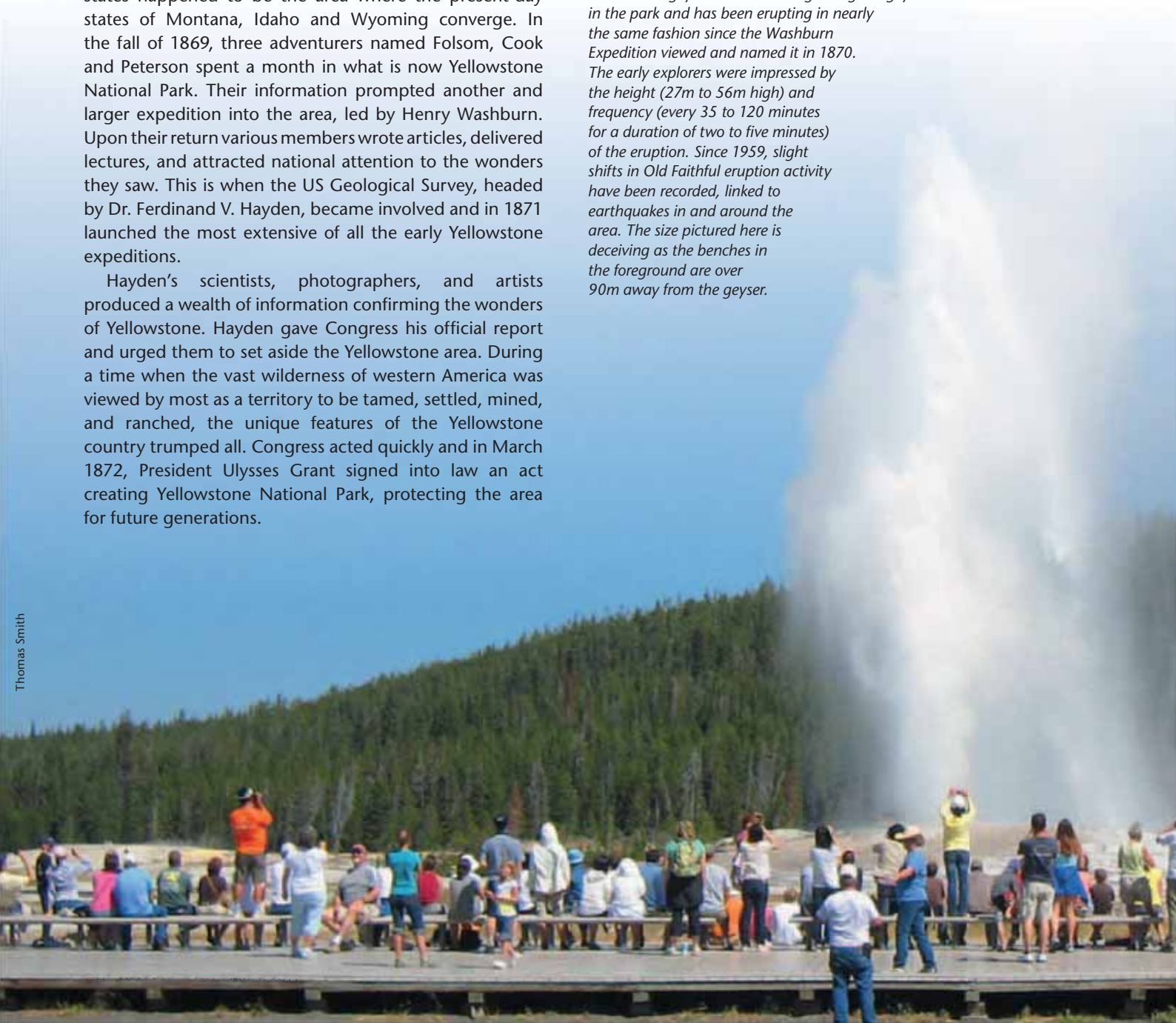
# The Wonders of Yellowstone

The world's first national park established a new concept in preservation and protection of special areas for future generations. Now, 140 years later, millions have benefited from the founder's foresight and can enjoy seeing half of the earth's geothermal features, jaw-dropping scenery, and abundant wildlife in Yellowstone's nearly intact ecosystem.

THOMAS SMITH

The last place to be explored in the current 48 contiguous states happened to be the area where the present-day states of Montana, Idaho and Wyoming converge. In the fall of 1869, three adventurers named Folsom, Cook and Peterson spent a month in what is now Yellowstone National Park. Their information prompted another and larger expedition into the area, led by Henry Washburn. Upon their return various members wrote articles, delivered lectures, and attracted national attention to the wonders they saw. This is when the US Geological Survey, headed by Dr. Ferdinand V. Hayden, became involved and in 1871 launched the most extensive of all the early Yellowstone expeditions.

Hayden's scientists, photographers, and artists produced a wealth of information confirming the wonders of Yellowstone. Hayden gave Congress his official report and urged them to set aside the Yellowstone area. During a time when the vast wilderness of western America was viewed by most as a territory to be tamed, settled, mined, and ranched, the unique features of the Yellowstone country trumped all. Congress acted quickly and in March 1872, President Ulysses Grant signed into law an act creating Yellowstone National Park, protecting the area for future generations.



Thomas Smith

*First of the iconic Yellowstone scenes is the viewing of Old Faithful geyser. This is the largest regular geyser in the park and has been erupting in nearly the same fashion since the Washburn Expedition viewed and named it in 1870. The early explorers were impressed by the height (27m to 56m high) and frequency (every 35 to 120 minutes for a duration of two to five minutes) of the eruption. Since 1959, slight shifts in Old Faithful eruption activity have been recorded, linked to earthquakes in and around the area. The size pictured here is deceiving as the benches in the foreground are over 90m away from the geyser.*

Thomas Smith

*Second of Yellowstone's iconic views, Lower Yellowstone Falls and the Grand Canyon of the Yellowstone. The Lower Falls is 94m high and was formed by the rapid erosion of progressively softer, less resistant rock.*

Most of the geyser basins around the park owe their existence to a mantle hotspot that caused a catastrophic eruption 640,000 years ago, forming the youngest Yellowstone Caldera. Since that time, over 80 eruptions of rhyolite and basalt have occurred in the past 160,000 years. Glaciers covered much of the area as recently as 13,000 years ago, depositing till and gravels that underlie the geyser basins. These deposits provide a storage area for the water that becomes heated and erupts to the surface as bubbling hot springs and geysers. The major geyser basins are the result of the formation over the past 14,000 years of large hydrothermal (steam)-explosion craters.

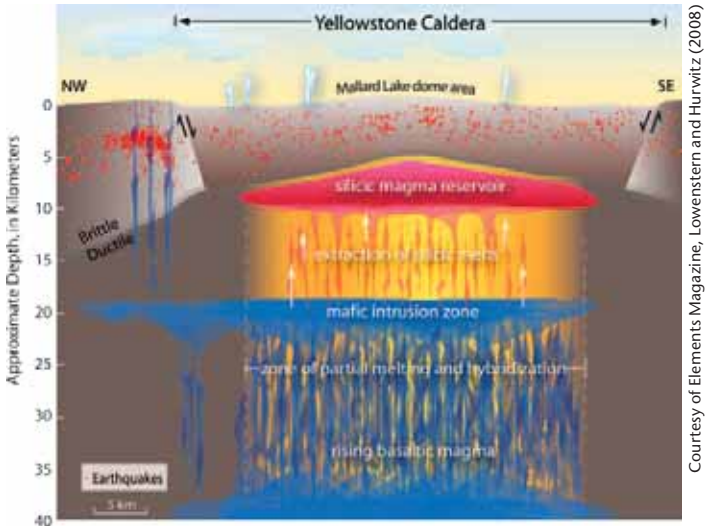
The high yellow-brown walls that form the Grand Canyon of the Yellowstone River are composed of rhyolite tuff and lava which erupted about 500,000 years ago early in the post-collapse history of the Yellowstone Caldera. The units have been intensely altered by hydrothermal fluids when a geyser basin formed in the area. The dark cliffs like the one seen to the left of the falls are little-altered rhyolites. The top of the canyon, the tree-covered white rim above the brown and yellow cliffs, is composed of lacustrine sedimentary rocks deposited in a lake that once filled the caldera. The lake was eventually drained by erosion from the Yellowstone River forming this magnificent 370m deep canyon.

Native Americans called this river *Mi tsi a da zi* which means 'Rock Yellow River'. French fur trappers translated this into 'Yellow Rock' or 'Yellow Stone', giving the area its present-day name, Yellowstone.

# A Supervolcano and the Yellowstone Volcano Observatory (YVO)

Through its volcanic history, three major eruptions have occurred at Yellowstone. The first and largest occurred 2.1 million years ago and ejected 2,550 km³ of material. A smaller eruption was recorded at 1.3 million years ago that ejected 170 km³ of ash and lava. The current Yellowstone Caldera formed 640,000 years ago from the violent and catastrophic eruption of over 1,000 km² of rhyolitic magma and spread ash over thousands of square miles. By contrast, the 1883 eruption at Krakatau ejected about 21 km³ of volcanic material and the 1980 Mt. St. Helens eruption a mere 0.6 km³. Both these eruptions had some major consequences to the surrounding area along with global consequences. The Krakatau eruption lowered global temperatures and disrupted climate patterns for five years. Imagine, therefore, an eruption emitting a hundred times or even a thousand times more material than historic eruptions. The effects would be devastating.

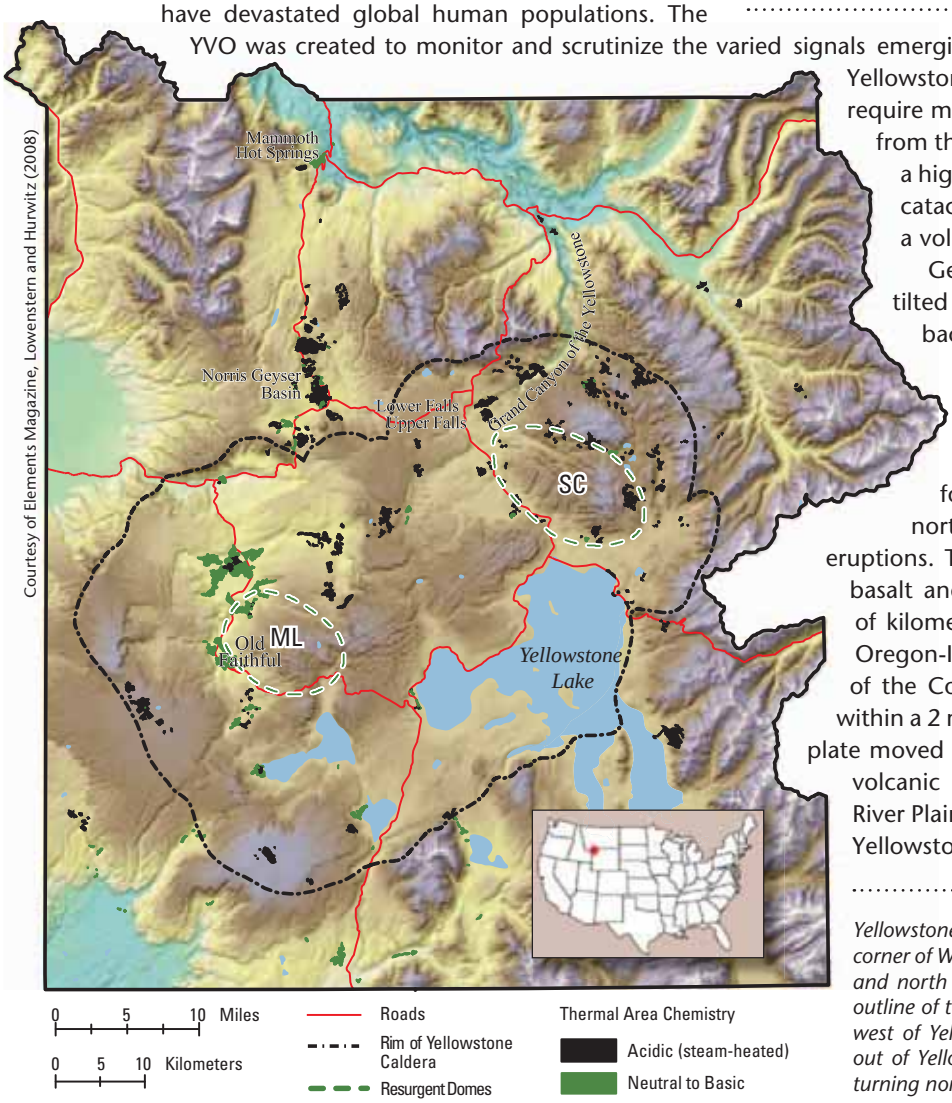
While the chance of an event of the magnitude of Yellowstone's past eruptions is very remote during our lifetimes, the Yellowstone Volcano Observatory (YVO) was formed to study this system. Dr. Jacob Lowenstern of the US Geological Survey and Scientist-in-Charge at the YVO states "Any of the previous eruptions at Yellowstone could have devastated global human populations. The YVO was created to monitor and scrutinize the varied signals emerging from restless calderas like the one at Yellowstone. The large thermal and $CO^2$ fluxes here require massive input of basaltic magma originating from the mantle. Overlying the basaltic magma is a high-silica magma reservoir, which caused the cataclysmic eruptions in the past and may pose a volcanic hazard in the future."




Courtesy of Elements Magazine, Lowenstern and Hurwitz (2008)

*Cross-section beneath Yellowstone Park showing basaltic magma rising from depths below 40 km and partially melting the lower crust. The silicic magma at the top is a hybrid derived from crustal melts and residual liquid formed as the mafic magma cools and crystallizes. The magma is only 5 to 7 km below the surface beneath the resurgent domes, shown on the map below as Mallard Lake (ML) and Sour Creek (SC). The red dots indicate earthquake activity.*

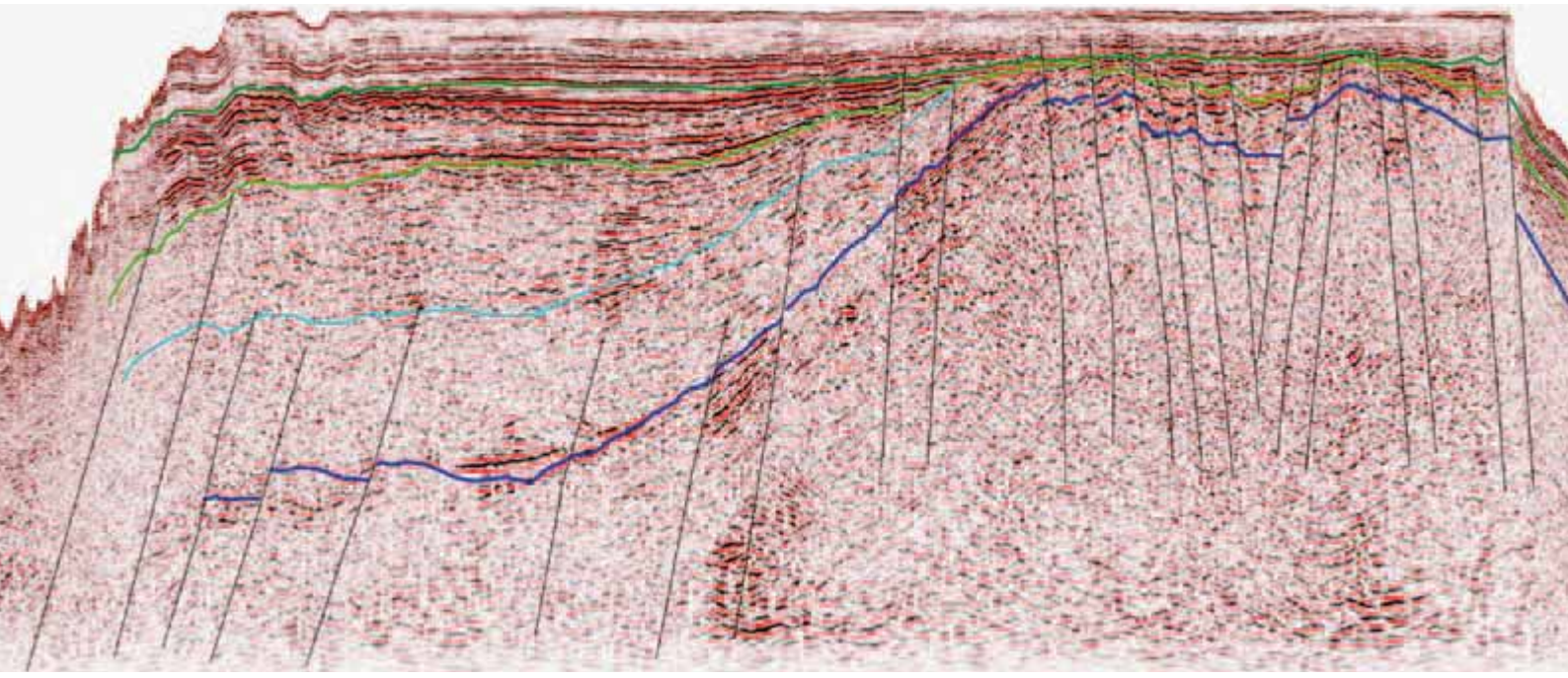
Geophysical imaging reveals that there is a tilted deep mantle plume, whose origin goes back 17 million years, extending 500 km below the Yellowstone Caldera. As the North American Plate moved west at about 4.5 cm per year over this hotspot, a 560 km trail of volcanic fields can be found across southern Idaho and into northern Nevada. All are sites of multiple eruptions. The track starts with a large area of flood basalt and rhyolite volcanism extending hundreds of kilometers out from a center near the Nevada-Oregon-Idaho border. Most of the 234,000 km³ of the Columbia and Steens flood basalts erupted within a 2 million year interval. As the North American plate moved across this mantle plume five more major volcanic areas were left behind along the Snake River Plain, until the plume finally arrived below the Yellowstone area 2.1 million years ago.




Courtesy of Elements Magazine, Lowenstern and Hurwitz (2008)

*Yellowstone National Park is located in the north-western corner of Wyoming and spills across the border west into Idaho and north into Montana. This relief map shows the dashed outline of the 50 km by 70 km caldera. Old Faithful is located west of Yellowstone Lake. The Yellowstone River flows north out of Yellowstone Lake, forming its canyon and falls before turning north-west and out of the park.*

# WHEN **QUALITY** COUNTS...



# ...COUNT ON **FUGRO**

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

- Geologically attractive area
- Unequivocal evidence of active petroleum systems
- Geological prospectivity related to rapidly emerging plays in East Africa & established plays in Western India
- 8 km streamer, 7 second records
- Shot point interval of 18.75 m
- Potential field data
- Regional integrated interpretation

**Fugro Multi Client Services**
Andrew Mulder
Mob: +61 403 462 862
Email: a.mulder@fugromcs.com.au
**www.fugromcs.com.au**

The Upper Geyser Basin and adjacent Black Sand and Biscuit Basins contain an amazing collection of hydrothermal features along boardwalks and paths with continuous views of the Old Faithful Geyser.

Yellowstone has more than 300 geysers, two-thirds of all those found on earth. Geysers erupt when superheated water is brought violently to the surface. The water starts out cold from snow melt in the mountains and slowly percolates down through permeable rocks and into a shallow magma body, where the water is heated to above 200°C. This superheated water is less dense than the cold water sinking around it and begins its journey back to the surface along fractures in the surrounding rock, most of which is siliceous rhyolite. Some of the silica is dissolved from the rhyolite and as the pressure decreases can be deposited along the fractures constricting the plumbing system, increasing the system's ability to withstand the pressure needed to produce a geyser. At the surface, silica precipitates, forming siliceous sinter deposits known as 'geyserite', giving the geyser basins a seemingly barren landscape.


Deborah Bertossa

*Much less crowded views of Old Faithful as seen from the Geyser Hill boardwalk with the base of Beehive Geyser in the foreground.*

There are more than a dozen hot pools in the area that offer many dazzling colors from bright yellows and reds to sky blue. Viewing pools such as the Emerald Pool in the Black Sand Basin seems to give a peek into the deep, unknown underground. The temperature of this 7.6m deep pool is 68°C, which is cooler than most of the others in the park. The colors displayed in the pools and springs are primarily produced by thermophiles or heat-loving organisms such as algae, bacteria, and archaea. The color of Emerald Pool (light green) has resulted from the cooler water temperatures allowing yellow bacteria to grow lining the pool. The crystal clear water reflects the blues but absorbs other hues of the color spectrum with the combination of blue and yellow producing the emerald green color. The edges of the pools are cooler yet allowing, in this case, yellow, orange, and brownish thermophiles to grow. ■


Thomas Smith

*Above: Emerald Pool*


Thomas Smith

*Right: Much hotter at 90.2°C, the clear blue water at Doublet Pool contrasts with greens found at Emerald Pool. The cone of Castle Geyser can be seen in the far background across the Firehole River valley.*

Thomas Smith

***Just as they inspired the early explorers to urge for its protection, the diverse experiences found in Yellowstone National Park continue to awe visitors from all over the world.***

*Scenery and geysers are not the only reasons to visit Yellowstone. Large traffic jams can be created by people parking and viewing some of the many large animals that roam the park. Buffalo, grizzly and black bears, elk, deer, and wolves are some of the wildlife that can be spotted.*

*Surreal landscapes are created at Mammoth Hot Springs located near the north entrance of the park. The terraces are built from deposits of travertine created by the dissolution of subsurface limestone beds by the hot water. Once on the surface, carbon dioxide is released and calcium carbonate precipitates out, resulting in the travertine deposits. The colors displayed here are again from the different bacteria that grow in the hot waters and coat the terraces.*

Thomas Smith

# Libya

## The Next Chapter



As a tentative and uneasy peace settles on Libya, what does the future hold for the North African oil producer, considered by many as underexplored?

JANE WHALEY

After more than six months of civil unrest and over 40 years of an increasingly wayward and unpredictable military dictatorship, the people of Libya are taking stock – and that will inevitably mean having a good hard look at their hydrocarbon reserves, production and infrastructure.

According to the BP Statistical Review, Libya's proved oil reserves at the end of 2010 stood at 46.4 Bbo, with 54.7 Tcf of gas, some 3.4% and 1.7% of the world's total respectively and the highest volume in Africa. The same source states that in 2010 Libya's oil production was 1,659 Mbpd, higher than the 1,470 Mbopd production quota set by OPEC, with 99.4 Bcf of gas, but virtually all production stopped after the imposition of UN sanctions in March this year. Reportedly, only three tanker loads have been shipped since then. Libya therefore has a long haul ahead of it to rebuild the only major source of wealth for the country, which, according to the International Monetary Fund, accounted for over 95% of export earnings, 25% of GDP and 80% of government revenue in 2010.

### A Chequered History

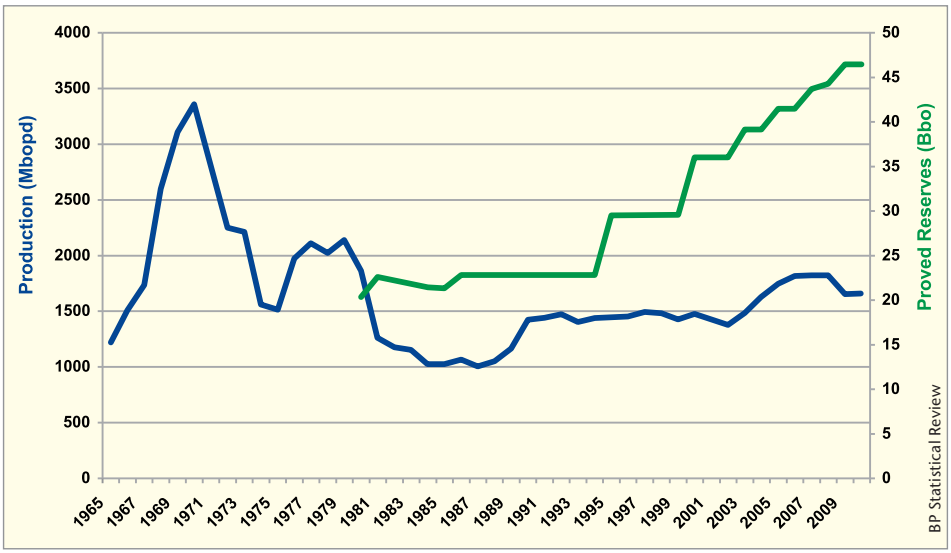
Geological surveys in Libya began under the auspices of the Italian National Academy in 1931 with an expedition led by Ardito Desio, which traversed the country from the coast to the Sudan border and back. Four years later, in consultation with other Italian geologists, he reported that there was little expectation of finding oil in commercial quantities in the country.

After WWII, and following the discovery of oil in Algeria, active exploration began in earnest in Libya in 1953. The first discovery well was drilled in the western Fezzan, in the south-western part of Libya, and the first commercial discovery followed three years later in 1959. By 1961 the first oil flowed by pipeline from Esso's concession at Zelten in the Sirte Basin to its export facilities at Brega. Other companies rushed to the country and by 1965 Libya was the world's sixth largest exporter of oil.

Very rapidly, Libya went from being one of the poorest nations in the world to a very rich one, based on average per capita GDP. But ordinary Libyans felt that little of the new wealth was filtering down from the elite, and so when a military coup, led by the 28-year-old Colonel Muammar al-Gaddafi, deposed the Libyan king in 1969, it was met with popular support. Gaddafi wanted to build a socialist state and in

*Exploration in Libya in the 1960s*

Dick Selley




*Libyan reserves and production since 1965.*

1970 the National Oil Corporation (NOC), which had been established two years earlier, was nationalized; by 1973 it had assumed control of exploration and development, production, refining, processing and marketing. Oil production, which had peaked in 1970 at over 3 MMbopd, began to decline, and in the mid-80s dropped to about 1 MMbopd as the effects of the US embargo on trade with Libya, put in place as a result of Libya's support for terrorist organizations, were felt.

UN sanctions on trade with Libya, enacted in 1992 after the Lockerbie plane disaster in which the Libyan government was implicated, also restricted oil exports. When they were lifted in 2003, followed by the raising of the US embargo the following year, investment in the Libyan oil industry by foreign oil companies increased and production and exports began to creep up, reaching a peak of 1.82 MMbopd in 2007.

There was considerable investment in exploration during the period 2005 to 2010, mainly by foreign companies, but also by the Libyan government, yet the results were disappointing, possibly because the authorities preferred to concentrate on the rehabilitation of existing fields. The difficult fiscal régime also meant that foreign companies were not encouraged to undertake major exploration. In fact, last year some of the exploration companies petitioned the NOC, saying that without a downward revision of tax investment, exploration would cease.

## Production Increasing

With an end to hostilities, how long before average Libyans can begin to see something from the bounty that lies beneath their ground?

Many of the wells were turned off when most expatriate workers left in March, but a number have begun pumping again, though progress will of necessity be slow. Many fields were mined or deliberately damaged, while others, such as the older wells in the Sirte Basin, which require water or natural gas injection to maintain pressure in the reservoir, have suffered from months of neglect.

Although foreign workers have yet to return in any significant number, production, which was down to 45,000 bopd in August, is increasing and by mid-November had already exceeded 600,000 bopd. It is set to rise to 1 MMbopd within a few months, and, if the Chairman of NOC is to be believed, to 1.5 MMbopd by the end of next year. And gas has started flowing again from the offshore fields, with Eni announcing in early November that it had restarted production from Bahr Essalam, 110 km north-west of Tripoli, one of the largest gas fields in Libya, which was closed down at the start of hostilities in February.

Libya has five domestic refineries, with a combined capacity of 378,000 bopd, all of which were damaged to some extent during the fighting. NOC have reported that the Az Zawiya refinery in north-western Libya is ready for operation and has received its first post-conflict shipment, while Ras Lanuf on the Gulf of Sirte, the largest Libyan refinery with a capacity of 222,000 bopd, should also be up and running soon.

There is a lot of interest in the prospect of being a part of the new Libya, and several countries have begun moves to cooperation – in fact, a group of French companies arrived in Tripoli to meet officials of the Transitional National Council a week before Gaddafi's death. Countries which participated in the NATO-led air support during the revolution hope that they

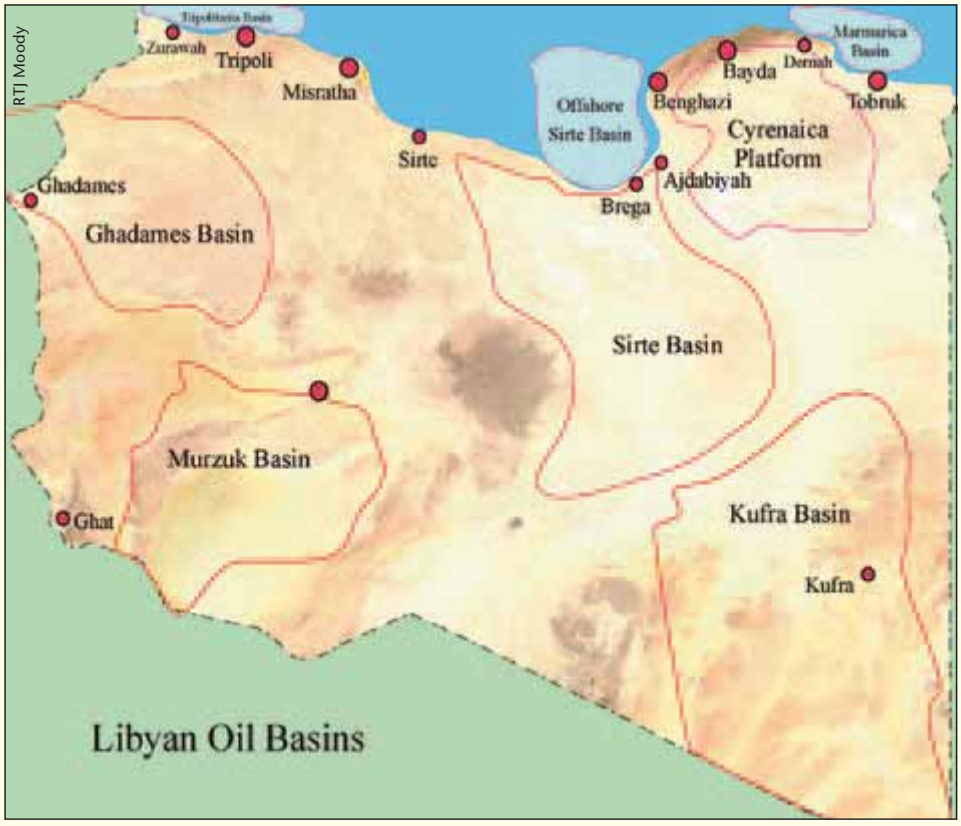
*Muammar Gaddafi at the African Union Summit in 2009.*

may be considered more favourably than, for example, China, which is reported to have been negotiating arms sales to the previous regime as recently as July. But until a new government is established, the terms for accessing Libyan hydrocarbons in the future will remain unclear. For the moment, it appears that a government oil minister will set policy and the new NOC head, who has stated that existing contracts will be honored for a while at least, will continue to oversee operations until a new government is elected.

There is, among some, a perception that Libya is now a mature oil-producing region, as most of the major discoveries were made during the 1960s, and discoveries have been getting smaller. However, despite the fact that Libya has the largest proven oil reserves in Africa, most analysts agree that the country is still underexplored. There is also possibly major gas potential in Silurian shales in the south, as yet unexplored. Despite the uncertainties and potential dangers of a precarious peace, many oil companies will find Libya too attractive not to consider. In the not too distant future, if a more efficient and decent system of government is safely established, Libya's young population may soon be among the most prosperous in the world. ■

# Many Underexplored Regions

Libya has five major onshore hydrocarbon basins, three in the east and two in the west. The Sirte Basin is the most productive, containing 16 giant oil fields and accounting for about two-thirds of Libyan oil production and 80% of the country's proven reserves. It is the youngest of the Libyan oil basins and is attributed to the collapse of a structural high that existed from around 400 Ma to 140 Ma. Early Cretaceous sediments in the basin were clastic, common in North Africa at the time, whilst from the Late Cretaceous to Tertiary carbonates predominated, along with large quantities of organic-rich sediments, which give rise to two major sources rocks, the Rachmat and Sirte Shales. The geological structures are dominated by a series of horsts and grabens, but there is also potential in Nubian sandstone stratigraphic traps in the southern Sirte Basin.




About 25% of production comes from the Murzuk Basin of south-west Libya, about 800 km south of Tripoli, which forms a large intracratonic basin between Algeria, Niger and Chad, and has some 3,000m of sediments from Cambrian to Quaternary age. The Silurian-aged Tannezuft shale is the major source rock, and hydrocarbons have been found trapped in large anticlinal features which are not heavily faulted. Due to its remote position, lying predominantly in the Sahara, it is relatively unexplored and the infrastructure is poorly developed, but a number of important discoveries have been made there, including the giant Elephant field, which in 2010 was producing an average of 126 Mboepd.

The western Ghadames Basin stretches into neighboring Algeria where the sediment thickness reaches about 7,000m and where the majority of the basin's discovered reserves are located, reservoired in Silurian and Devonian rocks. Areas of particular exploration potential in this basin include late Ordovician glacial deposits. The Cyrenaica Platform in north-east Libya to the east of the city of Benghazi has no commercial discoveries but has potential in the form of a series of troughs and uplifted blocks.

A number of discoveries have been made offshore, which accounts for the remaining production, mostly from the Pelagian Shelf Basin near Tripoli. Success rates for discovery offshore are higher than onshore and the area is considered highly prospective, although predominantly for gas. Potential is also thought to reside in the Jurassic and Cretaceous of the offshore Sirte embayment.

*Acknowledgement: Thanks to Dr Danny Clark-Lowes (Nubian Consulting) and Professor Richard Moody for information on the geology of Libya.*

Anglo-Persian Oil Company

# Persia
## Land of Black Gold

Iran holds about a tenth of the world's proven reserves of oil and 16% of the gas, and is the fifth largest oil exporter. Here we review the country's oil and gas fields and reservoirs, particularly in the prolific south-west.

BEHROOZ ESRAFILI-DIZAJI, FARKHONDEH KIANI HARCHEGANI; University of Tehran


Mehrnews agency

*The first Middle East drilling oil field: Well No. 1 of Masjid Suleiman in 1908 (top) and in 2011 (above).*

Iran is one of the richest regions in the world in terms of hydrocarbon resources. It has the world's third biggest reserves of oil, after Saudi Arabia and Canada, and also the world's second largest gas reserves, behind Russia. According to the *Oil and Gas Journal*, as of January 2010, Iran has an estimated 137.6 Bb of proven oil reserves, roughly 10% of the world's total reserves, and 1,045 Tcf of proven natural gas reserves, around 16% of the world's total. Moreover, at 2.58 MMbopd, Iran is OPEC's second largest exporter of crude oil after Saudi Arabia, according to that organization.

Iran has more than a century of history in exploration and production activities; the first successful exploration well was Masjid Suleiman-1 on May 26, 1908. Since then, based on the latest oil and gas reports, 145 hydrocarbon fields and 297 oil and gas reservoirs have been discovered in Iran, with many fields having multiple pay zones. A total of 102 fields are oil and the remaining 43 are gas, and there are 205 oil reservoirs and 92 natural gas reservoirs. According to *Iran Energy Balance Sheet* (2009, in Persian), 78 of these fields are currently active, with 62 onshore and 16 offshore, leaving 67 fields inactive at present. Some 23 hydrocarbon fields lie in border areas and are shared between Iran and adjacent countries, including Kuwait, Iraq, Qatar, Bahrain, UAE, Saudi Arabia and Turkmenistan.

Fields have been found in North Central Iran, in the Southern Caspian Basin and most recently in the Kopet-Dagh Basin in North East Iran. However, 140 fields, the vast majority of those discovered to date, are in the Zagros and Persian Gulf Basins in the south-west, and we will concentrate on those in this article.


*Map showing Iran's oil and gas provinces and fields. After a century of exploration and production, Iran has 145 petroleum fields, most clustered in the Zagros and Persian Gulf Basins.*

## Prolific Basins

The Zagros Basin can be divided into three sub-basins – Eastern, Central and Western – based on stratigraphic framework, structural elements and petroleum habitat. Similarly, the Persian Gulf Basin is split into the Eastern, Qatar Arch and Western sub-basins. Enormous gas/condensate reservoirs like the Dehram or Khuff formations are situated in the Qatar Arch and the Fars province of the Eastern Zagros; the Qatar Arch alone is estimated to contain about 19% of the world's non-associated gas reserves, including the super-giant North Dome/South Pars fields. The Central Zagros, particularly the Dezful Embayment, is famed for its supergiant and giant oil fields based on the Asmari and Sarvak reservoirs. There are 16 exploration blocks in these sub-basins, four offshore and the remaining 11 onshore.

In nearly 90% of Zagros fields the hydrocarbons are found in structural traps at depths of less than 4,500m. The Iranian part of the Zagros Basin has more than 300 anticlines with north-west to south-east dominant trends, and roughly one third of these contain petroleum resources. There are approximately 200 salt domes in Eastern Zagros and the Persian Gulf, and many studies show that salt tectonics in the Hormuz salt horizons in this area are related to petroleum accumulations. In fact, some workers believe that as many as 60% of traps in the Persian Gulf are configured by evaporite diapirism, including North Pars, Iran's second largest gas field, as well as the Abuzar, Froozan, Nowruz, Esfandiar and Soroush fields.


*An aerial view of a double plunged anticline in the Zagros Mountains. About a third of these anticlines contain hydrocarbons.*

## Important Carbonate Reservoirs

Hydrocarbons are found in the Zagros and Persian Gulf Basins in reservoirs which range in age from the Guri limestone member of the Neogene Mishan formation to the Lower Permian Faraghan Sandstone formation.

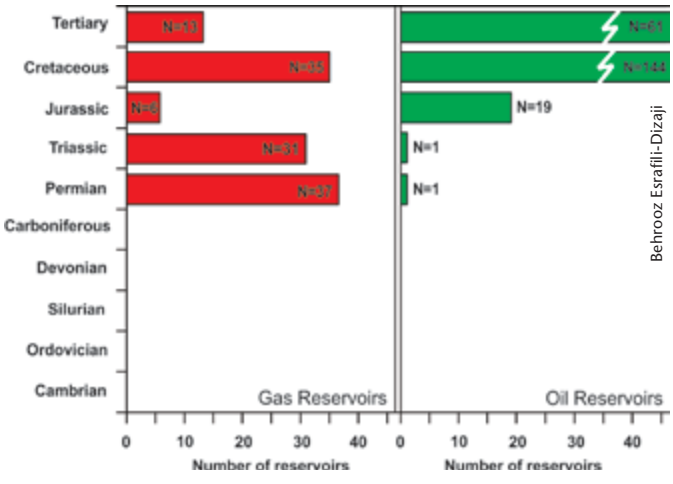
In the Zagros and Persian Gulf Basins the highly porous Cretaceous and Tertiary carbonate rocks make very important oil reservoirs, while Permo-Triassic carbonates, particularly the Dalan and Kangan formations, are the main gas and condensate reservoirs. In fact, it is reported that a total of 38 gas/condensate pools have been discovered in the Dalan and Kangan formations in these basins alone. The mid Cretaceous Sarvak formation is significant for the volume of recoverable oil it holds, while the Oligo-Miocene Asmari formation is the best current producer.

Our estimates indicate that in the Zagros and Persian Gulf Basins nearly 85% of oil reserves and more than 90% of gas/condensate reserves are hosted in carbonate rocks, including dolomitic, karstic, fractured and reefal limestones. For example, more than 60 fractured and karstic carbonate reservoirs are found in Asmari and Sarvak sequences in the Dezful Embayment. Not all the hydrocarbons are found in carbonates, however, and there are a number of major sandstone reservoirs in south-west Iran. The Ahwaz, Feridoun, Nowruz, Foroozan, B-structure and Soroush fields all have oil reservoired in sandstone rock units of the Ahwaz, Ghar, Zubair and Burgan sandstone members.

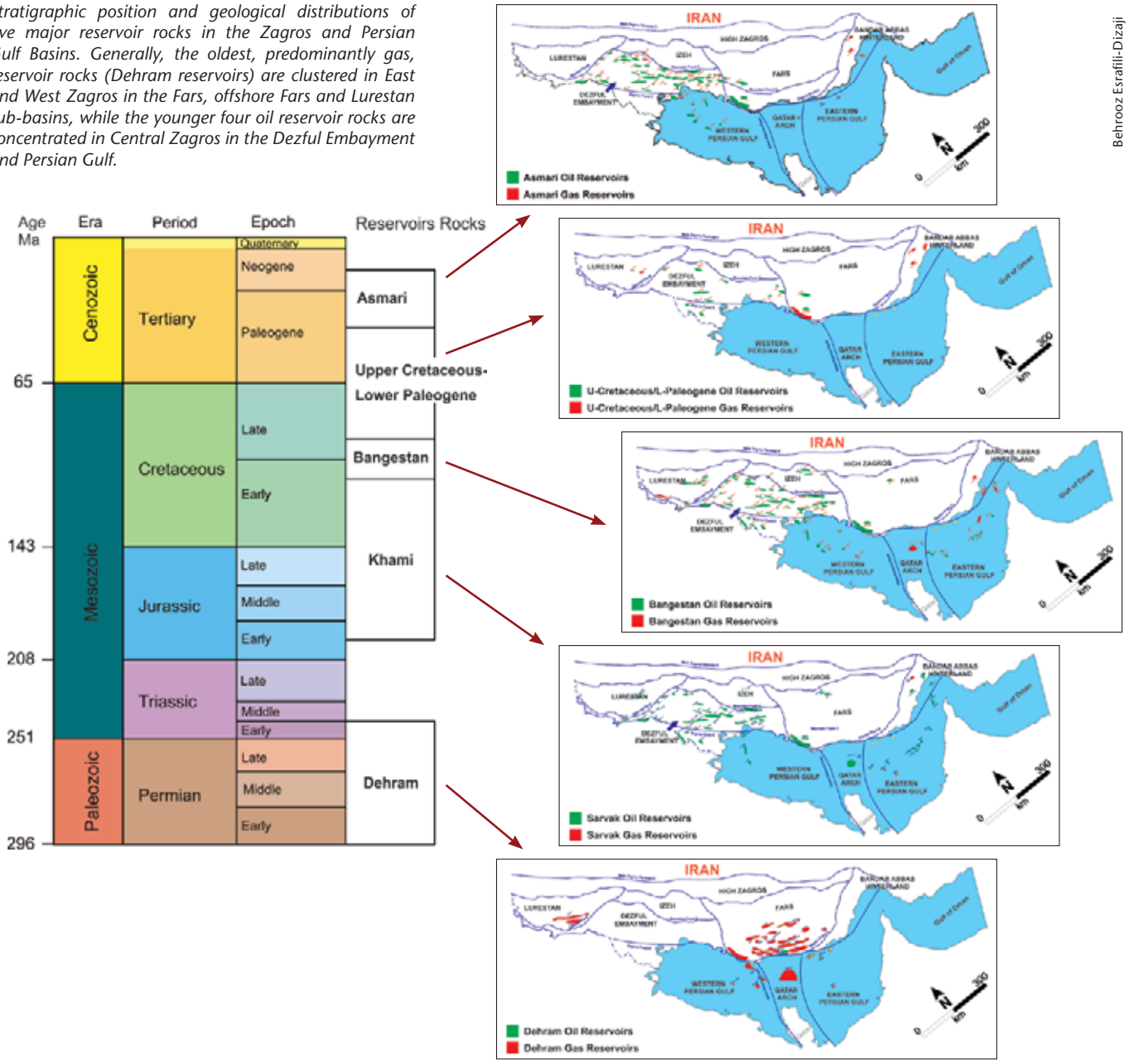
At a regional scale, the Dalan and Kangan formation gas reservoirs (Khuff equivalents) are sealed by Dashtak formation anhydritic-shaly rocks, while the Gachsaran formation and the formations of the Bangestan groups are the main cap rocks to the Cretaceous and Tertiary oil fields respectively.

The sapropelic shaly rocks of Silurian age, such as the Sarchahan

*The majority of gas fields in the Zagros Basin are found in Permo-Triassic carbonates, while Cretaceous and Tertiary carbonates host most of the oil.*



*Stratigraphic position and geological distributions of five major reservoir rocks in the Zagros and Persian Gulf Basins. Generally, the oldest, predominantly gas, reservoir rocks (Dehram reservoirs) are clustered in East and West Zagros in the Fars, offshore Fars and Lurestan sub-basins, while the younger four oil reservoir rocks are concentrated in Central Zagros in the Dezful Embayment and Persian Gulf.*




Behrooz Esrafili-Dizaji

formation, and the Jurassic and Cretaceous Khami and Bangestan groups, particularly the Pabdeh and Gurpi formations, are the main source rocks for the Zagros/Persian Gulf hydrocarbon fields. Iran's crude oil generally has medium sulfur content and is in the 28°–35° API range.

Based on their stratigraphic position, petroleum system types, reservoir rock nature and properties, significance and geological distributions, the oil and gas reservoir rocks in the Zagros and Persian Gulf Basins have been classified into five carbonate sequences, ranging from the Oligo-Miocene Asmari to the Permo-Triassic Dehram. In some cases they also contain important sandstone reservoirs.

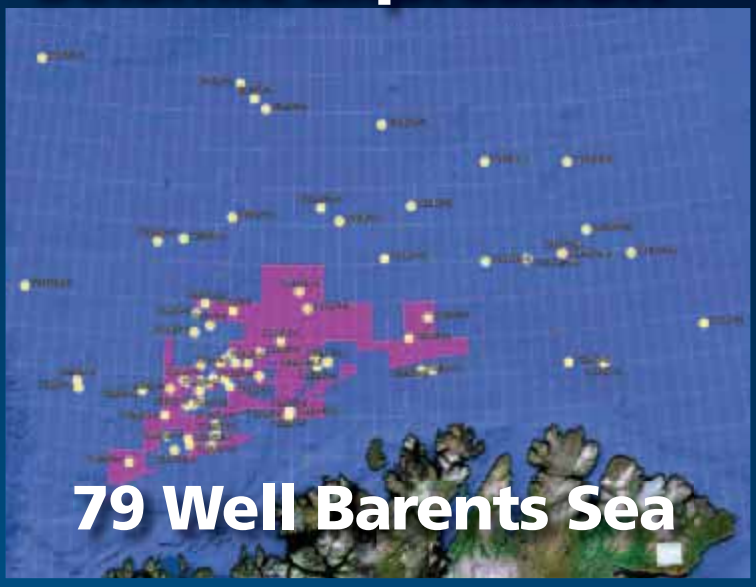
## Discoveries Continue

Iran has several supergiant and many giant oil and gas fields, all in the south-western area. Gachsaran in Central Zagros, the largest oil field in Iran, has three oil pay zones with an astonishing 66.7 Bbo in place and 23.7 Bb of recoverable reserves. And the South Pars gas field in the Qatar Arch is the largest gas field in the country with over 509 Tcf of recoverable gas, in combination with Qatar's North Dome field. More than a half of Iran's total gas reserves are accumulated in this single supergiant field.

In the last four years alone, 17 fields or reservoirs in existing fields have been found in Iran. These include the offshore Binaloud oilfield, and Sefid-Baghoun and the 11.2 Tcfg Sefid Zakhour fields in Fars, as well as fresh finds in the existing Changouleh and Azar oilfields in western Iran, several additional pay zones in the Azadegan oilfield in the Dezful Embayment, and a new Jurassic gas reservoir in the oldest field of all, Masjid Suleiman. In 2008, the discovery of 525 MMb (in place) of light gravity oil in the Kangan horizon in the East Assaluyeh field in the Fars province came

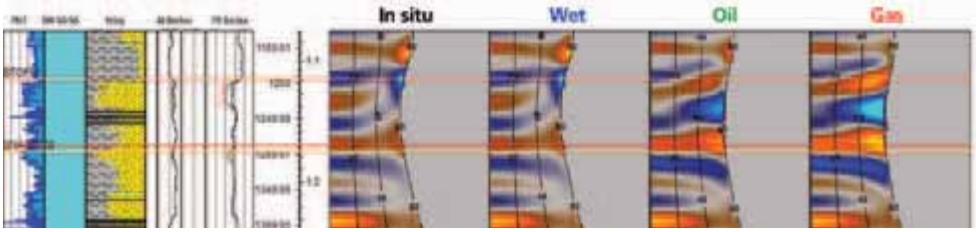
# RSI Rock Physics Studies & Atlases of Seismic Expression

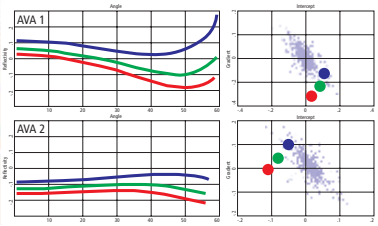
61 Well Mid-Norway



79 Well Barents Sea

**Following the success of the recently completed 79 well Barents Sea Rock Physics Study and Atlas of Seismic Expression, RSI announces the 61 well Mid-Norway Rock Physics Study and Atlas of Seismic Expression.**




Be prepared for the APA 2012 licensing round and the 22nd licensing round with GWLA® conditioned well logs, rock physics modeling to assess the seismic AVO response to changes in fluid saturation and other deliverables.

The studies focus on understanding the fluid signatures in prospective areas such as the Cretaceous Springar, Nise, Lysing and Lange formations for the Mid-Norway and Skrugard analogues in the Bear Island Fault Zone for the Barents Sea.

To find out how you can improve your de-risking process in the region, contact us @ RockSolidImages.com/Norway

**Extraordinary Results. By Any Measure.**

RSI

RockSolidImages.com/Norway

| Reservoir | Reservoir Formations | Geological Location | Hydrocarbon | Properties (Average) | Field Examples |
|---|---|---|---|---|---|
| Asmari (Oligo-Miocene) | Asmari | Dezful Embayment | Oil dominant, Gas | 12% Porosity, 32° API oil, 1.6% Sulfur, 0.3 – 3.3 km depth | Lali, Kabud, Kuh-e Asmari, Qaleh Nar, Par-e Siah, Ramshir |
| Upper Cretaceous – Lower Paleogene | Ilam, Pabdeh, Jahrum | Zagros Basins and Persian Gulf | Oil dominant, Gas | 10.5% Porosity, 27.5° API oil, 2.5% Sulfur | Jufair, Yadavaran, Rudak, Zagheh, Nargesi, Golkhari |
| Bangestan (Middle to Upper Cretaceous) | Kazhdumi, Sarvak, Surgah | Central Zagros, Lurestan | Oil dominant, Gas | 8.5% Porosity, 27.5° API oil, 2% Sulfur, 1 – 3.5 km depth | Yadavaran, Kupal, Danan, Karun, Dalpari, Hamoon, Shoroum |
| Khami (Jurrasic-Lower Cretaceous) | Surmeh, Fahliyan, Gadvan, Darian | Dezful Embayment, Izeh, Persian Gulf, Bandar Abbas Hinterland, Mesopotamian | Oil dominant, Gas | 7.5% porosity, 34.5° API oil, 1.2% Sulfur, 1.5 – 4.5 km depth | Masjid Soleiman, Azadegan, Bibi Hakime, Ahwaz, Gachsaran, Aghajari |
| Dehram (Permo-Triassic) | Faraghan, Dalan, Kangan | Fars, Persian Gulf, Lurestan | Gas and Condensate | 9 % Porosity, 3 km depth | South Pars, North Pars, Tabnak, Kish |

*Classification of reservoir rocks of Zagros/Persian Gulf Basins based on stratigraphic position, petroleum system types, reservoir rock nature and properties, significance and geological distributions (modified after Motiei, H., 1995).*

| Field Class | Recoverable Petroleum | Examples |
|---|---|---|
| Supergiant | More than 10 Bbo or 30 Tcfg | South Pars, North Pars, Kish, Golshan, Gachsaran, Aghajari, Marun, Ahwaz |
| Giant | More than 500 MMbo, or 3 Tcfg | Masjid Suleiman, Rag-e Sefid, Bibi Hakime, Lab-e Sefid, Abteimur, Kupal, Dehloran, Shadgan, Mansuri, Haftkel, Parsi, Pazenan, Darquain, Kharg, Khangiran |
| Small and very small | Less than 500 MMbo or 3 Tcfg | Ramin, Lali, Kuh-e Rig, Ramshir, Khesht, Kilur Karim, Sarvestan, Paydar, Naft Shahr, Binak, Shorum, Karun |

*Classification of Iran's hydrocarbon fields based on total recoverable reserves.*

*Iran's first drilling rig at the Masjid-Suleiman-1 well (1908) being prepared by local Bakhtiari workers. This photo was published by NIOC in the honor of the one hundredth anniversary of the founding of Iran's petroleum industry.*


as a surprise, because the field had been producing gas from the Dalan and Faraghan formations. Based on current data, Early Permian and peri Permian sequences, notably the Faraghan and Zakeen formations, may now be targeted as gas reservoirs, particularly in the Persian Gulf, so deeper drilling will be necessary for new discoveries in this area.

So, after over a century of exploration and production in Iran, exciting new discoveries and pay zones continue, even in the well explored Zagros and Persian Gulf Basins. At the same time the north-west and north-east parts of the country remain almost unexplored and a large number of potential structures have been identified in the Iranian Southern Caspian basins.

The exploration potential of this major hydrocarbon-producing country means that there will be many more discoveries before the oil runs out. ■

*Behrooz Esrafili-Dizaji undertook his undergraduate studies at the University of Zanjan (2001–2005) and received a Master's degree from the University of Tehran in 2008. He is at present a Ph.D student in sedimentology and sedimentary petrology at the University of Tehran. His research projects focus on the characterization of Zagros/Persian Gulf carbonate reservoirs.*

*Farkhondeh Kiani Harchegani received her B.Sc in geology from the University of Isfahan in 2000, and her Master's degree in sedimentology and sedimentary petrology from Azad University (Khorasgan Branch), Iran in 2010. Her area of interest is carbonate reservoirs, sedimentology and diagenesis.*


# SEE THE BIG PICTURE.

**Delivering new insights into the deep geology of the Gulf of Mexico.**

Gain critical insights into the deep basin architecture, basin fill and structural history of the northern Gulf of Mexico region. With over 25,000 miles of customized pre-stack time and depth-imaged data, GulfSPAN gives you an unprecedented look at the evolution of this vital region and its deeper, less explored areas.

**To interact with our BasinSPAN™ library on Google Earth, visit: iongeo.com/SPANS**

**BasinSPANS Highlights:**

**Collaborative Program Design.**
Surveys are designed in collaboration with regional geoscientists and experts within participating E&P companies.

**Advanced Geophysical Technologies.**
Data is acquired using the most advanced source, acquisition, and streamer steering technologies and is processed by GX Technology, the leader in depth imaging.

**Basin-scale Understanding.**
BasinSPANS feature imaging and interpretation of entire petroleum systems, including source, migration, and trapping mechanisms, and provide analysis of thermal and tectonic basin evolution.

ion GEOVENTURES™

# Western Florida: A New Exploration Frontier in the US Gulf of Mexico

This new regional dataset gives a more complete understanding of the crustal architecture of the entire Gulf Basin and adds important elements for rift models around the world

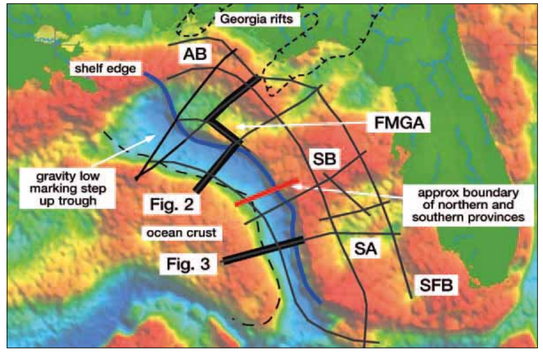



*Figure 1: Location map for FloridaSPAN survey. Positions of Figures 2 and 3 approximate only. Position and known extent of Georgia rifts from numerous sources. Edge ocean crust approximate partly based on ION-GXT seismic. Base map is free air gravity, courtesy of Getech, from Geological Society of London Special Paper 328, 2009.*

*AB = Appalachicola (Destin) Basin*
*FMGA = Florida Middle Grounds Arch*
*SB = Sarasota Basin*
*SA = Sarasota Arch*
*SFB = South Florida Basin*

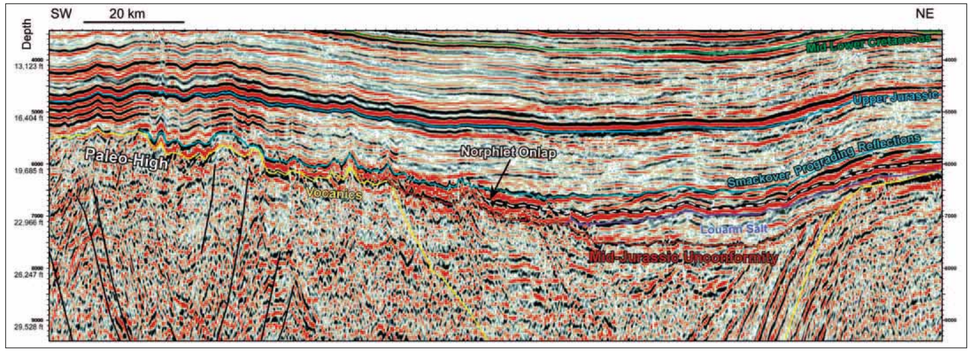



*Figure 6: Detail of a shelf portion of the composite seismic line (Figure 2) showing the Norphlet high amplitude seismic reflection onlapping to the south-west onto a prominent paleo-high. The Smackover shows prograding seismic reflections to the south-west. The downlap geometry defines the top Norphlet Formation in the subsurface. Both units are in the focus area for migrating hydrocarbon from areas to the north and from the basinward deep water to the south-west.*

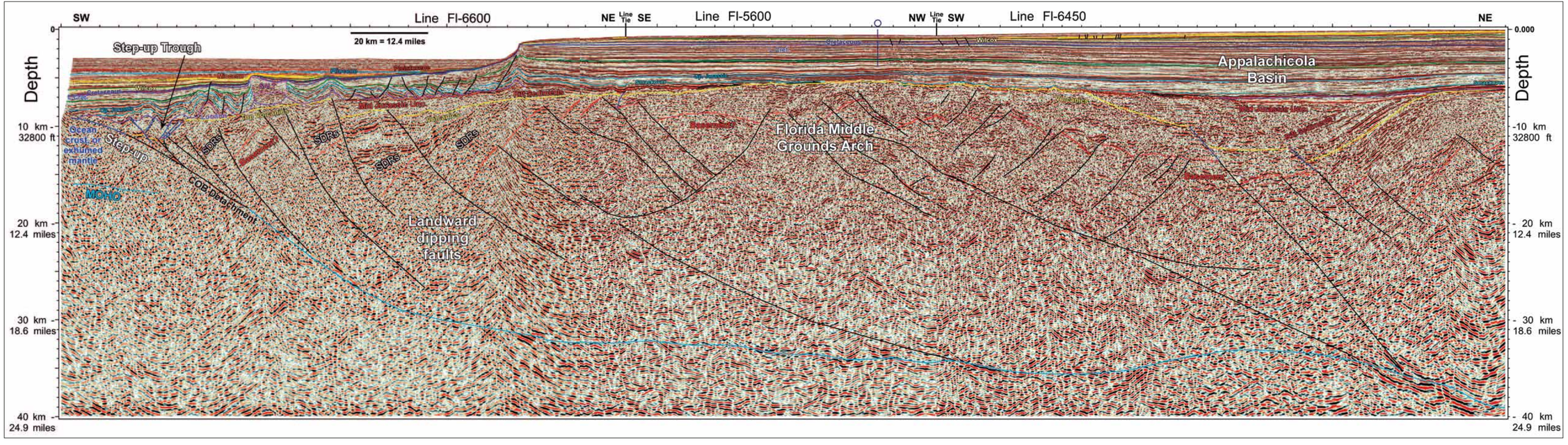



*Figure 2: Composite ION Line FI-6600-5600-6450 across North East Gulf of Mexico and North West Florida Shelf (Appalachicola Basin). Basement rift faults are mainly landward dipping, Louann salt is present on both flanks of Middle Grounds Arch, SDRs are apparent outboard of the shelf edge, and the Middle Jurassic (or sub-salt) unconformity is fairly planar, except very near to the continent-ocean boundary (COB). The COB is marked by a structural basement low (Step-up Trough), where the continental hanging wall of the outer Florida margin is thought to have been detached from over the exhumed mantle and/or oceanic basement. This was the last syn-rift event before seafloor spreading, and was responsible for rapid tectonic subsidence of the outer margin to paleo-water depths >2.5 km, basinward tilting of the sub-salt unconformity, and associated Late Jurassic onset of downslope slumping of salt, probably with overlying Norphlet sands. Salt rollers filled the step-up trough in compressional toes, but did not migrate past it. Subsequent deposition involved marine onlap (Smackover) and continued accumulation that was strongly dependent on relative sea level history.*

ion GEOVENTURES™

# A New Perspective on Rifting

Long-offset seismic reflection data over the western Florida shelf and eastern Gulf of Mexico provide new insights into local geology, illuminate new exploration plays and increase understanding of rift models worldwide

**JAMES PINDELL, ION Geophysical Corporation and Tectonic Analysis Ltd; BARBARA RADOVICH AND BRIAN W. HORN, ION Geophysical Corporation**

The FloridaSPAN™ seismic survey extends ION's existing mega-regional Gulf of Mexico (GoM) dataset to include the important rift history and exploration potential in the offshore Florida margin. Long-offset seismic reflection data (10 km streamer, depth imaged to 40 km, deep-tow acquisition) over the western Florida shelf and slope provide new insights for the local geology and add to the inventory of exploration plays. Key results include a more complete understanding of the crustal architecture of the GoM basin and rift models around the world.

## Unprecedented Detail Revealed

A great value of 'SPAN' data is the superb resolution of crustal-depth structures and the deep sedimentary section. The crustal images constrain the rifting process as well as the Mesozoic tectonic evolution of the Gulf of Mexico. The deep-tow seismic acquisition technique allows strata to be imaged with unprecedented detail in carbonate shelf areas where seismic reflection multiples and paleo-karst challenge seismic imaging.

At the basement level, two contrasting structural and early depositional provinces comprise the 'outer continental margin', which lies outboard of the present-day shelf edge and inboard of the deep GoM's oceanic crust (*Figure 1*). The northern province (Florida Middle Grounds region) is characterized by three main features: landward dipping listric basement faults; fault-bounded packages of seaward-dipping reflectors that appear to be at least partly volcanic; and a fairly smooth, planar sub-salt or 'break-up' unconformity overlain by deformed sections of Louann Salt. This surface tilts basinward to structural levels as deep as the adjacent oceanic crust (*Figure 2*).

In contrast, the southern province comprises seaward dipping basement faults, no clear sign of volcanics, and little mobile salt (*Figure 3*). A regional break-up (i.e., 'end of basement faulting') unconformity occurs at a higher stratal level than the one in the northern province. As in the north, this unconformity also dips basinward to structural levels as deep as the adjacent oceanic crust. Upon close inspection, this unconformity overlies an older unconformable surface that is faulted up to the time of the younger unconformity. The older surface may be related to the sub-salt unconformity in the northern province. The existence of two unconformities in the south is predicted by regional models (e.g., Pindell and Kennan, 2009) that call for two stages of GoM evolution. The older one probably relates to intra-continental stretching across the entire region (~Early Oxfordian culmination), and the younger to the end of rotational seafloor spreading that is expressed in the southern province as rift propagation between north-east Yucatán and western Florida (Early Cretaceous, well after GoM salt deposition).

The two basement provinces also share some common aspects. Both terminate basinward in a structural depression where the rifted margin transitions into the structurally higher oceanic domain of the deep GoM. This rise to the top of the oceanic crust has been termed the 'basement step-up' (Pindell, 2002; Pindell and Kennan, 2007) and the basement depression the 'step-up trough'. The step-up trough can be 30 to 50 km wide and coincides closely with the eastern GoM's gravity low outboard of the shelf edge (*Figure 1*). Secondly, both provinces show a deep landward-dipping (often about 20°) surface that appears to connect the step-up trough with the continental Moho beneath the Florida shelf edge. One could refer to this surface as the Moho beneath the thinned crust of the outer continental margin. We assign a second tectonic significance to this structure, namely that it is a lithospheric scale, low-angle,

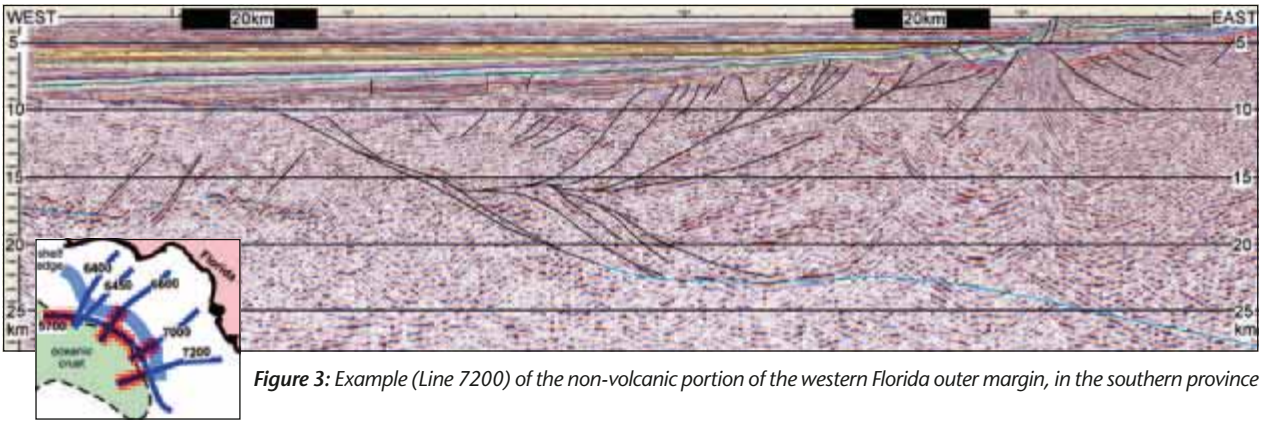



***Figure 3:*** *Example (Line 7200) of the non-volcanic portion of the western Florida outer margin, in the southern province*

extensional detachment shear zone that effectively defines the continent-ocean transition. *Figure 4* highlights the key aspects of the southern province that we believe pertain to the continental break-up process. We believe normal movement on this surface is responsible for the rapid collapse and basinward tilting of the outer margin at tectonic subsidence rates at the time of the rift to drift transition (Pindell *et al.*, 2011).

The presence of SDRs and landward dipping faults beneath the sub-salt (break-up) unconformity in the north makes it tempting to consider the Middle Grounds region as a volcanic margin (e.g., Imbert and Philippe, 2005), with implications for the northern GoM margin. However, if the half grabens and volcanic fill are of Central Atlantic Magmatic Province age (200 Ma) rather than Middle Jurassic, then the magmatism would predate the onset of seafloor spreading in the GoM by some 35 Ma, and the two would not be genetically related. Here, we acknowledge the volcanic nature in the north on geometrical grounds only and disregard the age and genetic causes of the inferred magmatism.

## New Exploration Plays

Using the two-stage rift model as a foundation of basin evolution, the syn-rift and early post-rift history of the western Florida margin created complex regional geology with distinct differences between the northern and southern areas. The Middle to Upper Jurassic isopach map (*Figure 5*) shows a series of depositional thicks related to rifting and subsequent subsidence in the Destin Dome area. Depositional thins demonstrate stratigraphic pinchout onto paleotopographic highs, and changes in isopach thickness also correlate with salt withdrawal in the area.

The structural troughs (e.g. Appalachicola, Sarasota) and highs (e.g., Middle Grounds, Sarasota arches) are inherited from early rifting (Stage 1). Middle and Late Jurassic sediments progressively onlap the early shelf to the south and are absent on the broad Sarasota Arch area. Early sediments are also missing at the break-up unconformity that surrounds the Destin or Appalachicola Basin. As the Florida Escarpment was built up and became a barrier, the sediment accumulations were greatest outboard of the building margin.

Several new play ideas are identified on the FloridaSPAN data. One example is a widespread Norphlet 'pinchout' play and it is delineated at several positions in the offshore Florida margin (*Figure 6*). The Middle Grounds Arch suggests four-way dip closure where Norphlet sandstone and Smackover carbonate build ups onlap onto this basement feature. The Smackover is defined by clinoforms that downlap onto the top Norphlet. Toplap seismic geometries define the top of the Smackover sequence. These units are positioned in the focus area for migrating hydrocarbons from the adjacent basins with a maturing Smackover source kitchen.

The long offset, deep-tow seismic data and advanced processing techniques have enhanced the imaging of these units as well as those below and above the break-up unconformities. With the improved image at depth a better understanding of the processes and geometries related to the basin evolution can help de-risk future hydrocarbon exploration plays worldwide. ■

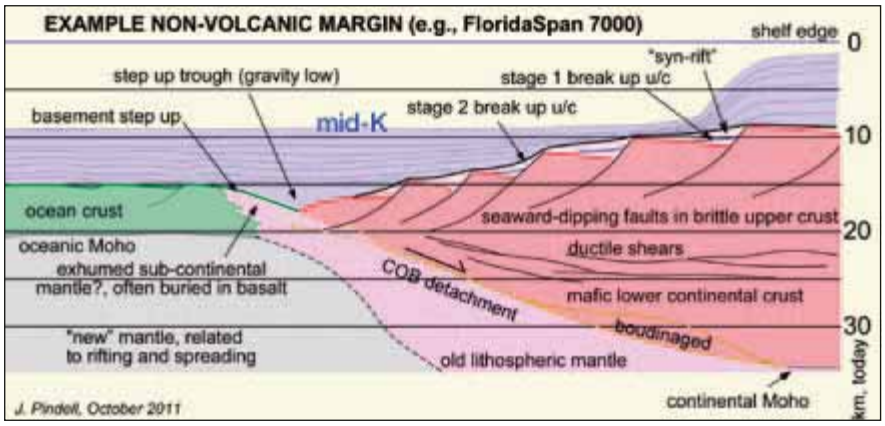



***Figure 4:*** *Schematic sketch of rift-related features of western Florida's southern province, a non-volcanic margin. Note section above mid-Cretaceous is not shown.*

***References:***

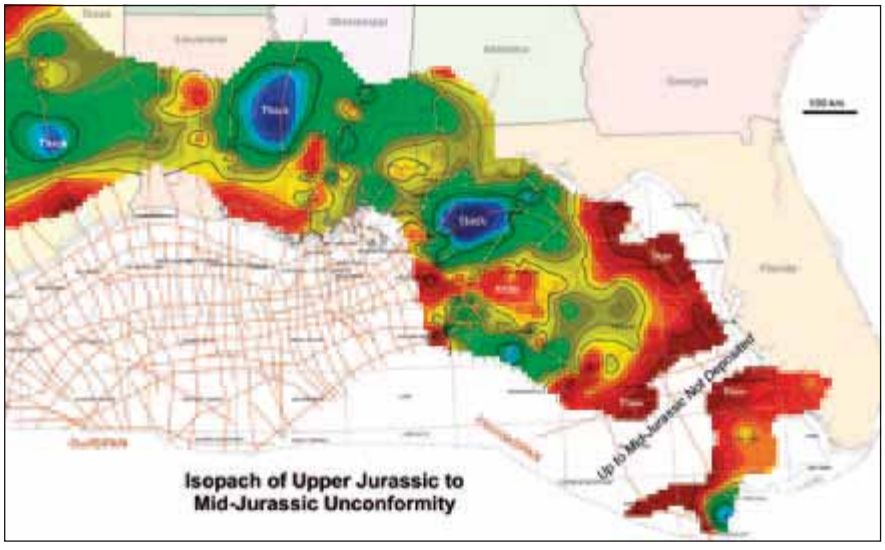

*Imbert, P., and Philippe, Y., 2005, The Mesozoic opening of the Gulf of Mexico, Part 2: Integrating seismic and magnetic data into a general opening model. GCSSEPM Foundation 25th Annual Bob F. Perkins Research Conference, p. 1151-1189.*

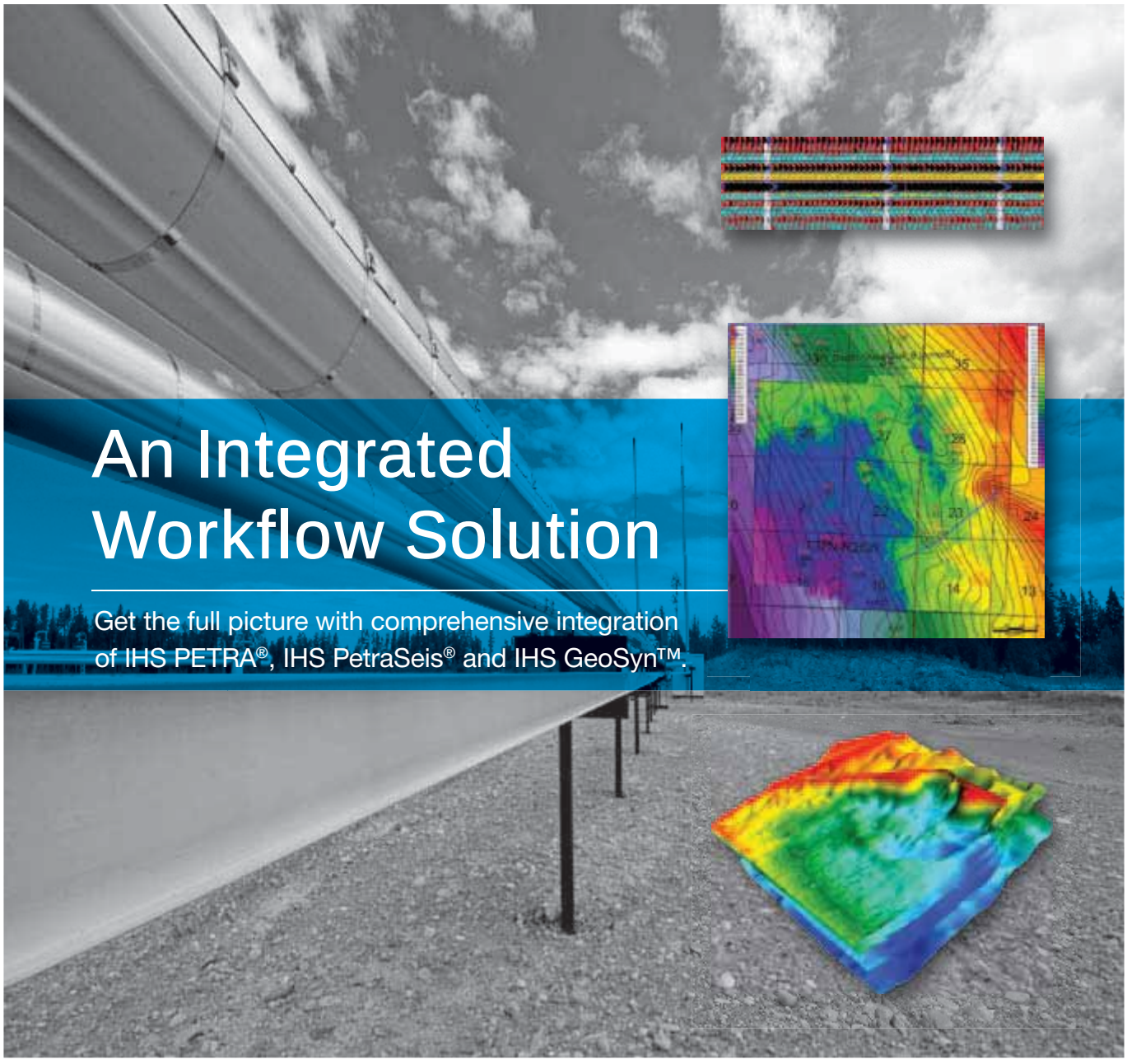
*Pindell, J., 2002, How deep was the Late Jurassic Gulf of Mexico?, Offshore Magazine, v. 62 (Feb 2002), p. 60, 62, 63, 100.*

*Pindell, J., and Kennan, L., 2009, Tectonic evolution of the Gulf of Mexico, Caribbean and northern South America in the mantle reference frame: an update. In: James, K. H., Lorente, M. A. and Pindell, J. (eds.), The Origin and Evolution of the Caribbean Plate. Geological Society, London, Special Publications, v. 328, p. 1-54.*

*Pindell, J., Heyn, T., and Horn, B.W., 2011, Rapid outer margin subsidence during the rift-drift transition in the eastern Gulf of Mexico: Implications for detachment faulting at continent-ocean boundaries during rifting, GCAGS Transactions, Veracruz, Mexico.*


***Figure 5:*** *Regional isopach map for the Upper Jurassic, illustrating the paleo-topography on the mid-Jurassic unconformity at the time of deposition as well as the effects of salt movement. The series of basins and paleo-highs are inherited from the Mid-Jurassic rifting. Hydrocarbons maturing in the north-western offshore Florida basin could source the surrounding paleo-highs. (Map generated using FloridaSPAN and GulfSPAN data)*






When these three solutions seamlessly connect, geological and seismic workflows are streamlined with easy-to-interpret data and modeling tools. This integrated bundle allows you to access, view and manipulate information within the same project; create multidimensional seismic models and synthetics; improve workflow collaboration; and deliver comprehensive proposals for new prospects. Get to the field faster with seismic, well, production, log and economic data at your fingertips.

See more solutions at www.ihs.com/geoexpro

IHS
The Source
for Critical Information and Insight™

# Marine Seismic Sources

## PART XI: EFFECT OF SEISMIC ON CRABS

*The Atlantic Ghost Crab (Ocypode quadrata) is a very common species on the beaches of north-east Florida, where it lives in burrows well above the high tide line. Although the crab itself is seldom seen during daylight hours, the round shaped entrances to its burrows and the tracks it leaves in the sand are quite conspicuous.*



*"You cannot teach a crab to walk straight"*

*Aristophanes, 446-386 BC, the 'father of old comedy'*

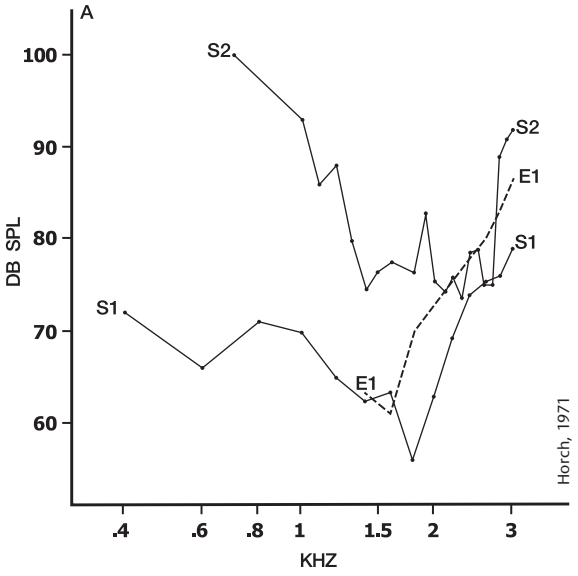
MARTIN LANDRØ AND LASSE AMUNDSEN

In previous editions of *GEO ExPro* we have discussed the effect of seismic shooting on mammals and fish. What about animals without ears, like the crab? In this article, we discuss how the crab's hearing system works and report from a Canadian research project investigating the effects of seismic shooting on snow crabs.

### Do Crabs Hear?

The crab is one of approximately 50,000 species described as crustaceans, ranging from small animals 0.1 mm long, up to the Japanese spider crab with a length of 3.8m. There are fossils which have been dated back to the Cambrian age, so this group of animals has an impressive track record. They are also invertebrates (animals without a backbone), which means they have no bones or cartilage – which is what forms ears as we know them. Therefore, all crustaceans lack ears similar to human beings. Instead, crabs are equipped with tiny microscopic hairs covering their shells. These hairs detect changes in water pressure and transform these changes into a signal that is sent to the crab's nervous system.

The knowledge related to hearing and sound communication for invertebrates is limited. Some invertebrates produce sound, which could mean that they also have hearing capabilities. In 1971 Kenneth Horch made a study on the hearing of the ghost crab (ocypode), and measured hearing curves between 0.4 and 3 kHz. He found that ghost crabs in air proved to be sensitive not only to tones presented by the speaker but also to talking, whistling, and playbacks of field recordings of crab sounds. Furthermore, he found that the legs were the most sensitive part of the animal to sound, with the fourth pair of walking legs generally the most sensitive. The experiment showed similar responses




*Hearing curves for two ocypodes. Thresholds determined electrophysiologically with recordings made from electrodes implanted in the brains of animals suspended in air. Tones presented by loudspeaker (S) or to individual walking legs with a small earphone (E). DB SPL: sound pressure relative to 0.0002 microbar.*

for vibration and sound, with the best sensitivity between 1 and 3 kHz.

Since the responses for vibration and sound were similar, it might indicate that the ghost crab cannot really distinguish between them. However, several later studies, coupled with the fact that marine invertebrates do not have swim bladders, clearly suggest that the crab is more sensitive to vibration or particle motion. In his experiment, Horch found that the walking legs were essential for hearing sensitivity, in contrast to the claws. No change in hearing ability was observed until more than half of the legs were removed. As more legs were removed from this point, he found a gradual weakening of the response until zero when all legs were removed. Horch also reports in his paper from 1971 that the painted ghost crab (Ocypode gaudichaudii) reacts to sudden sounds such as the calls of shore birds.

## Mating Dances Use Sound

In several species of American Fiddler Crabs, males use both visual and acoustical signals to find a mate. First, they perform their mating dance by waving their large claw in specific patterns. Then, at night, the male produces sounds from just inside his burrow to attract females. These sounds begin at a low rate, and then steadily increase in frequency. In European species of Fiddler Crabs, the mating dance is similar, although the males produce two different sounds to attract a female. The first is called a 'short drumroll' and is made when the male is unable to be seen by the female for a short period during his claw-waving dance. The second sound is a 'long drumroll' and is used under different circumstances.

This acoustic communication not only reaches female crabs, but is also heard by other male crabs. When other nearby males hear the mating calls of other males, they then increase their amount of dancing and mating calls.

It is assumed that crabs orient themselves according to smells in the water (A. K. Woll, 2006), with visual orientation being probably of less importance. However, can underwater sound give crabs an orientation cue to find the way from the open ocean to the coast?

Jeffs *et al.* (2003) used artificial underwater sound sources to study if the larval and post-larval stages of coastal crabs were attracted to coastal reef sound. The results demonstrated that the pelagic stages of crabs respond to underwater sounds and that they may use these sounds to orient themselves towards the coast. The orientation behavior was modulated by lunar phase, being evident only during first- and last-quarter moon phases, at the time of neap tides. Active orientation during neap tides may take advantage of these incoming night-time tides for predator avoidance or may permit more effective directed swimming activity than is possible during new and full moon spring tides.

## Effect of Sound on Crabs

There are very few studies where the focus has been to study the effect of sound on crabs. A recent comprehensive

*Photo (from Christian et al., report 2003) of sensory hairs in the snow crab statocyst. The crab is equipped with at least three various hair types. One detects vibration or direct contact, another is sensitive to chemicals and the third is designed to detect pressure changes in the water. These hairs are similar to seismic hydrophones used to record seismic signals. Experiments show that crabs do not respond to sound signals like music; however, they react instantly if you jump close to them.*

study was performed by Christian *et al.* in 2002, in which they studied snow crab behavior using air gun sources of 40 and 200 cubic inches. The purpose of the test was to examine a number of health, behavioral, and reproductive variables before, during and after seismic shooting. Snow crabs reacted slightly to sound in the laboratory when sharp noises were made near them. However, in the field the video camera showed that crabs on the sea bottom gave no visible reactions to a 200 cubic inch air gun array being fired 50m above them.

Effects on eggs were also conducted in this study. Here the researchers found that exposure to high levels of sound (221 dB) may retard the development of eggs. However, it is stated that this result needs further investigations.

The overall conclusion from the Canadian study is that no obvious effects were observed on crab behavior, on the health of adult crabs, and on experimental commercial catches. Despite this, it should be noted that this study was not conducted during normal seismic acquisition, and the total number of seismic signals to which these crabs were exposed was therefore less than would occur during a normal seismic acquisition. However, it should also be noted that the air gun exposures during each study trial were characterized by higher energy levels than those to which crabs would be subjected during normal seismic activities. Snow crabs tend to naturally occur in somewhat deep water so considerable signal attenuation has occurred by the time the sound reaches the crab on the seabed.

In conclusion, therefore, we can say that there is limited knowledge of the effects of seismic acquisition on crabs. Even knowledge about the hearing capabilities of various types of crabs is limited. It is commonly agreed that crabs respond to acoustic sound, and, for instance, the ghost crab has a maximum hearing sensitivity around 1–3 kHz. It is therefore likely to assume that crabs notice seismic activity. Initial experiments performed in Canada showed practically no behavioral or other impacts on adult crabs. ■

*Acknowledgement: Many thanks to John Christian for discussions and help.*

***References***

*J. R. Christian, A. Mathieu, D. H. Thomson, D. White and R. A. Buchanan, Effect of Seismic Energy on Snow Crab (Chionoecetes opilio), report for National Energy Board, Calgary, Canada, 2003.*

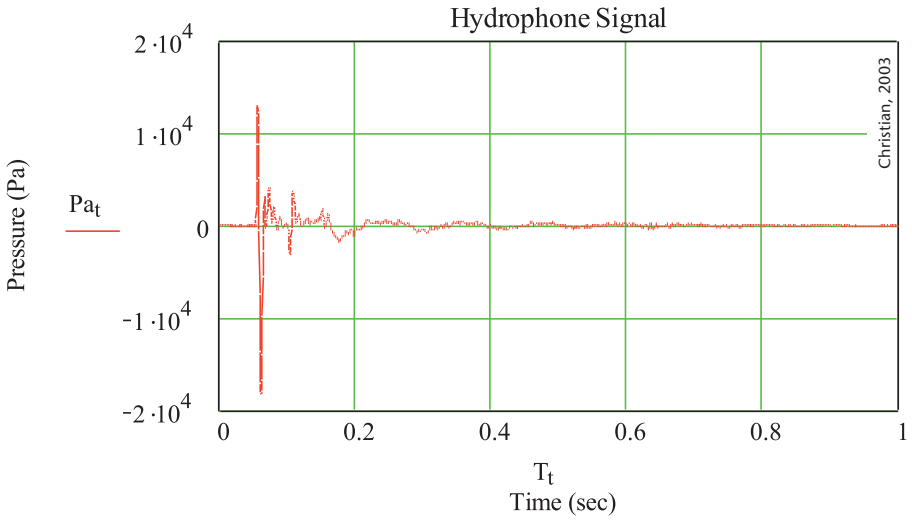
*A. Jeffs, N. Tolimieri and J. C. Montgomery. Crabs on cue for the coast: the use of underwater sound for orientation by pelagic crab stages, Marine and Freshwater Research 54 (7) 841 – 845, 2003.*

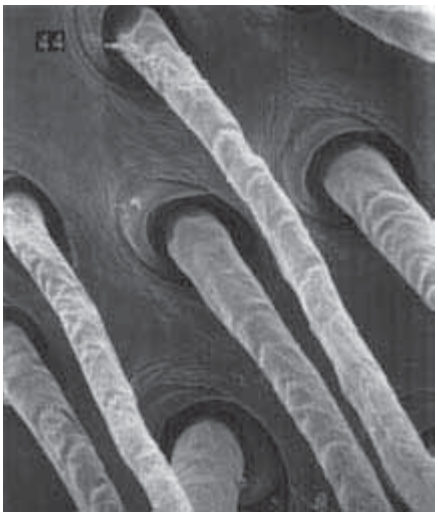
*http://sitemaker.umich.edu/ling111ec/fiddler_crabs*

*Horch, K., 1971, An organ for hearing and vibration sense in ghost crab ocypode, Z. vergl. Physiologie, 73, 1-21.*

*A.K. Woll, The Edible Crab, Møreforskning, 2006.*

*Hydrophone signal measured 50m below the 200 cubic inch air gun array was used in the Canadian study on seismic and crabs.*



*Scanning microscope photo of crab hearing hairs (Christian et al, 2003). Typical length of these hairs is 300 micrometers. These hairs are similar to seismic streamer cables, although the dimensions are 'slightly different' – 300 micrometers versus 6 km. Another similarity with seismic acquisition is the use of several streamers: while seismic contractors can tow up to 20 streamers, the snow crab is equipped with even more receptors!*

*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.*


Dolphin
geophysical
Marine seismic
for the next decade of
hydrocarbon exploration
www.dolphingeo.com
intelligent, fast & friendly

# A Tireless Quest for Buried Treasure

JANE WHALEY

**Marlan Downey**, Chairman of the Board and Founder of Roxanna Oil Company, has reinvented himself many times over the course of his 50-year career and shows no signs of slowing down. In each new venture, he brings a unique combination of technical expertise in chemistry and geology, a lifelong love of learning and a desire to collaborate with the best and the brightest.

How does one shift from a career path in chemistry to one in geology and the oil and gas industry? For Downey, it began by going to war. "In 1952, the day I graduated with an undergraduate degree in chemistry, I was drafted into the US Army," he says. "I spent two years in Korea and the Philippines, after which I was shipped back to the US"

While convalescing in a Veterans Administration hospital in Lincoln, Nebraska, Downey began graduate studies in chemistry at the University of Nebraska. During this time, he took part in a series of Army-administered IQ and aptitude tests. "These tests indicated that I had particular strengths in spatial visualization, mathematics and physics. They also suggested that these strengths were best suited to the fields of architecture and geology," he says.

And while Downey was still content with chemistry, his experience in the war had changed his perspective. After spending the past two years sleeping out of doors in squad tents or jungle hammocks, he felt confined by the long hours spent inside the chemistry lab. "As you might imagine, coming back to a non-air conditioned, indoor laboratory setting in the middle of summer in Nebraska made me feel a bit like a caged animal."

At this time, and with the encouragement of a friend, Downey met with the chairman of the university's geology department, who was looking for graduate students with an aptitude for math and physics to transfer into geology. "To my astonishment, he offered me a place in the geology graduate program, even though I had never taken a geology course in my life," Downey says. "I took all my courses in parallel, and accumulated both a BS degree and MS degree in geology, and logged 100 hours of course work towards a PhD degree."

## Shell Come Calling

His PhD pursuit was cut short when his education funding through the US federal government's G.I. Bill ran out. However, Shell Oil came calling for Downey, where

he began an illustrious career that presented opportunities that were both personally rewarding and unexpected, at times. "One such unexpected opportunity came after I had been working for Shell as a geologist for a few years," Downey recalls. "Out of the blue, I received a call from a Shell vice-president in New York, who remembered that I had a chemistry background."

Downey was transferred out of the E&P segment and assigned to Shell's R&D laboratory in Bellaire, Texas to work with a group of world-class chemists on a special project aimed at understanding the occurrence, origin and migration of oil. Within one year in the group, Downey had been promoted to project supervisor, with 35 researchers reporting to him.

"I have had the opportunity to manage many teams over the years, in many different companies, and I have always been fortunate to be surrounded by really bright, capable people," Downey says. "I've always maintained that a good manager is not necessarily a star player, but rather a coach who knows how to get the best work out of their people and gives them the proper credit. I always loved the saying, 'There's no limit to the good you can do, so long as you don't care who gets the credit.'"

After four years of working in R&D, Downey's career took another pleasant and unexpected turn. "After just a decade of work experience, I was made Chief Geologist. I was shocked, as this promotion made me the youngest Chief Geologist in Shell history at the time. I was only 35," Downey says.

Over the next 20 years, Downey held a number of management and executive roles within Shell, including his final one as President of Shell's international business arm, Pecten International. He retired at the young age of 55, with no thoughts of entering into a new oil and gas venture – at least, not initially.

### Retiring from Retirement

"After laying about at home for a few weeks, a friend of mine called to tell me about a lease sale in the Philippines, and to see if I was interested in putting together a bid," Downey says. "Just like that, I found myself back in the international oil business."

Downey founded Roxanna Oil Company in 1987, with a mandate to evaluate oil and gas plays on behalf of its clients – which include Shell, Matador Resources, Maersk, Marathon Oil and Petrohunt – and to participate in their development. The company's name has an interesting origin – one that helps explain how Roxanna Oil has evolved over the past 20 years.

"Roxanna was the name of the Persian princess who was wedded to Alexander the Great in an effort to seal the peace between the ancient Greeks and Persians," Downey explains. "It was also the name chosen for Royal Dutch Shell's US company when it was formed in the 1920s, because of its allusions to bridging different cultures."

Downey selected the name for his company after realizing that Shell had not copyrighted it, or even used it for 30 years. "The name suits our unique business model, as we bridge the cultural and technical gaps between pure geology and making money from exploration."

Under Downey's leadership, Roxanna quickly established itself with significant holdings of international acreage and a number of wildcat wells drilled. His career path then took another unexpected turn, thanks to a request from Atlantic Richfield's (Arco's) board of directors to join the company as Senior Vice-President of Exploration

in Arco International. Soon after, he was promoted to President of Arco International, with separate functional responsibility for reviewing all exploration in Arco for the board of Arco.

Upon retiring from Arco at 65, Downey then joined the faculty of the University of Oklahoma as the first Bartell Professor of Geoscience, as well as the Chief Scientist of the university's Sarkeys Energy Center.

After three years of teaching, Downey was elected president of the American Association of Petroleum Geologists (AAPG) before finally returning to Roxanna Oil, which remains a privately held, debt-free, family-owned company.

"I had turned the company over to my six children, and I basically work for them," Downey says. "My daughter, Julie Garvin, who was formerly a chief geophysicist for Marathon Oil, runs the company. But, as father and chairman, I participate in any final decision on investments."

## Both Prospector and Partner

Roxanna consists of a segment that originates and participates in conventional oil and gas investments, as well as a consulting arm that finds particular classes of oil and gas acreage for its clients. The company takes this consultation a step further by offering to take a working interest position with each client.

"You can think of our consulting group as a supplement to our clients' own exploration teams. We don't recommend anything that we are not also prepared to invest in," Downey says. "This gives us a unique perspective and special interest in carefully selecting the right plays, since it is our money going into their development, right beside the money of our clients."

Roxanna's team is comprised of experts in the fields of geology, geochemistry, geophysics, reservoir engineering and economics, with each person bringing an average of 30 years of experience. Many retired recently from major oil companies but, like Downey, were not ready to stop working. "We have all been in the oil business so long that we know most of the senior-level people in many of the operating companies, and they know us by name and reputation," Downey says.

A typical exploration assignment for Roxanna lasts for one year and begins with the Roxanna team selecting a region to study for their client. This is usually a data mining exercise using modern geographic information system technologies, in which a large number of well logs, perhaps hundreds of thousands, are winnowed down to a more manageable number of representative wells that meet certain geological and structural criteria.

"We tend to analyze resource plays in a way that draws from my research background with Shell, which identified geological and geochemical markers that indicate the origin and migration of oil in a reservoir," Downey says. "I had looked at almost all of the areas that we commonly call shale gas or shale oil plays as part of my original work there, and I have kept up to date with the ongoing research and studies in these plays. As far as I know, I have been in this field longer than anyone else who is currently active in the industry."

Further analysis narrows the search down to those reservoirs that have the best prospect for success, at which point Roxanna conducts lease reviews until they are satisfied with the play. If the client decides to develop the play, Roxanna takes an overriding royalty or working interest, depending on the client's preference.

*Roxanna shareholders gather to celebrate Marlan's 80th birthday and another good year. Back row (left to right): Alex, Don, Marlan, Nick, Justin. Front row (left to right): Julie, Karen.*

"I tend to be fairly fiscally conservative with my company's money, and because we are so heavily invested in the success of our clients' projects, we recommend acreage with more modest lease prices," says Downey. "We don't present US$10,000 per acre leases to our clients. Most of our recommended acreage has been bought at prices from US$50–US$200 per acre."

Over the past several years, Roxanna has focused a great deal of its exploration attention on shale gas plays. The company currently holds nearly 600,000 acres (2,428 km$^2$) of royalty and working interest in plays across the US, including the Marcellus, the Barnett, the Chainman, the Phosphoria and the Woodford.

## Perpetual Motion

After approximately one year of exploration in a given area, Roxanna moves on to explore other regions for clients. "To put it bluntly, it is not in the best interests of our clients or ourselves to continue working past the point of useful return in a given area," Downey says. "There are plenty of other places to explore."

One major exploration category for the company is shale oil, which it has been pursuing in earnest for the last several years. Downey estimates that good shale oil plays are three to five times harder to find, on a technical basis, than shale gas.

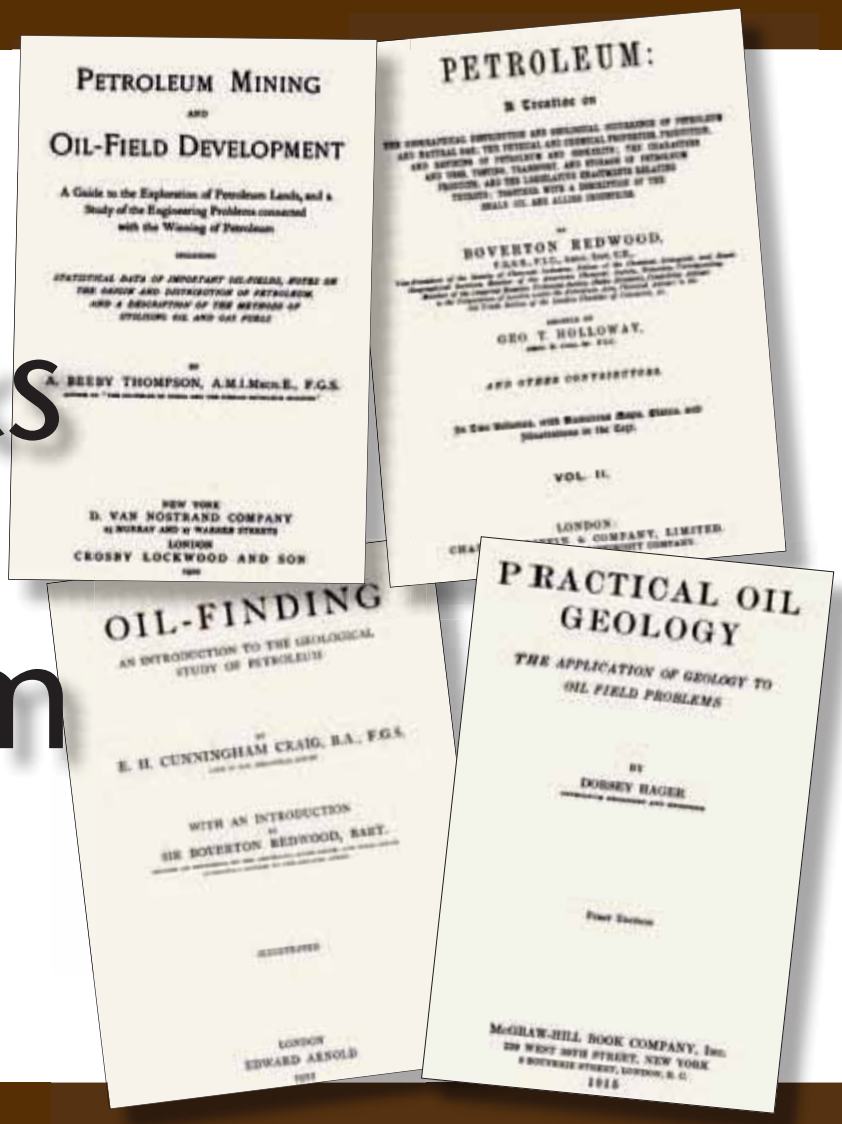
"For many shale oil plays, the technology has not advanced to the point where the reservoir can be developed in a commercially viable way. This puts a much greater burden on the early searchers to find shale oil reservoirs that are most amenable to field trials designed to prove their viability," he says. "We have been working hard on this, partly because the economics of shale oil are much better than gas, and partly because we like the exploration challenge this presents to us."

Downey's accomplishments have been recognized many times by the industry he has faithfully served for half a century. His many awards include a Hedberg Medal for outstanding scientific achievement, the distinction of 'Legendary Oil Finder' by the Petroleum History Foundation and the Sidney Powers Memorial Award – the highest honor bestowed by the AAPG – for outstanding contributions to oil and gas exploration.

And while many people might be content to reflect on these accomplishments and accolades in retirement, Downey has no intention of slowing down any time soon.

"People ask me why I still keep myself so busy, but work is something that has been engrained in me since my childhood. I've worked in one capacity or another since I was 12," he says. "Honestly, I don't consider what I do to be work. It's fun… It's searching for buried treasure and getting paid for it into the bargain." ■

# Early Textbooks of Petroleum Geology




RASOUL SORKHABI

Petroleum geology textbooks have been an essential tool for training generations of teachers, researchers, explorers, and managers in the petroleum industry. Here we look at some of the early textbooks in this field as a way of paying tribute to these works and their authors, upon whose shoulders stand the writers, teachers and textbooks of our time.

In the mid-19th century, industrialists, chemists and geologists in Europe and North America began to appreciate the usefulness of petroleum ('rock oil'). Scientific journals gradually started to publish papers on oil refining, location of oil seeps, the anticlinal theory for oil accumulations, and so on. As knowledge and activities in the oil sector accumulated, the first educational books on petroleum in English appeared in England in the 1880s and 1890s.

In March 1886, Sir Boverton Redwood gave four lectures on the history, production, refining, and uses of petroleum at the Society for the Encouragement of Arts, Manufactures, and Commerce in London. These lectures were collected in a book, *Cantor Lectures on Petroleum and Its Products*, published in London in 1886 and a year later in New York as *Petroleum: Its Production and Uses*.

R. Nelson Boyd, a member of the Institution of Civil Engineers in London, published a slim book, *Petroleum: Its Development and Uses,* in London in 1895. Its 86 pages covered topics as diverse as the origin of petroleum and geological strata in which it is found; chemical composition; 'winning' petroleum; storage and transport; liquid fuel; the flashing point and lamp accidents; petroleum engines; and the future of petroleum. Boyd begins his book with some interesting data: "Since the introduction of petroleum into this country the consumption has continuously and enormously increased. In 1859 the imports into the United Kingdom amounted to 2,000,000, and in 1893 they had reached a total of 155,126,667 gallons… To the quantity of the oil imported

must be added the mineral oil produced in Scotland from the 2,000,000 tons of shale raised and treated, which will probably amount to 20,000,000 gallons of illuminating oil."

Sir Boverton Redwood's *Petroleum: A Treatise* – two volumes totaling 900 pages – was the first comprehensive text on petroleum, published in 1896. Being a useful manual, it went through subsequent editions in 1907 (two volumes) and 1913 (three volumes); the fourth edition was posthumously printed in three volumes in 1922 with an introduction by Sir Frederick W. Black (1864–1930), an officer with the Royal Admiralty who was then serving as the managing director of the Anglo-Persian Oil Company. Volume I of the book dealt with the geology and geography of oil; volume II was on oil refining, and volume III on oil laws and regulations.

## Into the Twentieth Century

Several events in the 1900s proved to be a turning point for the petroleum industry worldwide. Before 1900, the producing oil fields in the USA were confined to the north-eastern states; in the 1900s, however, large oil discoveries in Texas, Kansas and California spread the upstream oil sector across the country. Meanwhile, Henry Ford's development of small, convenient automobiles generated a huge demand for gasoline (petrol). In the UK, the Royal Admiralty made a strategic decision to replace coal with oil as the main fuel for its fleet. The discovery of oil in Iran (Persia) in 1908 and the subsequent formation of the Anglo-Persian Oil Company (controlled by the British government) put the Middle East on the global petroleum map.

In 1910, Arthur Beeby Thompson (1873–1968), a British petroleum engineer (and son of a geologist) and a pioneer oil explorer in Trinidad, published *Petroleum Mining and Oil-Field Development*. The book formed a basis for Thompson's more exhaustive work, *Oil-Field Exploration and Development*, in which volume I was dedicated to 'oil-field principles' and volume II to 'oil-field practice'.

In 1912, Edward Hubert Cunningham-Craig (1874–1946), a Scottish geologist with the Burma Oil Company, published a purely petroleum geology text titled *Oil Finding: An Introduction to the Geological Study of Petroleum*. A second edition came out in 1920 with an introduction by Cunningham-Craig's mentor – none other than Sir Boverton Redwood. The book consisted of ten chapters covering subjects ranging from the origins of petroleum to migration and subterranean storage of petroleum, geological structure, stratigraphy, and field-work for beginners. It also presented 13 field photos from Burma, Iran, and Trinidad. In discussing the origin of oil, Cunningham-Craig supported the notion of 'terrestrial vegetation' source because the oil basins he had studied were associated with coal deposits.

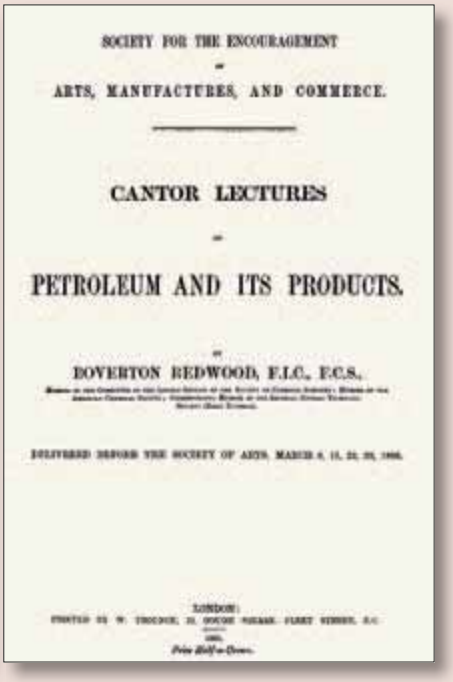
The largest effort in the UK to synthesize the knowledge of oil during the first half of the 20th century was a four-volume publication, totaling a massive 3,200 pages, called *The Science of Petroleum*, edited by A.E. Dunstan, A.W. Nash, B.T. Brooks, and Sir H. Tizard and published by Oxford University Press in 1938.

## North America

In North America, Dorsey Hager (1887–1971), a petroleum expert and a founding member of the American Association of Petroleum Geologists (AAPG), was also a pioneer author of books on petroleum geology and industry. His publications included: *Practical Oil Geology: The Application of Geology to Oil Field Problems*, initially published in 1915, but with a sixth edition coming out in 1951; *Oil-Field Practice* (1921); and *Fundamentals of the Petroleum Industry* (1939).

The early history of oil was shaped by wildcatters. However, between the two world wars field-based knowledge of petroleum geology was rapidly accumulating. In order to synthesize this knowledge and to formulate better practices for oil exploration both in the


Portrait sketch by Setsuko Yoshida


SOCIETY FOR THE ENCOURAGEMENT
OF
ARTS, MANUFACTURES, AND COMMERCE.

CANTOR LECTURES
ON
PETROLEUM AND ITS PRODUCTS.

BOVERTON REDWOOD, F.I.C., F.C.S.

DELIVERED BEFORE THE SOCIETY OF ARTS, MARCH 9, 11, 23, 25, 1886.

LONDON:

*Sir Boverton Redwood (1846–1919), a chemical engineer, ran a petroleum consulting firm in London. He was vice-president of the Society of Chemical Industry in London; a member of American Chemical Society, Imperial Russian Technical Society; a fellow of the Chemical Society, Geological Society, and Royal Geographic Society; and consulting advisor to the Corporation of London, the London Chamber of Commerce, the Admiralty, the Home Office, and the India Office, amongst others. The Redwood Baronetcy was created for him in 1911. Sir Redwood wrote the first textbooks on petroleum:* Cantor Lectures on Petroleum and Its Products *(1886) and the two-volume* Petroleum: A Treatise *(1896).*

USA and overseas, several encyclopedic volumes appeared, including *The Oil Encyclopedia*, by Marcel Mitzakis in 1922, the three volume *Structure of Typical American Oil Fields: Symposium on Relation of Oil Accumulation to Structure* published between 1929 and 1948; *Problems of Petroleum Geology*, edited by William Embry Wrather and Frederic H. Lahee and produced by the AAPG in 1934, and *Finding and Producing Oil: A Comprehensive Manual*, published in 1939.

### Economic Resources Versus Subsurface Structures

There is more than one approach to teaching a subject. In the traditional division of geology into the physical, historical and economic (applied) disciplines, petroleum geology in academic circles usually comes under the category of economic geology. It is thus not surprising that some early books on petroleum geology written in the style of modern college texts came from the pen of economic geologists. One such text, *The Geology of Petroleum and Natural Gas,* was by Ernest Raymond Lilley (1895–1949), a professor at New York University. Lilley had previously published *The Petroleum Industry* (1925) which dealt with oil resources, production, transportation, refining, and marketing.

Mention should also be made of William Harvey Emmons (1876–1948), who obtained a Ph.D. in geology from the University of Chicago in 1904, and who after teaching at Chicago joined the University of Minnesota and also served as the director of the Minnesota Geological Survey. Primarily an ore mineralogist, Emmons wrote *Geology of Petroleum*, first published in 1921, based on his course notes; a second edition came out in 1931.

A different perspective on petroleum geology, especially held by structural geologists, was to focus on the subsurface geologic methods involved in oil exploration. Influential publications following this line of thought include *Subsurface Geologic Methods: A Symposium*, edited by Leslie Walter LeRoy (1950); *Structural Geology for Petroleum Geologists* by William Low Russell (1955); *Structural Methods of the Exploration Geologist* by Peter C. Badgley (1959); and *Handbook of Subsurface Geology* by Carl Allphin Moore (1963).

### After World War II

After World War II oil consumption increased worldwide (especially because of Europe's reconstruction); therefore, petroleum geology courses were in high demand. Several textbooks to address this need came out. In 1949, Cecil Gordon Lalicker, professor of geology at the University of Kansas, published *Principles of Petroleum Geology*: In 1951 two other books appeared; William L. Russell, then a professor at Texas A&M, published *Principles of Petroleum Geology* (a second edition came out in 1960) and Kenneth Knight Landes, professor of geology at the University of Michigan, published *Petroleum Geology*. Its second edition came out in 1959, and this edition was also reprinted in 1975 and 1981.

In the preface to the 1951 edition, Landes remarks that the growth of petroleum geology in the first half of the 20th century was along three lines: "These are: (1) the geologic occurrence, by which is meant the origin and accumulation of the natural hydrocarbons; (2) the geographic occurrence or distribution of these substances; and (3) the methods and techniques of searching for oil and gas deposits."

### Then and Now

Every age and generation has its own share of college textbooks, but new books are built upon their predecessors. Therefore, even though the works and authors introduced in this article may not be familiar to the young generations of geologists today, their legacy lives on.

A comparison of the early petroleum geology textbooks with those of our age reveals a marked difference in their contents: The early textbooks focused on oil habitats, field descriptions, structures, and regional understanding, while the modern texts attempt to teach the processes of the petroleum system and the methods of basin analysis with only supportive field examples. ■

## Levorsen and *Geology of Petroleum*

Arville Irving Levorsen (1894–1965), of Norwegian origin, was one of the renowned American geologists of the 20th century. He proposed a simple guideline for oil exploration: "Find a trap – then drill it." Levorsen's textbook, *Geology of Petroleum*, stands on the border between the early and the modern textbooks of its kind and has educated several generations of geologists (including this author). First published in 1954, its second edition came out in 1965, shortly after the author's death.

Levorsen did not think that 'petroleum geology' was a proper term: "Rather, it is more accurate to say 'geology of petroleum' just as we say 'geology of iron,' or 'geology of clay,' although the shorter term, 'petroleum geology,' is commonly used." *Geology of Petroleum* contains 15 chapters arranged under five sections: Introduction, The Reservoir, Reservoir Dynamics, The Geologic History of Petroleum, and Applications. It also has a glossary, abbreviations, and a list of bibliographies. Levorsen places 'the reservoir' at the heart of his book; even what we now call petroleum geochemistry is discussed in his book as 'reservoir fluids.' The reprinting of *Geology of Petroleum* by AAPG in 2001 indicates its usefulness in our time as well.

Portrait sketch by Setsuko Yoshida

# Fast forward your exploration

**In exploration, time is money.**

So how do you highgrade basins and screen opportunities faster, safe in the knowledge that you have evaluated the full regional picture?

This is where Neftex can help. Our unique Earth Model suite of products use a vast library of geological data and combined with high-resolution sequence stratigraphy and plate models, to deliver detailed evaluation of basins worldwide. Our Consultancy team can do the same using your data.

Put simply, we give explorers the ideal platform to build on, helping you to target exploration success more quickly, and with less risk.

For more details on how Neftex can fast-forward your exploration programme, contact us today.

Neftex

For more information contact: enquiries@neftex.com
Call + 44 (0) 1235 442 699 or visit www.neftex.com

# Brief Biography of a Biogenic Gas Play

Recent commercial discoveries and modern 2D seismic in the Tobago Basin suggest that prolific natural gas reserves may extend far beyond the established trend and play concepts.

RICK ROBERSON, PGS

In May 1971, a shallow water new field wildcat (NFW) located in the southern Tobago Basin offshore north coast Trinidad reached total depth in basement at 2,740m. The seismically derived objectives of well KK 6-1 – bright, Mio-Pliocene sandstones on structure – tested dry gas and were consequently abandoned. Although stranded at the time, KK 6-1 had discovered the Patao-KK biogenic gas trend, a play boasting 2P recoverable reserves of 935 MMboe within Trinidad's North Coast Marine Area (NCMA) and 1,206 MMboe within eastern Venezuela's Mariscal Sucre field complex.

## The Tobago Basin

The Tobago Basin is a forearc basin located in the south-east Caribbean Sea between the Lesser Antilles Arc and the Barbados Accretionary Prism. The basin is bound on the north by the St Lucia Ridge and to south by the Araya-Tobago metamorphic basement of the Araya Peninsula, Venezuela and the Northern Range, Trinidad. It holds up to 14 km of Cenozoic sedimentary fill with thick sequences of Mio-Pliocene sediments.

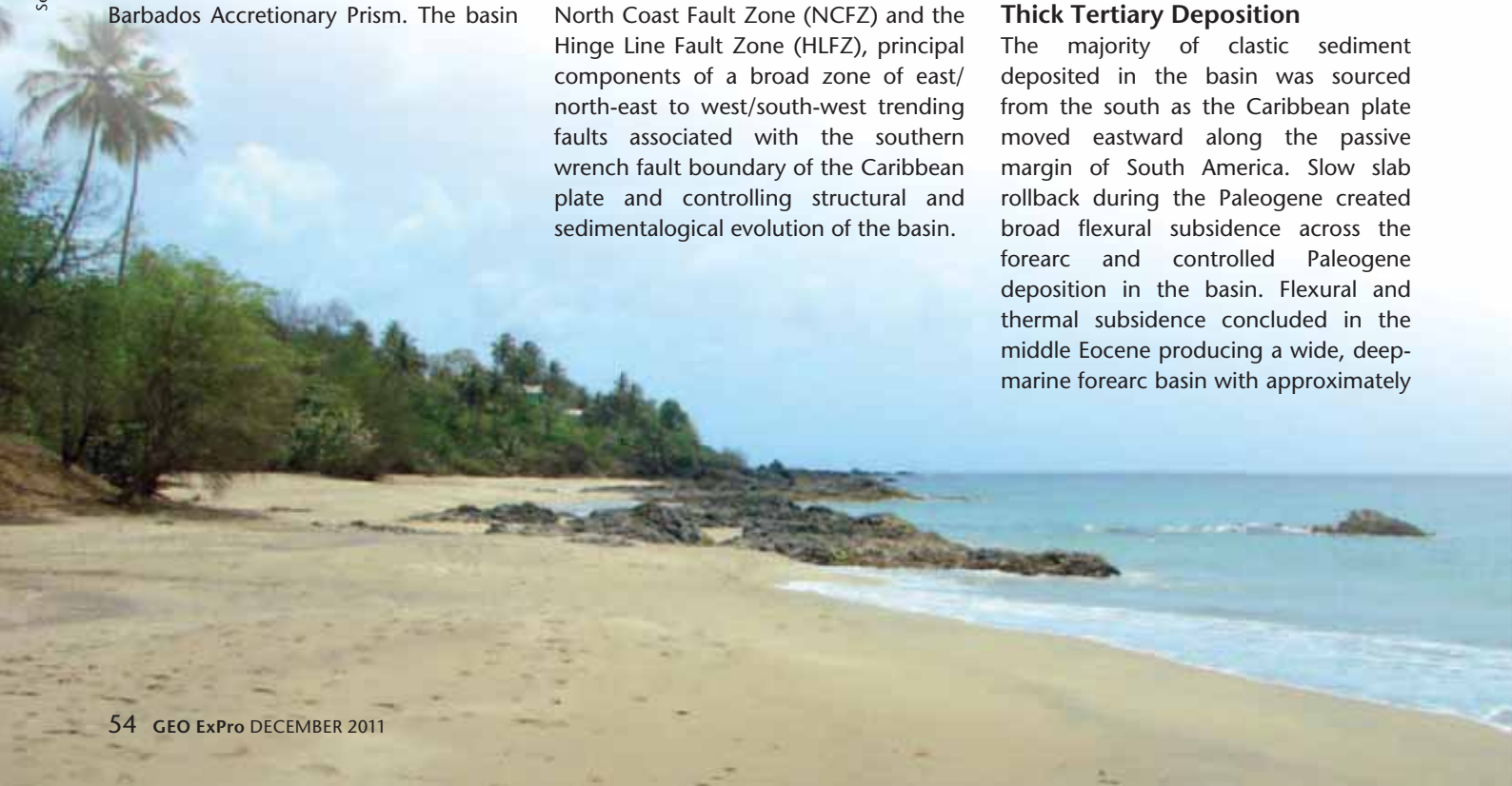
The basin formed through an initial phase of oblique collision tectonics between the Caribbean Arc and South American continent and evolution to an oblique transform margin with transpressional tectonics governing the Paleogene and transtensional tectonics dominating the Neogene. The age and origin of the basin's basement is unknown, but evidence suggests that it is Late Cretaceous and of arc affinity.

Predominant structural features in the southern Tobago Basin are the North Coast Fault Zone (NCFZ) and the Hinge Line Fault Zone (HLFZ), principal components of a broad zone of east/north-east to west/south-west trending faults associated with the southern wrench fault boundary of the Caribbean plate and controlling structural and sedimentalogical evolution of the basin.

The approximately 135 km long HLFZ is a right-lateral strike-slip fault running north-east to south-west, dipping steeply to the north-north-west, and with a component of dip-slip displacement down to the south in the west and to the north in the east. The HLFZ defines a structural and bathymetric break between the shelf to the south and the deepwater Tobago Basin to the north, and possibly coincides with a major tectonic terrain boundary separating the northern edge of the Caribbean arc from thinner, oceanic basement underlying the basin to the north (Robertson and Burke, 1989). Distal to the HLFZ the basement steepens rapidly northwards. Basement faulting along the HLFZ remains active and cuts the overlying Neogene section.

## Thick Tertiary Deposition

The majority of clastic sediment deposited in the basin was sourced from the south as the Caribbean plate moved eastward along the passive margin of South America. Slow slab rollback during the Paleogene created broad flexural subsidence across the forearc and controlled Paleogene deposition in the basin. Flexural and thermal subsidence concluded in the middle Eocene producing a wide, deep-marine forearc basin with approximately

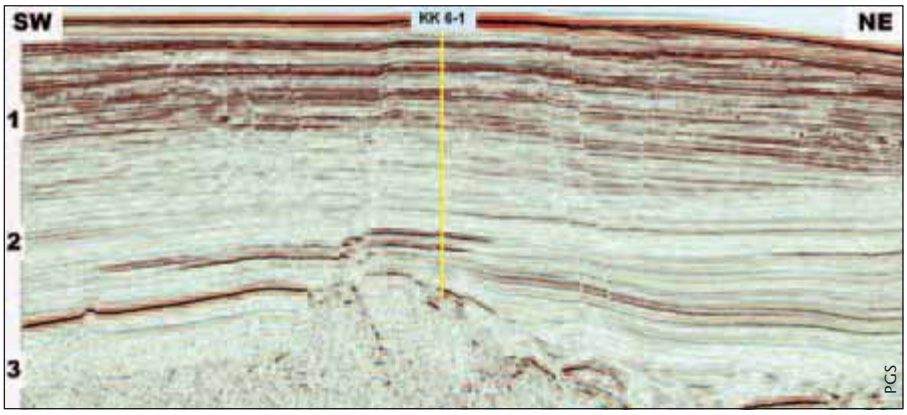


Sergio Leenan

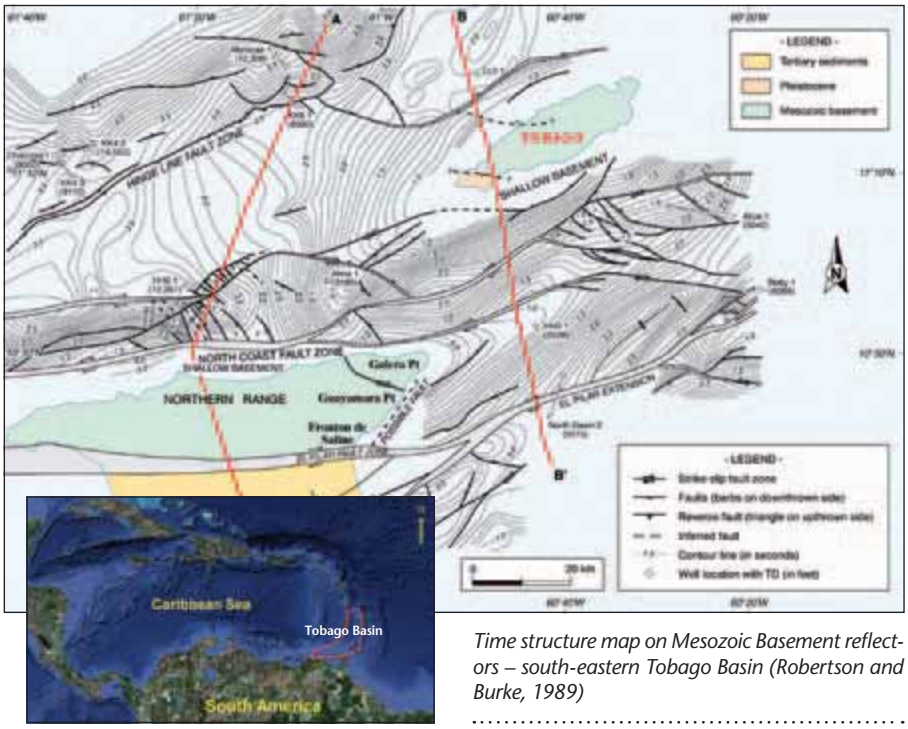
8 km of Paleogene sedimentary fill of predominately deep-marine pelagic shales and siltstones and deepwater turbiditic sandstones (Aitken, 2005).

Steady eastward advancement of the Caribbean plate brought it to oblique convergence with the South American plate during the Late Oligocene to Middle Miocene. Outcrop and well data indicate continued deep-marine sedimentation dominated by turbidites in the Early to Middle Miocene when abrupt regional shallowing of clastic facies culminated in the Middle Miocene unconformity. Sedimentary infilling of the Tobago Basin's southern shelf and slope began in the Early Miocene with conglomerates and sandstones up to 900m thick unconformably infilling lows between structural highs defined by the NCFZ and HLFZ. In areas of paleo-highs, conglomerates are absent and sands and shales lie directly on basement. Clinoforms in the basin indicate north-north-east progradation of the distal Proto-Orinoco delta in response to forced regression during Miocene uplift of the Northern Range in Trinidad and the Paria Peninsula in Venezuela (Robertson and Burke, 1989). Sediment thickness of the early Neogene section below the Middle Miocene unconformity is approximately 3.5 km.

Upper Miocene deposition is characterized by diffuse transtensional tectonics with Upper Miocene and Lower Pliocene sediments downlapping onto the Middle Miocene unconformity as the depocenter in the basin shifted to the south-south-east due to increased Proto-Orinoco sediment influx. Transtensional, oblique strike-slip motion along both the NCFZ and HLFZ increased accommodation on the shelf through the late Pleistocene, allowing deposition of thick sequences of Miocene and Pliocene clastics south of and across the Patao High and Tobago Arch. Pliocene sediments deposited along the shelf and slope of the Tobago Basin are predominantly silty claystones with thin interbeds of fine-grained sandstones, conformably overlying Top Miocene and reaching thicknesses of ~1,200m. Pleistocene sediments are primarily shales with interbeds of deltaic sands and reefal limestone conformably overlying Top Pliocene. Sediment thickness above the Middle Miocene unconformity is approximately 3.5 km.




*Seismic section through KK 6-1, the discovery well for the Patao-KK biogenic gas trend*




*Time structure map on Mesozoic Basement reflectors – south-eastern Tobago Basin (Robertson and Burke, 1989)*

## Patao-KK Biogenic Gas System

Most hydrocarbon reservoirs offshore Trinidad and Tobago are found in Tertiary shelf and shelf-edge deltaic depositional systems and the Patao-KK fields are no exception. Reservoir, trap, and seal for the Patao-KK petroleum system reside within the Upper Miocene and Lower Pliocene progradational shelf and shelf edge deltaic depositional systems of the Tres Puntas and overlying Cubagua formations. These sediments were deposited within actively deforming basins in shallow marine settings along the northern margin of South America.

Patao-KK gas is very dry (>98% methane) and assumed to be either autochthonously sourced from prodeltaic mudstones coeval with Mio-Pliocene reservoir units (Schenk, 2000) or the product of anaerobic bacterial decomposition of thermogenically derived hydrocarbons sourced from deeper in the Tobago Basin. Condensate production, higher in Patao-KK fields nearest the shallowing basin axis in Venezuela, confirms at the least a thermogenic system functioning in the deeper Tobago Basin. Reservoirs are Upper Miocene to Lower Pliocene fine-grained deltaic sandstones and siltstones with porosities ranging from 13–29% and permeabilities ranging from 10–1,100 mD. These sands are highly unconsolidated with interstitial clays and interbedded shales. Some reservoirs within the Mariscal Sucre field are rumored to be turbiditic sandstones.

If autochthonously sourced, hydrocarbon migration occurs from underlying mudstones into sandstone reservoirs and updip into structural and combination

traps developed along the HLFZ. Vertical migration along faults is observed, often charging Pleistocene sands. Seals in the play are formed by intraformational argillites and shales.

## Discovery – and Revival

Geophysical surveys first commenced in the southern Tobago Basin offshore north coast Trinidad in the late 1960s and continued into the early 1970s when operators were first granted exploration concessions.

With structurally conforming bright amplitudes in Mio-Pliocene sands along the HLFZ as a road map, Deminex GmbH followed their 1971 KK 6-1 (Orchid) discovery in 1975 with NFW KK 4-2 drilled on a broad, faulted anticline establishing the Poinsettia Field. Looking east again, Deminex drilled the NFW LL 9-1 just off the north shore of Tobago in early 1976, testing dry gas in Pleistocene sands as well as Mio-Pliocene reservoirs. The Chaconia field was discovered by TRINTOC in early 1981, followed by Hibiscus later that year. All Patao-KK field discoveries in Venezuela were made by PDVSA between 1979 and 1981.

BG Group, AGIP and VEBA signed a unitization agreement with Petrotrin in 2000 to jointly develop the Chaconia, Hibiscus, and Poinsettia fields. The unit's sole production platform was constructed on Hibiscus in 2001 jointly with a 100 km pipeline to Point Fortin on the west coast of Trinidad. The Hibiscus platform began production in August 2002 and currently supplies 365 MMscfpd to local LNG trains (BG Group, 2011). The Orchid and LL 9-1 (Iris) fields remain undeveloped and within the recently assigned NCMA-4 concession.

After years of delays and several consortiums later, PDVSA is currently drilling development wells in Mariscal Sucre and profess plans to bring these fields on-line in the near future.

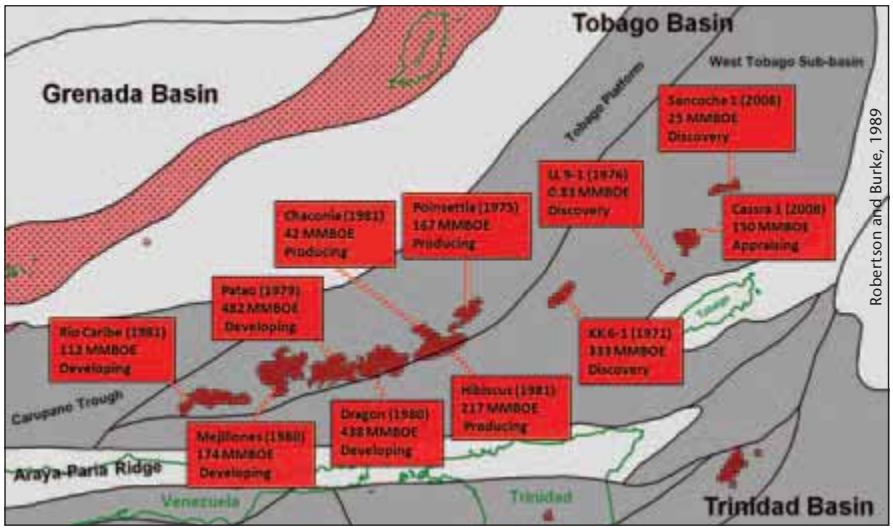
Decades after all the original Patao-KK discoveries were realized, Petro-Canada discovered the Cassra and Sancoche fields in 2008, extending the Patao-KK biogenic gas play north-eastward with what appear to be gentle combination traps unrelated to traditional structural mechanisms of the HLFZ. Cassra is currently under appraisal.

## A Fork in the Road?

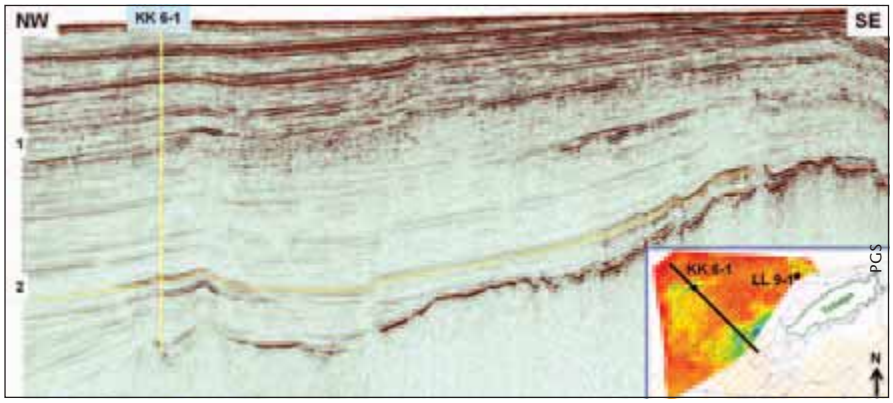
Although the established trend of commercial Patao-KK discoveries parallel and are north of the HLFZ, 2009 2D seismic indicates that charged Mio-Pliocene reservoirs exist updip from the HLFZ in combination traps associated with strike-slip faults within the NCFZ.

Comprehensive 2009 2D seismic coverage of the deeper West Tobago Basin and Tobago Platform suggest Mio-Pliocene reservoirs exist along the Tobago Ridge north-east of the island, and extending northward from Sancoche into the deeper Tobago Basin.

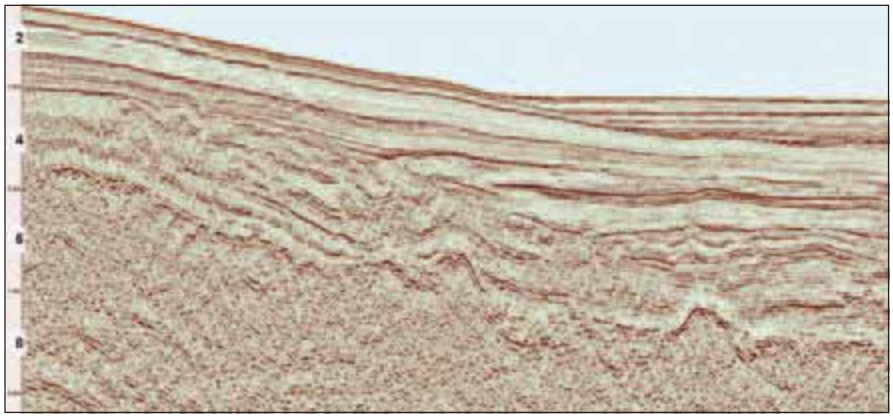
Although elusive to date, the quest to establish a commercially viable thermogenic petroleum system in the under-explored Tobago Basin persists. Given the structural and sedimentological disposition of the deeper basin, there is reason to be optimistic. ■




*Established Patao-KK gas fields (2P RRE from IHS 2011)*




*Seismic shot in 2009 indicates that charged Mio-Pliocene reservoirs exist updip from the HLFZ (Upper KK 6-1 Reservoir with VATRMS +/- 0.05s)*



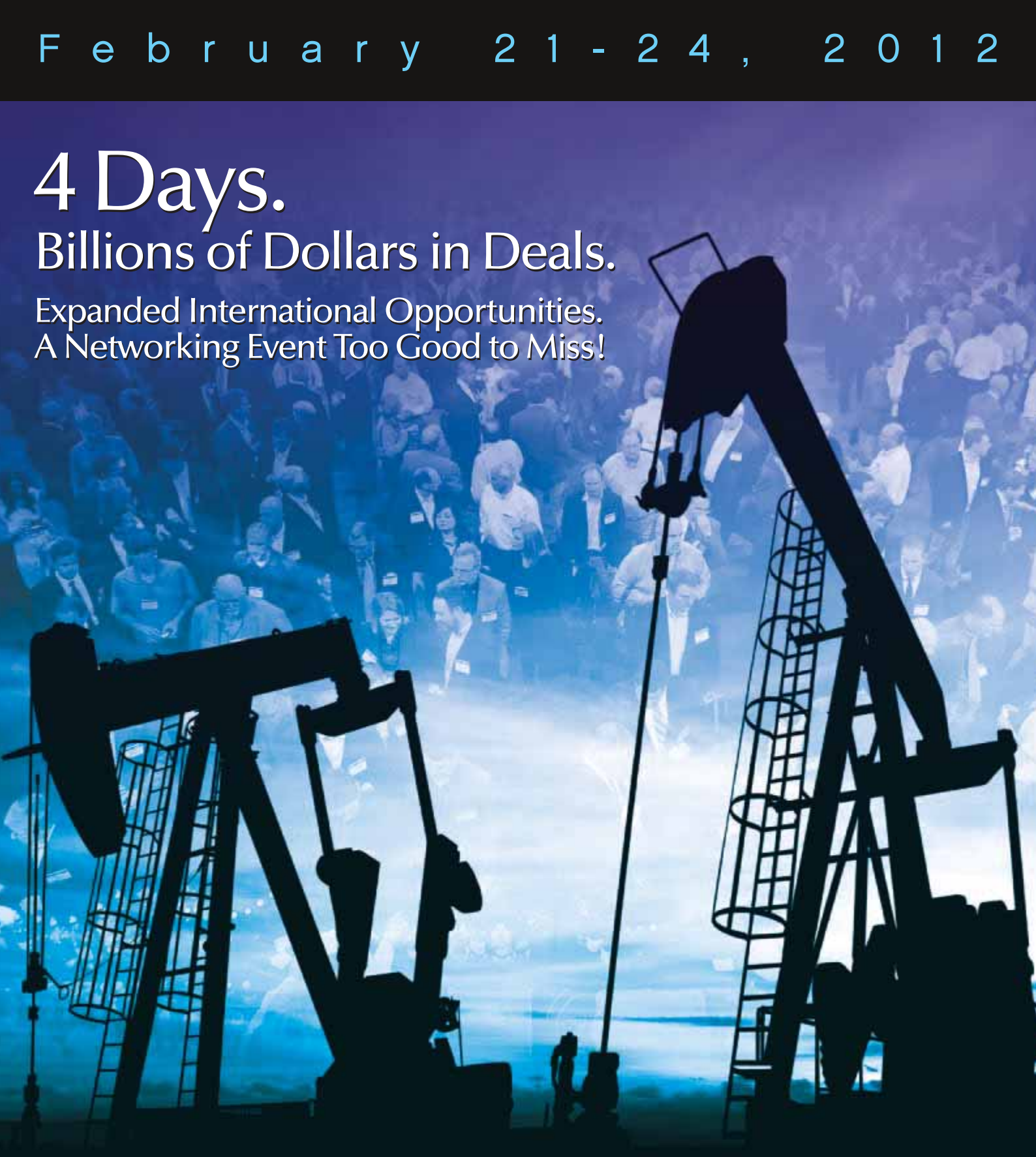

*Dip seismic section Tobago Basin, Trinidad and Tobago.*

February 21-24, 2012

# 4 Days.

## Billions of Dollars in Deals.

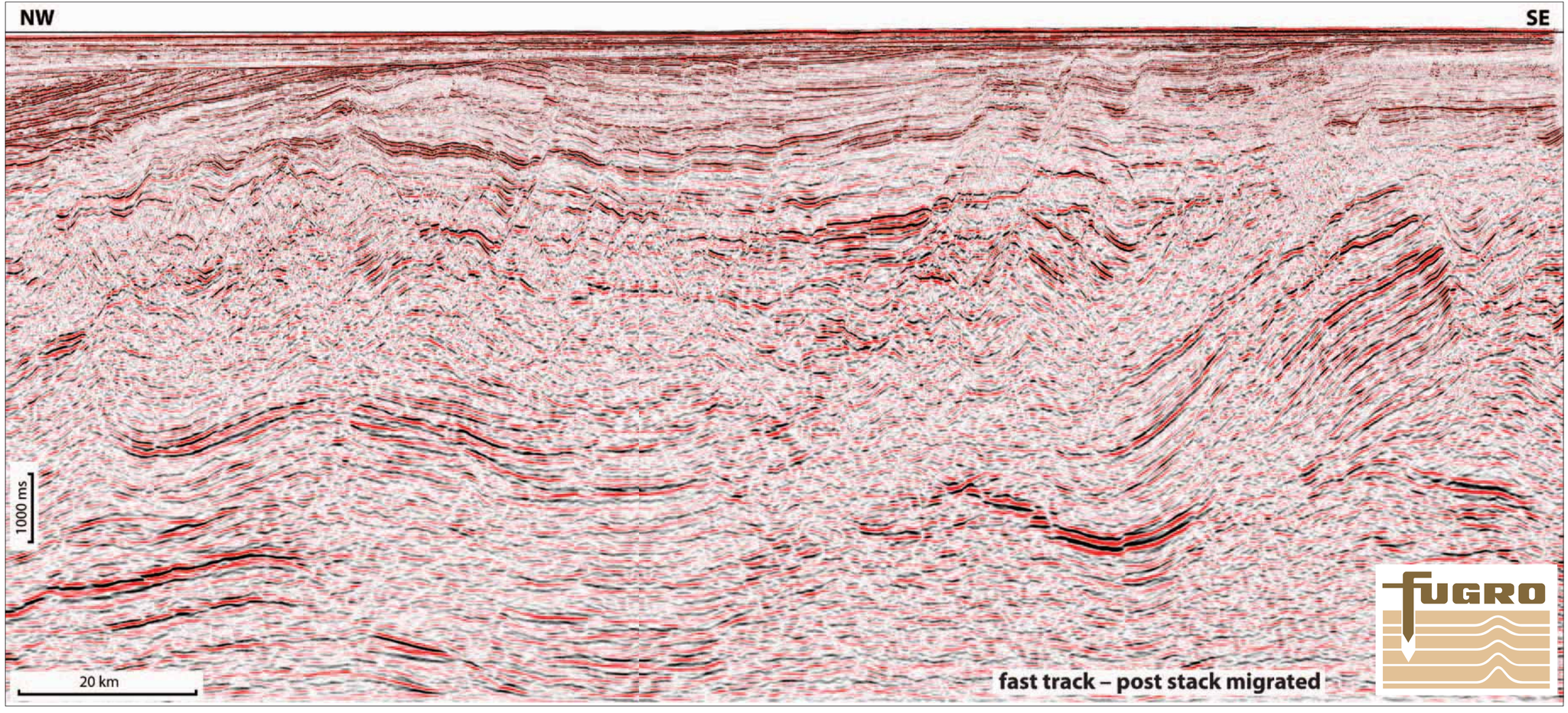
Expanded International Opportunities.
A Networking Event Too Good to Miss!

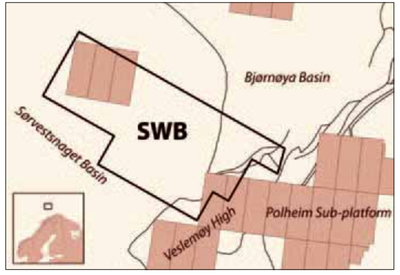


NAPE EXPO

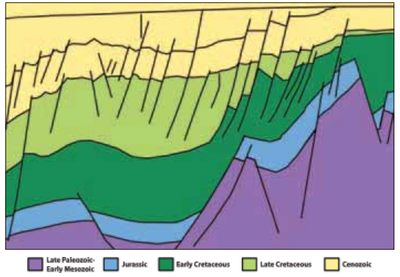
www.napeexpo.com

# South West Barents Sea: Complex Structuring and Hydrocarbon Migration Revealed by Regional Multiclient 3D




*Survey area superimposed on the main structural elements and license situation of the western Barents Sea.*




*Geoseismic representation of an inline within the South West Barents Sea fast track – post stack migrated cube*

*The multiclient 3D fast track – post stack migrated cube dataset from the South West Barents Sea (SWB) considerably improves the seismic imaging of the deep basin in the western Barents Sea and opens up new and promising opportunities for hydrocarbon exploration. The SWB 3D dataset covers the outer part of the Bjørnøya Basin and the northern part of the Sørvestsnaget Basin. The main targets within the South West Barents Sea are a large Middle Jurassic fault-assisted three-way closure and Late Cretaceous-Middle Eocene submarine fan deposits that form significant reservoir sandstones in the Sørvestsnaget Basin. The SWB data was acquired using a cable length of 8,100m, enabling very good imaging down to 10 seconds.*

# South West Barents Sea: The Next Hydrocarbon Frontier

Three hydrocarbon plays and considerable potential are identified by the South West Barents Sea (SWB) dataset

OLAV A. BLAICH AND GUSTAV A. ERSDAL, Fugro Multi Client Services

The April 2011 Skrugard well (7220/8-1) marks an explorational breakthrough for frontier exploration in the south-western Barents Sea, improving the understanding of the prospectivity of the area and increasing the optimism for this remote area of Norway, which lies within the Arctic Circle. As the 22nd Norwegian licensing round approaches, the south-western Barents Sea remains the focus area for the oil and gas industry. The improved seismic imaging of the deep basin in the western Barents Sea, in combination with fresh discoveries, opens up new and promising opportunities for hydrocarbon exploration.

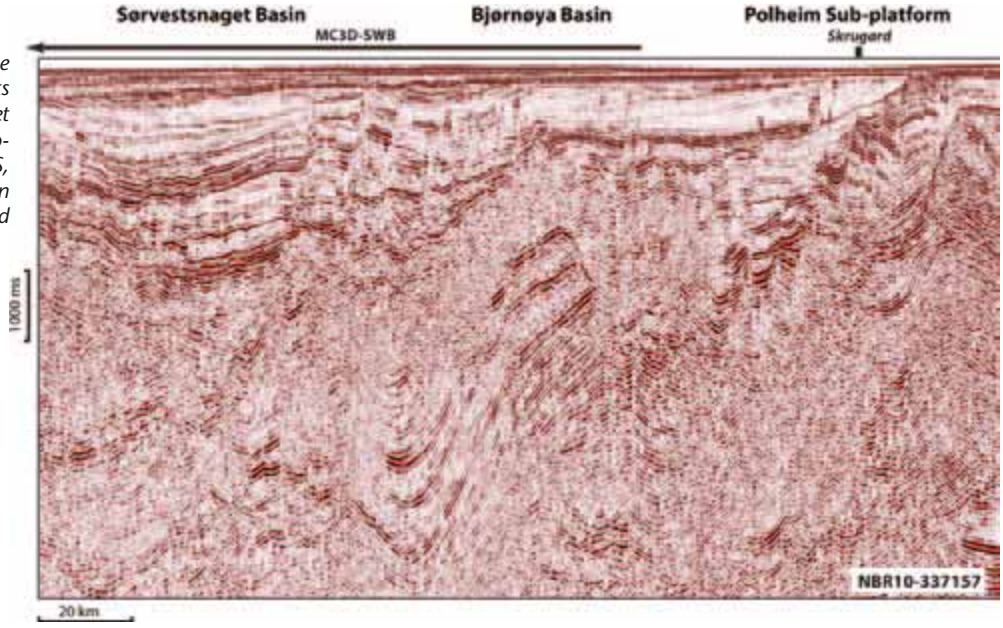
The multiclient 3D SWB dataset covers the outer part of the Bjørnøya Basin and the northern part of the Sørvestsnaget Basin. The main targets within the SWB area are a large Middle Jurassic fault-assisted three-way closure and Late Cretaceous-Middle Eocene submarine fan deposits that form significant reservoir sandstones in the Sørvestsnaget Basin. Late Cretaceous-Middle Eocene sand deposits occur in both rotated fault blocks and stratigraphic traps.

## Hydrocarbon Potential

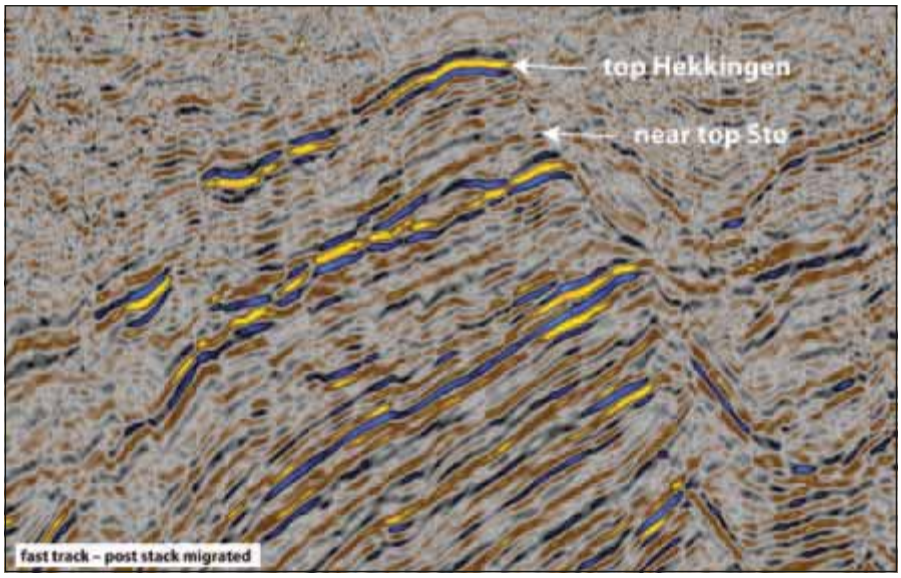
Petroleum systems related to the Late Jurassic (Hekkingen) source rock are considered to be dominant in the south-western Barents Sea. In the more deeply buried Tromsø and Bjørnøya Basins, the Late Jurassic source rock is oil-mature along the basin margins. Below the thick Cretaceous strata within the Bjørnøya and Sørvestsnaget Basins, the Late Jurassic source rocks have most likely been through the oil window in the Late Cretaceous or early Cenozoic. Later tectonic events (from Paleocene until Pliocene-Pleistocene) have caused the redistribution of oil and gas over laterally large distances, thus charging traps (e.g. Mid Eocene) which otherwise would not have been reached (Ohm *et al.*, 2008). The large 3D dataset provides the best tool to map and understand regional migration and re-migration patterns.

Source rock intervals with high organic content have been recognized within shales of the Early Cretaceous (Barremian) Kolje Formation in several wells in the south-western Barents Sea (e.g. 7120/7-1, 7321/9-1). The Barremian sediments achieve full oil or gas maturity within the Tromsø, Bjørnøya and Sørvestsnaget Basins, giving the potential for charging traps within the SWB area.

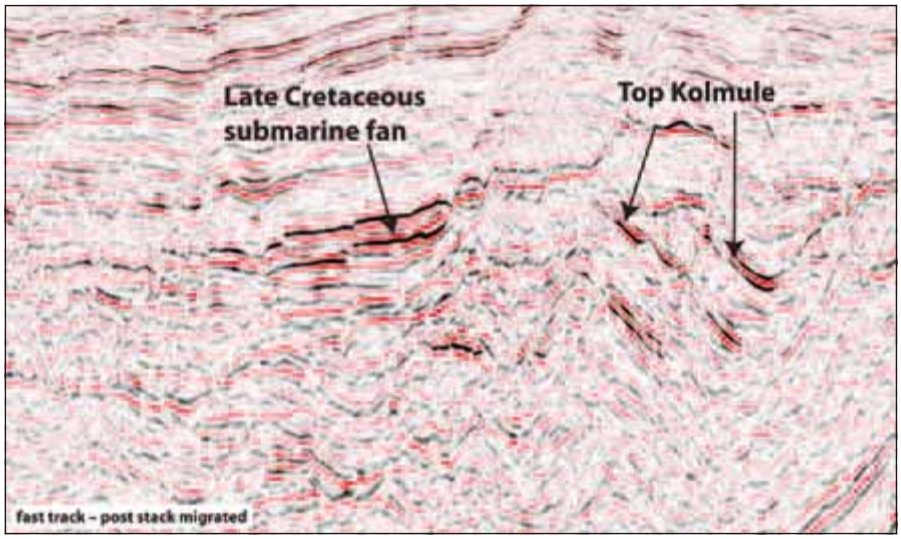
The Vestbakken Volcanic Province and the northern part of the Sørvestsnaget Basin formed in a pull-apart setting related to the releasing bend at the margin during Late Cretaceous/Early Cenozoic times, resulting in extensional faulting and local depocentre (e.g., Faleide *et al.*, 1991). In this regime, lacustrine/restricted marine facies are suggested, and under such conditions sediments with source rock potential often develop (Rasmussen *et al.*, 1995). Local untested source rock may have been formed in this setting, charging the Mid Eocene play. ■



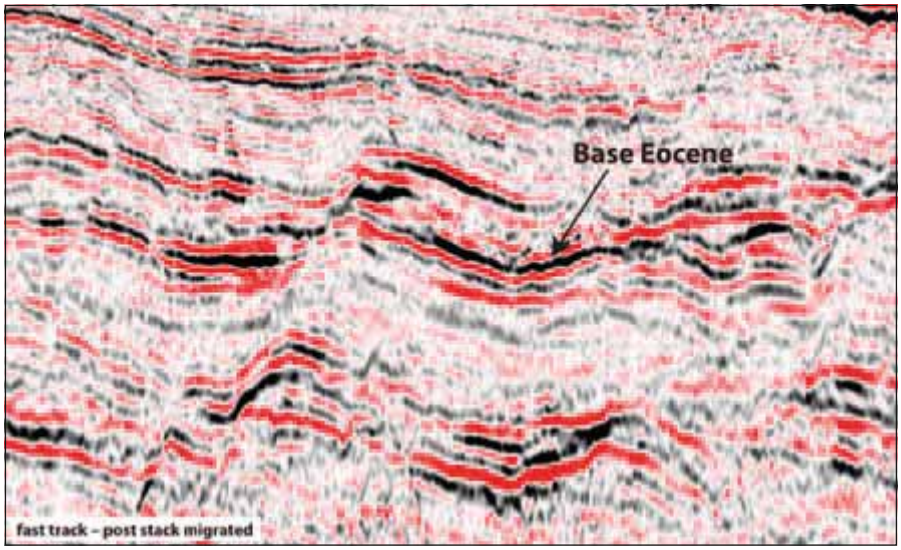

*2D seismic example of the long-offset Norwegian Barents Sea Regional survey dataset (NBR) acquired by Fugro in co-operation with partner TGS, showing the relation between the SWB 3D and the Skrugard oil discovery.*




***Jurassic Play**: Fluvial and deltaic conditions prevailed through the Early Jurassic times, resulting in the deposition of sand rich reservoirs in the Fruholmen, Tubåen and Nordmela Formations. A major change in reservoir facies occurs towards the Middle Jurassic, when marine transgression led to a dominantly shallow marine shelfal facies. Reservoirs in this interval (Stø Formation) represent the most prolific reservoirs in the entire Barents Sea region. This seismic example from the SWB dataset shows a robust fault-assisted three-way closure covering more than 100 km$^2$ and comprising Jurassic and Early Cretaceous Strata. High seismic amplitudes and a flat event associated with the Stø Formation are observed within the structure.*




***Cretaceous Play**: Early Cretaceous section locally contains well developed sandstones deposited as a series of mass flows and turbidites into a relatively deepwater depositional setting (Knurr Formation). The sandstones derived from erosion of basin margin highs (e.g. Loppa High), and consist of reworked Jurassic and Triassic sandstones. The new SWB 3D dataset show similar fan bodies within the Late Cretaceous section that form large depositional systems characterized by high seismic amplitudes. These untested deposits also appear to derive from erosional reworking of basin margin highs. The line shows Late Cretaceous submarine fan deposits which have been affected by Late Cretaceous/ Early Cenozoic structuring, forming robust fault-assisted closures.*




***Cenozoic Play**: The Stappen High was uplifted during the Cenozoic due to tectonism and volcanism, acting as a regional high on the Western Barents Shelf (e.g., Faleide et al., 2003). The Stappen High played an important role as a provenance area for sand deposits to the surrounding basins. In particular, well developed seismic clinoforms are observed in the northern part of the Sørvestsnaget Basin, indicating south to south-westwards progradation of shorelines from the Sappen High during Middle and Late Eocene times. The Middle Eocene gravity-driven deposits in submarine fan and high-density turbidites form the most significant reservoir sandstones in the Sørvestsnaget Basin, and consist most probably of reworked Early Jurassic sandstones eroded from the uplifted Stappen High. Based on the excellent quality of the fast track – post stack migrated dataset, numerous rotated fault-blocks can be mapped out, forming robust structural traps for Mid Eocene sandstones. As shown on this inline, these elongated rotated fault-blocks extend throughout the SWB and reveal DHIs in the Eocene strata.*

# CALL FOR PAPERS

## THE 11TH HGS-PESGB CONFERENCE ON AFRICAN E&P

***Africa: Continent of Discoveries***

**September 11-12, 2012**
The Westin, Memorial City
945 Gessner Road
Houston, Texas 77024 USA

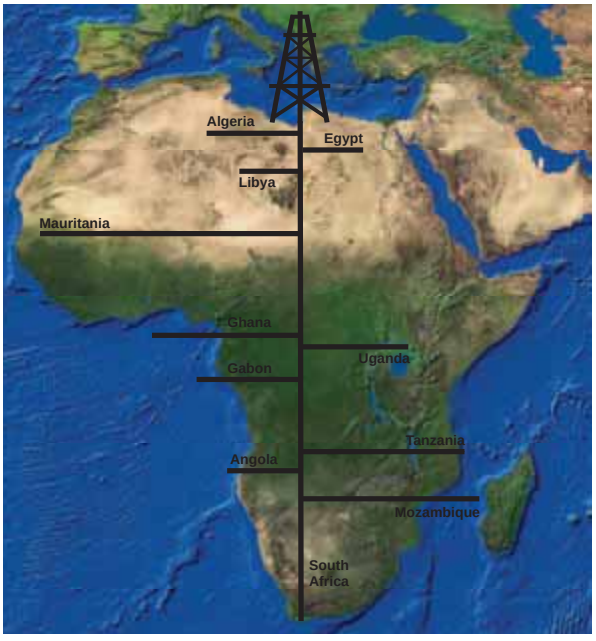
This conference, the primary technical E&P conference on Africa, will be held on September 11-12, 2012 in Houston, Texas USA. A program of talks, technical posters and vendor exhibits will be presented. The conference series, organized by the Houston Geological Society (HGS) and Petroleum Exploration Society of Great Britain (PESGB) covers all aspects of African E&P, with particular emphasis on new ideas for plays and prospects, the geology of the continent and its conjugate margins, and application of emerging technologies.

Short abstracts should be submitted as soon as possible and no later than March 16, 2012 to the technical committee, africa2012@hgs.org. The program will be finalized by end April.

Extended abstracts and information on the sponsors will be included in the conference CD and proceeding.

To become a sponsor or enquire about exhibit space, contact lucyplant@hgs.org or sandra@hgs.org

Early bird registration will be available from April 2012. Further details will appear in the HGS and PESGB bulletins and websites.




Conference Committee for 2012: Al Danforth, Ian Poyntz, Martin Cassidy, Justin Vandenbrink, Lucy Plant and Claudia Lopez (HGS), Ray Bate, Richard Dixon and Duncan Macgregor (PESGB).

NASA/JPL

## Promising Giant New Hydrocarbon Frontier:

# The Namibian Continental Margin

New geochemical data reveal similar petroleum systems to those found in the prolific sub-salt off Africa and Brazil and significant potential for Namibia's offshore basins

*Off Namibia's Skeleton Coast and west of a barren, dune-covered landscape lie undrilled prospects that could hold billions of barrels of oil. This space-borne radar image of the west coast of southern Africa shows the Namib Sand Sea in magenta while the orange colors depict the surface of the South Atlantic.*

**MARCIO ROCHA MELLO, NILO AZAMBUJA, WEBSTER MOHRIAK, ANTONIO CATTO, JOÃO FRANÇOLIN; HRT**

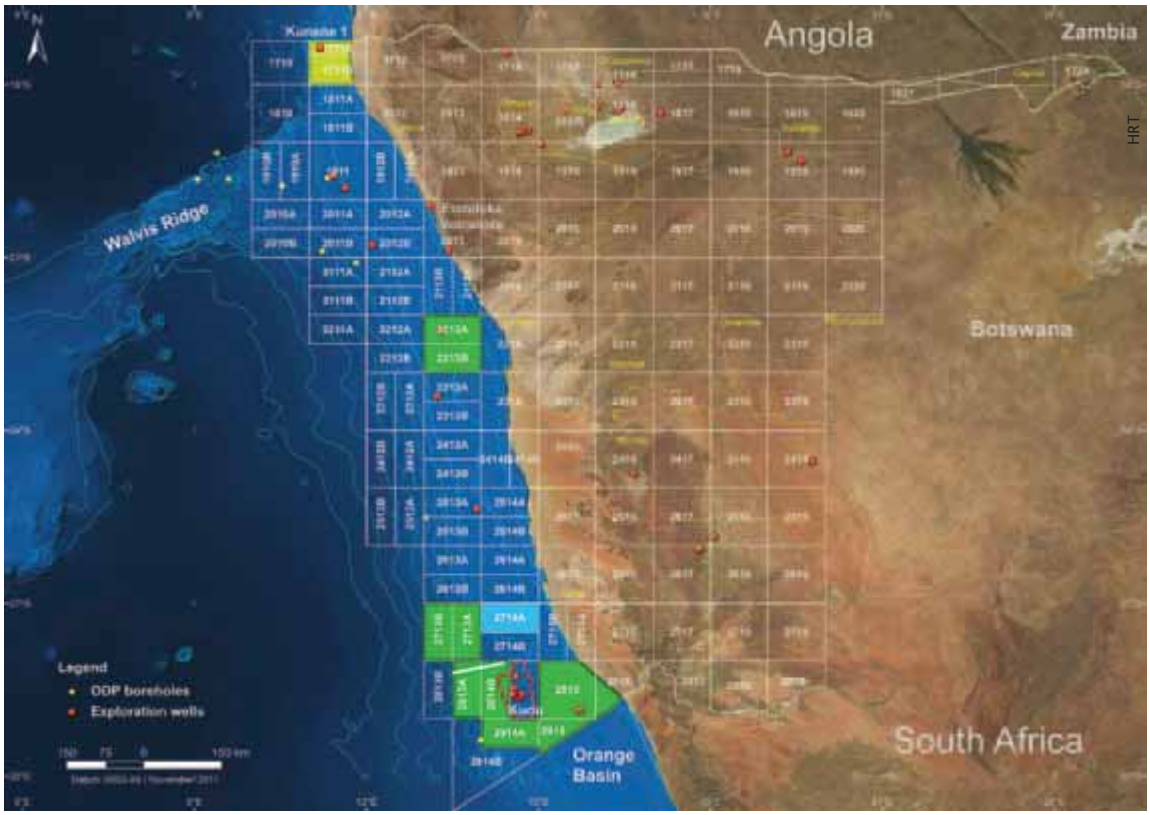
Recent discoveries in the Brazilian margin have highlighted the importance of the pre-salt lacustrine petroleum system extending along the margins of the South Atlantic Ocean. The Namibian continental margin is characterized by lack of salt in the transition from continental to marine environments. However, geochemical data from hydrocarbons recovered from the Kudu and 2815/15-01 wells in the Orange Basin indicate the presence of oil types similar to the ones that are present in the salt basins north of the Walvis Ridge and its conjugate Greater Campos Basin. Consequently, they share similar source rock systems.

Since gaining political independence from South Africa in 1990, the Namibian government has pursued free-market principles to promote commercial development of their resources. According to Isak Katali, Minister of Mines and Energy, "Considerable offshore data acquisition and studies have finally identified the location of drillable targets… and the country has to prepare itself for rigorous drilling activities in the oil and gas exploration sector starting November this year (2011)."

### Exploration History

The Namibian continental margin is located south of the Walvis Ridge and has been considered a frontier region for oil exploration since the first wildcat, Kudu 9A-1, was drilled in Block 2814A by Chevron in 1974. This successful borehole discovered a large hydrocarbon accumulation (gas reserves between 1.3 and 3.0 TCF) in Lower Cretaceous sandstones intercalated with volcanic layers.

The Kudu Field lies 130 km from the coastline between Namibia and South Africa in bathymetry less than 200m. Here, aeolian sands constitute the reservoir rocks, which occur at a depth of 4,400m, interbedded with volcanic rocks. The sediments and basalts are

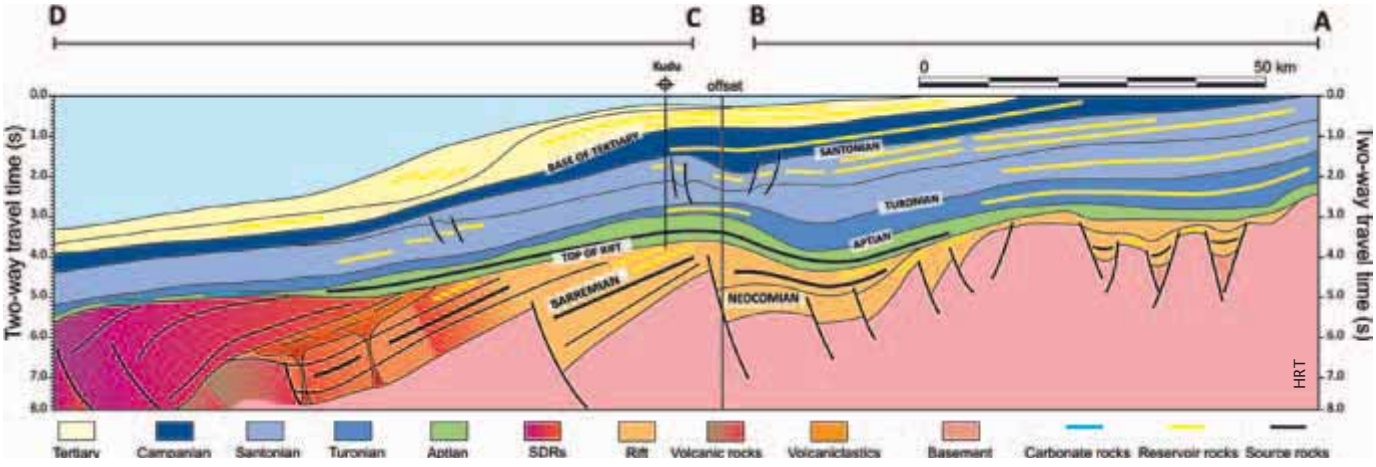


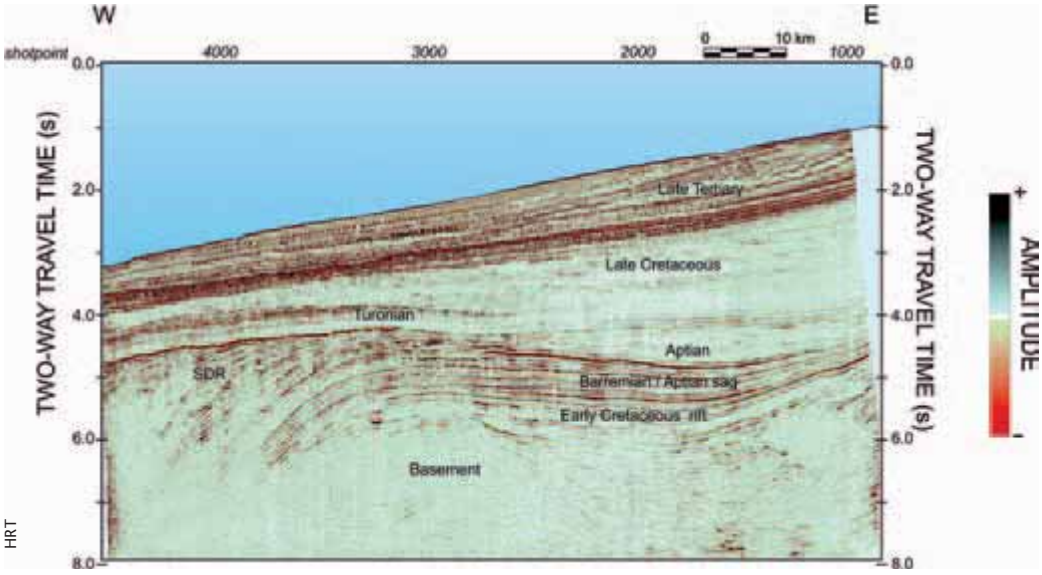

*Satellite image of the Namibian margin with bathymetry, major structural elements and the location of exploratory blocks. Borehole Kunene-1 is located in Block 1711 (north of the Walvis Ridge). The location of a regional seismic profile extending from Blocks 2813 to 2814 (NW of Kudu) is shown as a white line. Operators for some of the offshore blocks: yellow – Energulf; green – HRT; blue – Petrobras.*

dated as Barremian (about 120 Ma), slightly younger than the Etendeka volcanics onshore Namibia (or the Serra Geral flood basalts in the Paraná Basin, Brazil). Seaward-dipping reflector wedges with volcanic layers occur basinwards of a marginal ridge in deep waters. There are multiple reservoirs in the Kudu Field with thickness around 50m and porosity of 12%. The gas accumulation has been evaluated by several appraisal wells but still remains undeveloped.

Since the Kudu discovery, only 14 wells have been drilled offshore; seven of those on the Kudu structure. The remaining exploratory wells failed to find commercial accumulations. Some, however, encountered oil and gas shows in Albian and Aptian reservoirs, as for example, the Walvis Basin boreholes drilled by Norsk Hydro in Block 1911. Up to now, only three boreholes have been drilled in deep water: one by Sasol in 1995, one by Norsk Hydro in 1998, and the Kunene well drilled by Sintezneftegas Namibia in 2008, all of them shallower than 700m. Other companies with past exploration activity offshore Namibia include Arcadia, Enigma, Pancontinental, Ranger, Sasol, Chevron, Shell and BHP. In recent years, HRT, Petrobras, and BP have been active in the area, attracted by the similarities


*Schematic geological section in the Namibian continental margin, composed of two regional seismic profiles, showing the location of the Kudu Field and the architecture of the Orange Basin.*






*Regional seismic profile extending from Blocks 2813 and 2814 (NW of Kudu), illustrating the basement high which separates the seaward-dipping reflectors (volcanic wedges) from the Barremian/Aptian sag basin that overlies Early Cretaceous rift sediments. Aptian sediments extend toward the marginal ridge, where carbonate rocks (microbiolites) possibly occur on top of a volcanic high. Turonian turbidite reservoirs conformably overlie the outer high and are covered by Late Cretaceous to Late Tertiary successions. The latter sequence is characterized by prograding wedges and local slope-toe thrusts.*

of tectonic evolution and petroleum systems for the basins formed during the Gondwana breakup in the Mesozoic.

## Geochemical Basin Comparison

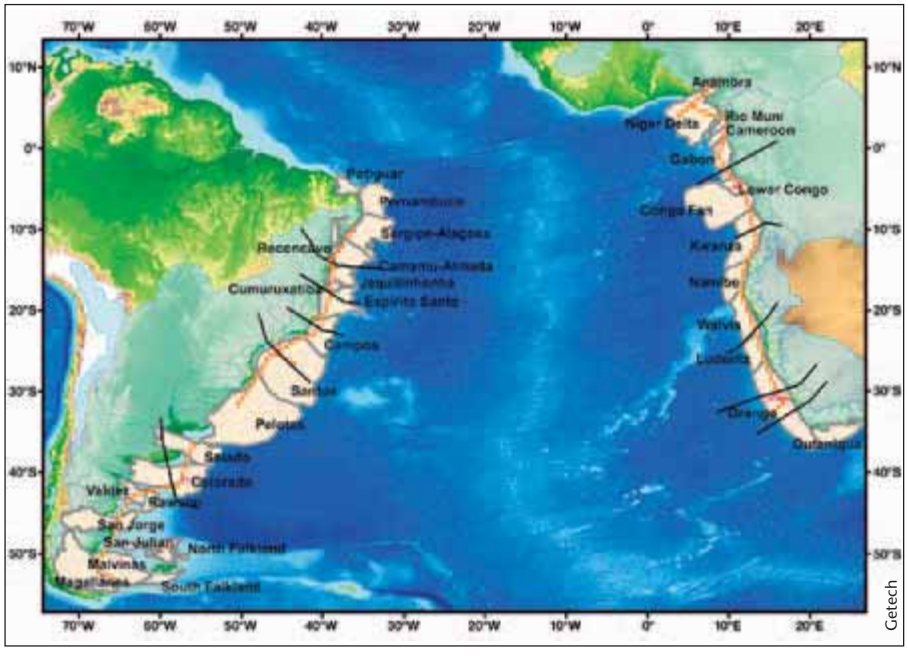
Plate reconstructions are very important to define regions with equivalent tectonic elements. In terms of exploratory plays, the explorationists aim to predict situations where one recognized prospect, such as the Tupi (now known as Lula) pre-salt discovery offshore Brazil, should be investigated on the other side of the ocean along the conjugate margin. This also implies that a reasonable fit between conjugate segments of the margins would conform to other stratigraphic, structural and geochemical constraints for specific situations.

Past reconstructions have used various mathematical fittings which resulted in unrealistic gaps from north to south and possibly missing key paleoenvironmental links. HRT Oil and Gas geoscientists have applied a new approach in conjugate basin comparisons based on high resolution biomarkers and compound specific isotope similarities between condensates from the Kudu and 2815/15-01 wells and oil and condensate samples from boreholes drilled along the Espirito Santo, Campos, and Santos margin. These geochemical components suggest that the lacustrine and marine source rocks that are extremely prolific in the Brazilian margin north of the Florianópolis Fracture Zone/Rio Grande Rise (and north of the Walvis Ridge) might also occur south of these tectonic elements, in deep water regions offshore Namibia. Aptian source rocks in Kudu wells may reach up to 3% in total organic carbon, whereas the occurrence of very rich Cenomanian to Santonian type II kerogen source rock intervals (up to 6% TOC) are reported in the boreholes drilled in Block 1911 (Walvis Basin).

The integration of biological markers and high resolution geochemical data from oils and condensate recovered from the exploratory boreholes offshore Namibia indicates two oil systems in the basin. One is characterized by black oils, in the early oil window stage, sourced by Albian-Cenomanian, marine calcareous mudstones. The second is characterized by highly cracked, very mature oils and condensates sourced by a lacustrine saline, alkaline, calcareous black shale deposited in a lacustrine brackish to saline anoxic depositional environment. Both of these oil types are recognized in the Brazilian margin north of the Rio Grande Rise (Greater Campos Basin), with the lacustrine Aptian/Barremian petroleum system responsible for 90% of the oil generated. The marine Albian/Cenomanian petroleum system has been identified from only a few wells in the south-eastern Brazilian margin.

The implication here is that simply matching conjugate margin basins, for example the Pelotas Basin off Brazil, with the Orange Basin off Namibia, does not

*South Atlantic conjugate margin basins*




## ION. Creating unique answers to the industry's greatest challenges.

To overcome the safety and efficiency challenges associated with 4D marine seismic acquisition, ION collaborated with a major oil company to develop a cost-effective solution. By leveraging a unique combination of ION marine acquisition technologies and acquisition optimization services, the client achieved over 20% infill reduction while exceeding repeatability requirements for the survey. Whether you are sizing up the prospectivity of a frontier basin or looking to extract maximum value from a mature reservoir, look to ION for breakthrough innovations that help you achieve your most ambitious objectives. iongeo.com

AREAS OF EXPERTISE

Unconventional Reservoirs

Challenging Environments

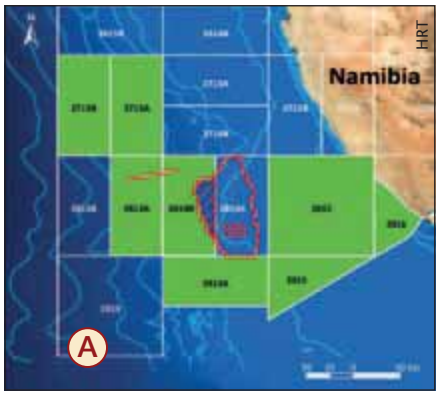
Complex Geologies

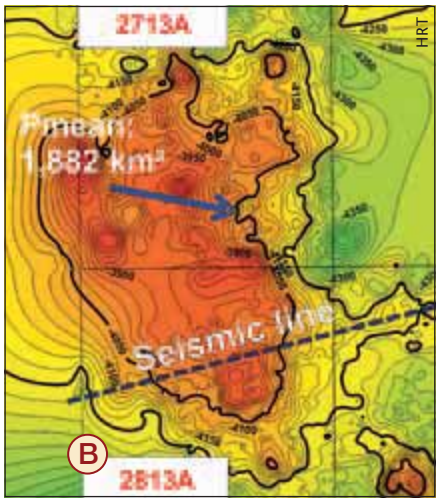
Basin Exploration

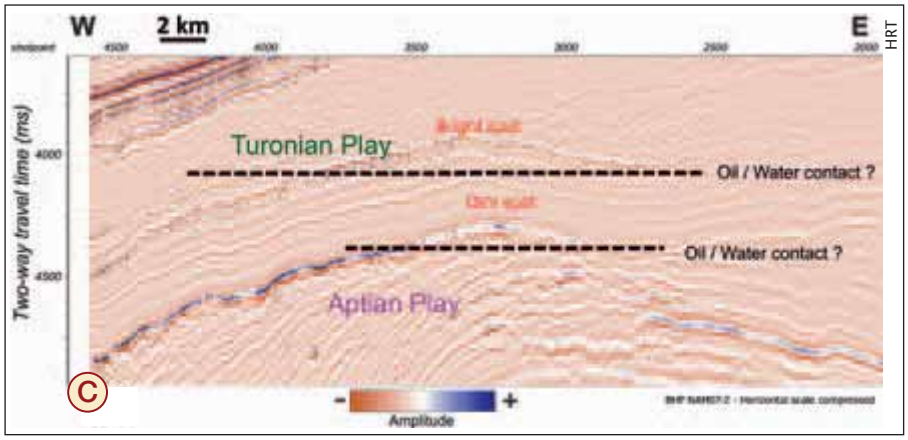
Reservoir Exploitation

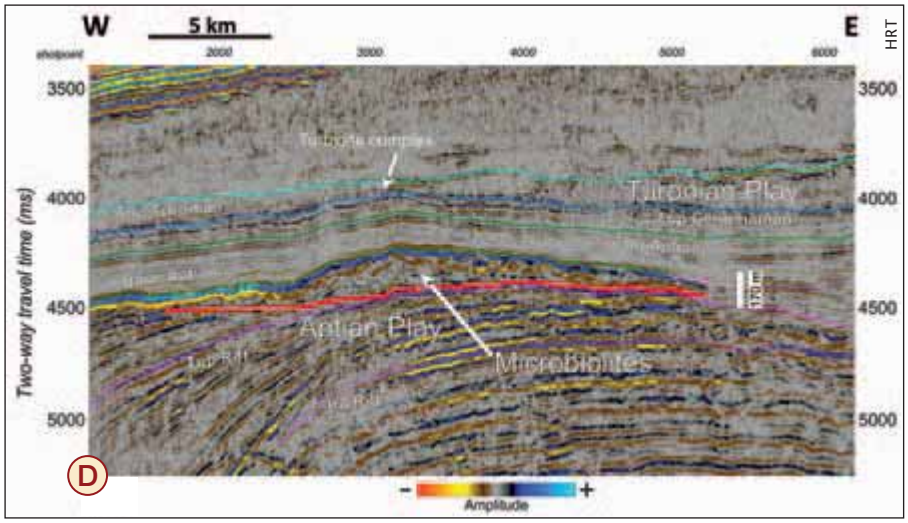
ion

→ Charged to innovate. Driven to solve.™




necessarily yield the entire story. There is a great deal of contrasting sedimentary development (explained in the next section) from basin to basin and margin to margin. The application of detailed geochemical analyses and integration of geological and geophysical methods can lead to better exploration models for these basins.

## Basin-Margin Differences

A robust basin analysis evaluation is based on the interpretation that rifting and continental breakup were diachronous and asymmetric, and there are major differences in margin characteristics from basin to basin. For example, it is accepted that the Gondwana breakup started in the southernmost South Atlantic (offshore Argentina/South Africa), probably associated with the Bouvet plume in Africa, by mid Jurassic times. It then advanced to the Pelotas/Santos (offshore Brazil) and Walvis/Namibe (southern Angola) Basins with the emplacement of the Tristão da Cunha plume in the Early Cretaceous, which also formed one of the largest igneous provinces in the world, the Paraná-Etendeka basalts. During the evolving extensional phase, rifts formed along the border of these margins and were filled with continental sediments. Anoxic intervals in Neocomian, Barremian, and Aptian times resulted in the deposition of the extremely rich source rocks that are essential to the petroleum systems that control the occurrence of giant oil fields in the Brazilian and West African margins.

*The Moosehead giant prospect, located in Block 2813A, north-west of the Kudu field, shows an intriguing geometry where Turonian turbidites drape over Albian to Aptian carbonate sediments, with possible Aptian carbonate buildups (microbiolites) overlying the outer high. The anticlinal structure is marked by bright and dim spots which might be associated with hydrocarbons. (A) is a regional map of the blocks offshore Namibia near the Kudu discovery; (B) is the structural map for the Turonian reservoir top; (C) and (D) are seismic displays illustrating the geophysical signature and amplitude anomalies of the Turonian turbidite complex and the Aptian carbonate play.*

Petrobras has drilled several dry boreholes in the Brazilian conjugate margin to Namibia (Pelotas Basin). There are major Tertiary depocenters along the Brazilian margin, whereas in the African (Namibian) side, the age-equivalent sedimentary sequences are much thinner, indicating a very asymmetric subsidence profile during the development of the margins and contrasting clastic inputs from the highlands onshore. In the Namibian side, the Upper Cretaceous sequences are very thick, suggesting an earlier maturation for the Lower Cretaceous source rocks as compared to the Brazilian side. Another element to distinguish between the two sides of the South Atlantic is that the continental rift developed asymmetrically between Brazil and Namibia. The Pelotas Basin is characterized by proximal rifts in shallow water, and although some geoscientists have suggested the occurrence of a wide and very thick rift in deep waters, this has only been confirmed in the African side. The flip-flop of rift depocenters in conjugate margins (and even salt basins, as is the case with the Santos–Benguela Basins) has clearly a major impact in the exploration strategies.

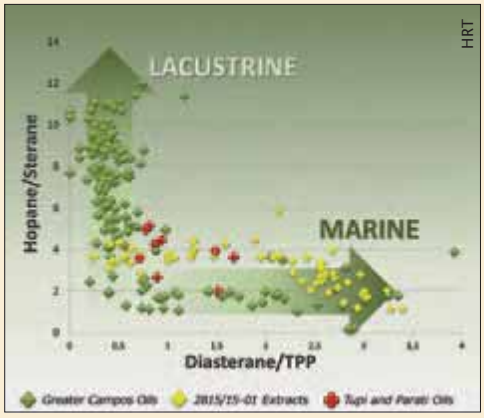
Applying high-resolution technologies such as geochemistry with biomarker identification of oils and source rocks, we can infer that the environments that existed in the Greater Campos Basin (with Late Aptian salt overlying continental lacustrine rocks) might also have occurred in the southernmost segment of the continental margin, before the first marine ingressions.

## Untested Large Prospects

New and improved seismic imaging of the stratigraphic and structural plays has helped to identify new prospects along the entire Namibian margin. The new seismic has also helped to demonstrate why some of the past wells were failures as well as identifying additional targets in Aptian to Late Cretaceous reservoirs.

HRT-Participações is the holding company of HRT Oil and Gas which currently holds twelve blocks offshore Namibia. HRT will start drilling four of their prospects in the Walvis (Blocks 2112B and 2212A) and Orange (Blocks 2713A and 2813A) basins by late 2012. The most important of them is the Moosehead prospect, involving the Aptian and Turonian plays, which is located in water depths ranging from 1,000m to 1,500m. This is the largest prospect mapped by HRT, with a mean area of about 1,880 km$^2$, and has carbonate reservoirs estimated to contain over 4 Bbo. The possible occurrence of carbonate mounds on top of rift blocks might constitute one major play in the Namibian margin. If successful, the reserves in this prospect alone could reach almost the size of the Tupi discovery, the largest field to date in the Santos Basin, which has a potential size over 4-8 Bbo in water depths of 2,000m, and lies below a salt layer about 2,000m thick.

In July 2011, Pancontinental was awarded an exploration license covering more than 17,000 km$^2$ in the Walvis Basin (Blocks 2012B, 2112A, 2113B), with prospects mainly involving ponded basin floor turbidites and other siliciclastic reservoirs in slope fans and channels. These targets are probably sourced by a restricted graben trough, which nonetheless might contain Early Cretaceous source rocks with high total organic carbon content. And in October 2011, COWAN Petroleum obtained a license covering around 10,000 km$^2$ in the Orange Basin (Blocks 2613A and 2613B), just north of the Moosehead giant prospect. The blocks present prospects mainly involving Cretaceous turbidite confined channels, basin-floor fans (unconfined turbidites), carbonate platform plays, toe thrusts (turbidite-sourced sand bodies affected by compressional tectonics), rift structural plays linked with basement highs and rift graben stratigraphic pinchouts.




*High Resolution Biomarker plot showing biomarker ratios (Hopane/Sterane plotted against Diasteranes/TPP) distinguishing and correlating lacustrine and marine oils from wells in the Greater Campos Basin, offshore Brazil, and Orange Basin, offshore Namibia. As can be observed, there is a very good correlation among marine and lacustrine oils (e.g. Tupi Field) from the Greater Campos Basin and hydrocarbons recovered from Kudu and 2815/15-01 wells in Namibia. Such data indicates that similar source rock systems are present in both areas.*

## Integrated Approach

The outlook for the Namibian offshore has benefited from an exploratory methodology based on the integration of high resolution geochemistry and new seismic imaging into traditional basin modeling. This, and the lessons learned from past exploration, has resulted in a better evaluation of risks and the selection of viable prospects even in this lightly explored area.

The next two years will mark a return to this frontier region, which was left aside for several decades while neighboring and conjugate margin basins witnessed a flourishing period with many giant discoveries. Diamondoid and biomarker analysis of oil and condensates from the Kudu and 2815/15-01 wells proves that the Orange Basin off Namibia contains similar source rocks to its neighbors to the north and across the Atlantic. Over the next few years, drilling should test innovative approaches and hopefully extend production to the Namibian continental margin. ■

# Emphasizing Vibrations

## CGGVeritas is applying new technology to extend seismic bandwidth and maximize production

CGGVeritas

PAUL WOOD

In the article 'Illuminating Resolution' (*GEO ExPro* Vol. 8, No. 3) we described the evolution of seismic acquisition technologies that aim to achieve the geophysicists' goals of illumination and resolution. One development featured in the article is the concept of extending the frequency content or bandwidth of seismic signals, especially at the low-frequency end, in order to achieve better vertical resolution and more accurate quantitative seismic interpretation. One of the seismic companies looking at this is CGGVeritas with its onshore and offshore broadband solutions, EmphaSeis™ and BroadSeis™.

### EmphaSeis for Vibroseis

EmphaSeis has been developed to extend the low- and high-frequency bandwidth of Vibroseis surveys to enhance the delineation and characterization of fractured, shallow, or deeper reservoirs. This enhancement comes from improvements to both structural imaging and stratigraphic inversion which both benefit from a broader bandwidth. Seismic surveys that use explosives as a source are able to record very low frequencies from broad bandwidth explosions. But surveys using drilled explosives are relatively more expensive, and can have significant environmental, safety and security limitations. So most modern seismic surveys on land use Vibroseis sources where access permits. Vibroseis trucks apply a sweep over a range of frequencies into the ground using hydraulic motors that shake a baseplate, with the force opposed by a heavy weight mounted on the vehicle.

The mechanics and hydraulics of Vibroseis sources and the associated force applied to the ground are quite complex. The force that can be generated at a given frequency is constrained by various factors that affect different segments of the output spectrum, varying with the make and model of the vibrator. At very low frequencies, between 1 and 10 Hz, two of the most important parameters governing the maximum output force are the reaction mass displacement (the distance it can move up and down) and the flow rate of fluids in the hydraulic drive system. The vibrator specifications are used to calculate these low-frequency limiting curves and then in designing the EmphaSeis sweep.

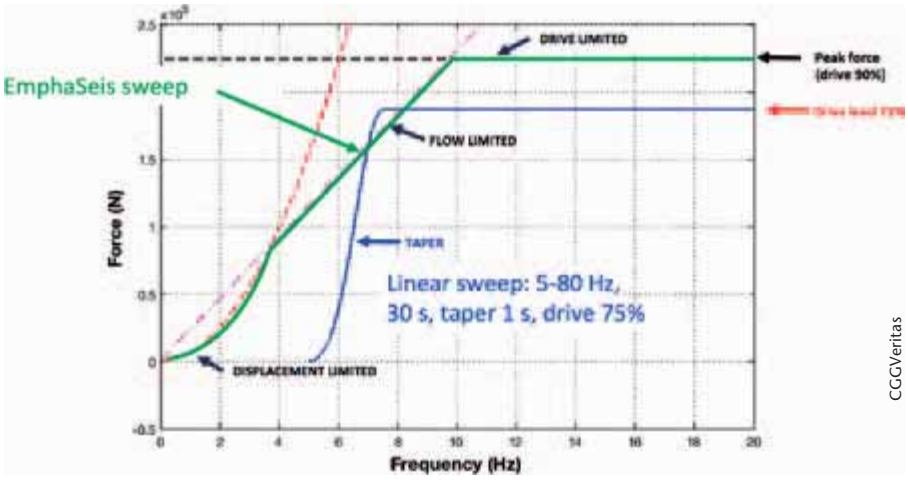
In the example shown (top of page 71), when trying to maintain a constant output force at low frequencies, the main constraint on the signal is the mass displacement, the parabolic red curve. Between 4 to 10 Hz, the hydraulic fluid flow (magenta curve) becomes the dominant limit on output as the hydraulic system tries to feed a large enough volume of fluid to actuate the piston. The electronics controlling the force of the signal have to avoid exceeding these curves, or significant distortion will occur. Normal Vibroseis sweeps are linear, running smoothly through the frequency band. Tapers are applied at low and at high frequencies to gradually increase the output force of the vibrator as the sweep starts and ends to avoid an increase in distortion. In the linear sweep shown here in blue, starting at 5 Hz, the limit of flow constraint is reached at around 7 Hz, by 8 Hz the 75% drive level set for this sweep has been reached, and the flow limit is no longer exceeded for the remainder of the bandwidth. But between 7 and 8 Hz the

vibrator is overdriven, often leading to a decision to use a longer taper, resulting in lower output at low frequencies.

## Non-Linear Sweep

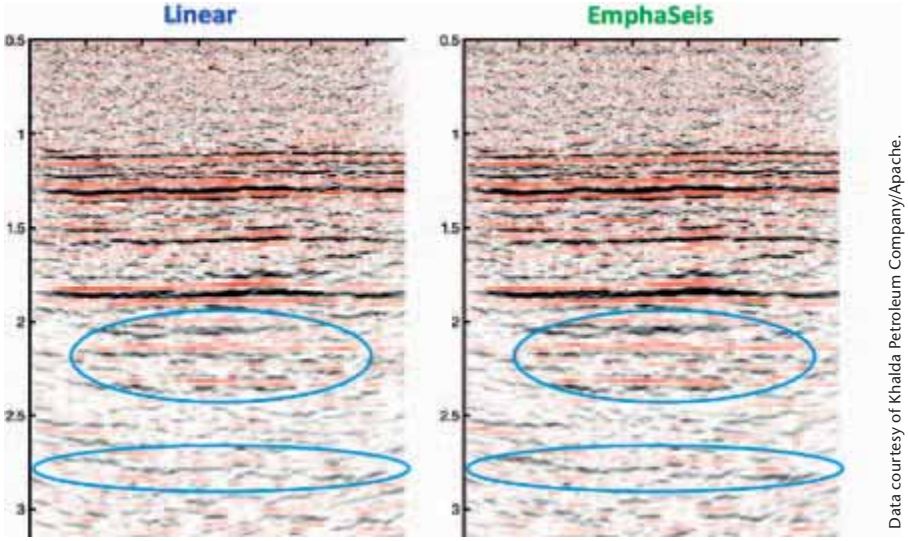
The EmphaSeis technology applies a customized non-linear sweep that is designed to stay within the mechanical and hydraulic limitations of the vibrator as shown by the green line on the graph. In addition to generating more energy at low frequencies (in production, starting as low as 1.5 Hz), the EmphaSeis drive level can be increased to achieve higher peak force (up to 90%) in the mid frequencies. One consequence of the non-linear sweep is that more time is required to generate the low frequencies – to allow the reaction mass and fluid flow to work smoothly without distortion. This can be compensated by spending less time on generating the mid frequencies, which is possible without degrading the signal because of the higher drive level achieved at these frequencies. This sweep design allows EmphaSeis to deliver more low-frequency energy while maintaining the conventional sweep length and productivity.

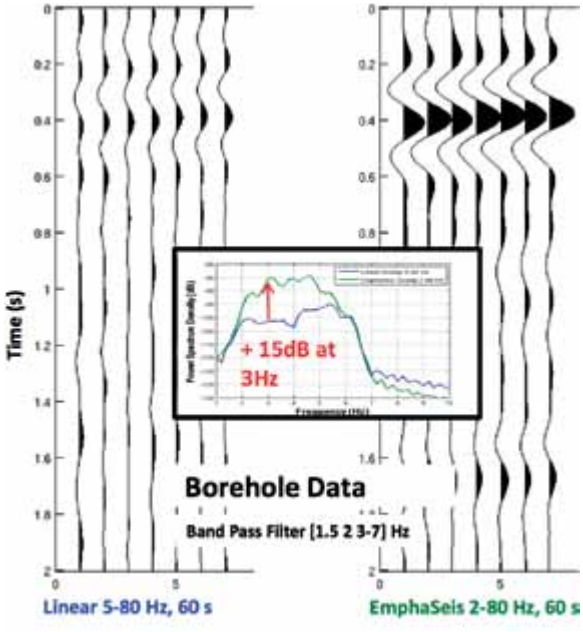
Early field trials of EmphaSeis verified that lower frequencies than are recorded with linear sweeps can be recovered with the EmphaSeis custom sweep. In a test that CGGVeritas conducted together with Shell International, an additional 15 dB of signal were recorded at 3 Hz in a borehole array (representing the far-field source signature) when using an EmphaSeis sweep of 2-80 Hz,



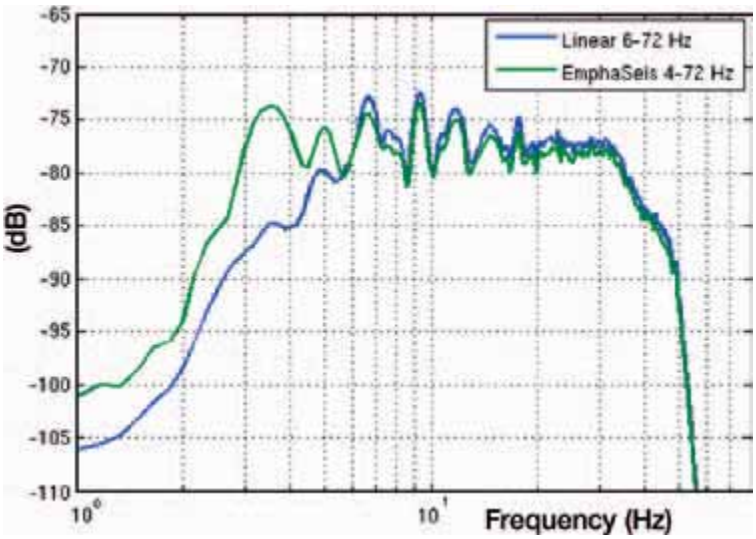

*Response curves of a seismic vibrator showing the constraints on the generated force at various frequencies.*

*Full bandwidth 2D seismic lines comparing linear (18s, 6-72 Hz) sweep with EmphaSeis (18s, 4-72 Hz) sweep sources.*




*EmphaSeis tests have shown improved recovery of low frequencies both in borehole data (left, Baeten et al, 2010) and reflection seismic data (right, courtesy Khalda Petroleum Company / Apache).*

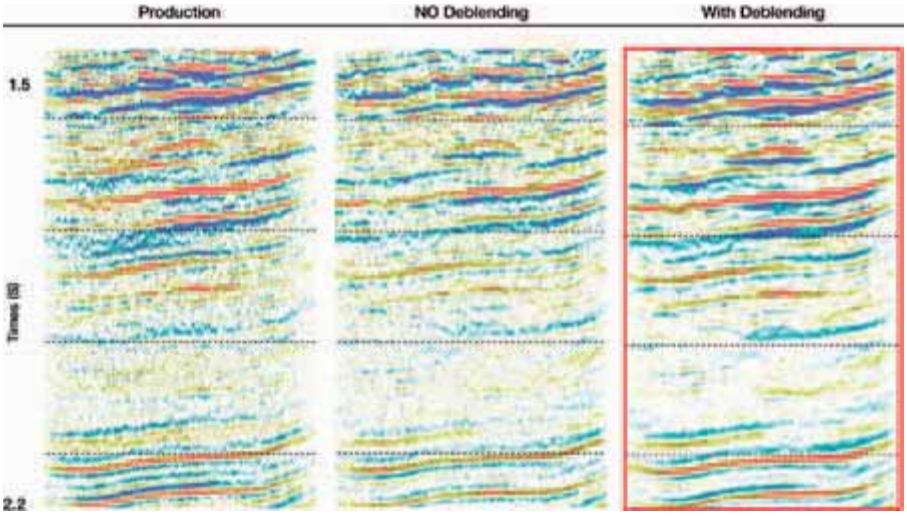


compared to a linear sweep of 5-80 Hz. In a production test on a 2D seismic reflection line conducted with Khalda Petroleum Company/Apache in Egypt, additional low frequencies were recovered using EmphaSeis. These low frequencies could be crucial for delineating new exploration or development targets, as the additional bandwidth improves the resolution and image quality of deeper reservoirs.

## Optimizing Production

In addition to extending the bandwidth of Vibroseis sources, CGGVeritas has developed techniques that optimize the productivity of Vibroseis crews. This is especially important in the Middle East where desert terrain allows sources to be distributed freely over a wide area with few obstructions. There is a continual need to improve image quality by reducing shot and receiver spacing and increasing the fold. So acquisition of a 3D survey over a given area would take much longer, perhaps becoming prohibitively expensive, if measures were not taken to improve production rates. CGGVeritas has also recently seen an increased need for high-productivity applications in regions like Alaska, Canada and parts of North America where seasonal constraints require crews to acquire data in a relatively short period of time. To conduct high-density surveys in these locations, a high-productivity Vibroseis technique is essential.

When 3D surveys started to become the norm rather than the exception in the Middle East, early techniques to speed up production used 'flip-flop' sources. One group of vibrators would move up while a second was 'shaking', minimizing the down time arising from changing source locations. Petroleum Development Oman introduced 'slip-sweep' (Rozemond, 1996), where one vibrator group would start vibrating before the previous one had finished their sweep. Because the frequency bands of their signals did not overlap (one group would be vibrating in a low-frequency band while the other was at the high end), the signals could still be decoded. In 2003, CGGVeritas introduced an in-field processing technique called High-Productivity Vibroseis Acquisition (HPVA) for slip-sweep operations that filters the harmonic distortion from the overlapping sweeps to improve image quality and increase productivity.




*Pre-stack migration results from a test utilizing ISS combined with unique coded sweeps (Pecholcs et al 2010)*

With the introduction of super-crews recording many thousands of channels, receiver spread layouts became large enough to support groups of vibrators, or even fleets of single vibrators, sufficiently far apart that they could vibrate simultaneously without causing interference. This technique, called Distance Separated Simultaneous Sweeping or DSSS, was introduced by BP (Bouska, 2008), which also implemented a simultaneous sweeping method, Independent Simultaneous Sweeping (ISS™) in 2008 (Howe *et al.*, 2008). In this method, individual Vibroseis units effectively act as autonomous units, positioned at various locations within a receiver spread, each sweeping independently when it is ready. The recorder is continuously gathering data and the records are reconstructed later.

Simultaneous source techniques, or blended acquisition such as ISS, are seen as one of the keys to future productivity gains in both land and marine acquisition. Vibroseis lends itself well to this arena by providing the opportunity to use uniquely coded sweeps for the individual sources. This enables the elementary, individual sources to be separated out from the tangle of simultaneous data much more accurately, a process known as deblending.

In a test in Saudi Arabia conducted with Saudi Aramco, CGGVeritas demonstrated that by using 18 separate vibrators, each with a unique sweep code, it was possible to log over 44,000 records in a 24 hour period (Pecholcs *et al.* 2010). Further, using unique sweeps with a pseudo-random character instead of linear sweeps, data quality was improved and productivity was pushed to over 45,000 records a day. The results highlighted the importance of deblending for simultaneous source acquisition as illustrated.

CGGVeritas aims to constantly improve its Vibroseis methods. Techniques such as EmphaSeis, HPVA, and V1 increase resolution while pushing the threshold and pioneering new industry records on productivity. ■

*EmphaSeis and BroadSeis are trademarks of CGGVeritas.*

*ISS and DSSS are trademarks of BP.*

***References:***

*Baeten, G.J.M., Egreteau, A., Gibson, J., Lin, F., Maxwell, P., Sallas, J.J., (2010), Low-frequency Generation Using Seismic Vibrators. 72nd EAGE Conference & Exhibition, Expanded Abstracts, B015.*

*Bathellier, E., Kirtland Grech, G., Scott, M., Branan, A. (2011), Slip-sweep key in 'superspread' survey, American Oil & Gas Reporter.*

*Bouska, J. (2008), Distance Separated Simultaneous Sweeping: the World's Fastest Vibroseis Technique. EAGE Vibroseis Workshop, Prague, Czech Republic, Expanded Abstracts, 15983.*

*Howe, D., Allen, A.J., Foster, M.S., Jack, I.J., Taylor, B., [2008], Independent simultaneous sweeping. 70th EAGE Conference & Exhibition, Expanded Abstracts, B007.*

*Pecholcs, P., Lafon, S., Al-Ghamdi, T., Al-Shammery, H., Kelamis, P., Huo, S., Winter, O., Kerboul, J-B., Klein, T., [2010], Over 40,000 VPs per day – with real-time quality control: Opportunities and Challenges, SEG Expanded Abstracts 29, 111.*

*Rozemond, H.J. [1996] Slip-sweep acquisition. 66th SEG Annual Meeting, Expanded Abstracts, 64-67.*

LONDON 2012

# APPEX

PROSPECT AND PROPERTY EXPO

6-8 MARCH 2012
BUSINESS DESIGN CENTRE
LONDON

***"What deal making is all about."***

Dr. James Edwards
Equinox Exploration Company
U.S.A.

# *A truly global A&D conference*

**For 11 years — APPEX, the Prospect and Property Expo — has brought together principals, senior managers, business developers and new venture managers for an unmatched opportunity to network and do business with NOCs, governments, financiers and global E&P deal-makers and decision-makers.**

- Your one-stop shop for global upstream opportunities
- The key forum for networking and international deal development, carefully designed to let you do real business
- Connect with buyers, properties and prospects from around the globe – find the next deal first
- Explore a programme of regional and topical speakers to keep you on top of worldwide trends and discoveries, including finance forum, prospect forums, and the international pavilion
- Discover thousands of exploration products and services from around the world
- Meet, discuss and negotiate deals with global decision makers

## Whether you're looking to buy or sell deals, expand into new areas, find new strategic partners, or just stay on top of the industry, APPEX is the place to be.

ORGANISED BY

ENDORSED BY

aipn

The Geological Society

MEDIA PARTNER

GEO ExPro

upstream
The International Oil & Gas Newspaper

europe@aapg.org | www.appexlondon.com | +44 (0)207 434 1399

# South East Asia – Where Are the Giant Fields Hiding?

DAVID BAMFIELD

Exploration in South East Asia has a long history – almost 150 years. Is its heyday gone or do giant fields still lie in wait?

The state-run oil and gas companies that are the operating entities of the Chinese government, namely Sinopec, CNPC and CNOOC, are globally active in seeking oil for China. Countries where these NOCs have completed deals in the last ten years or so cover the globe, from Australia and Mongolia to Kazakhstan and Oman; across Africa from Kenya to Algeria and Mauritania and throughout South America. All inevitably accompanied, of course, by support from 'China Inc.' in the form of loans, infrastructure and the like.

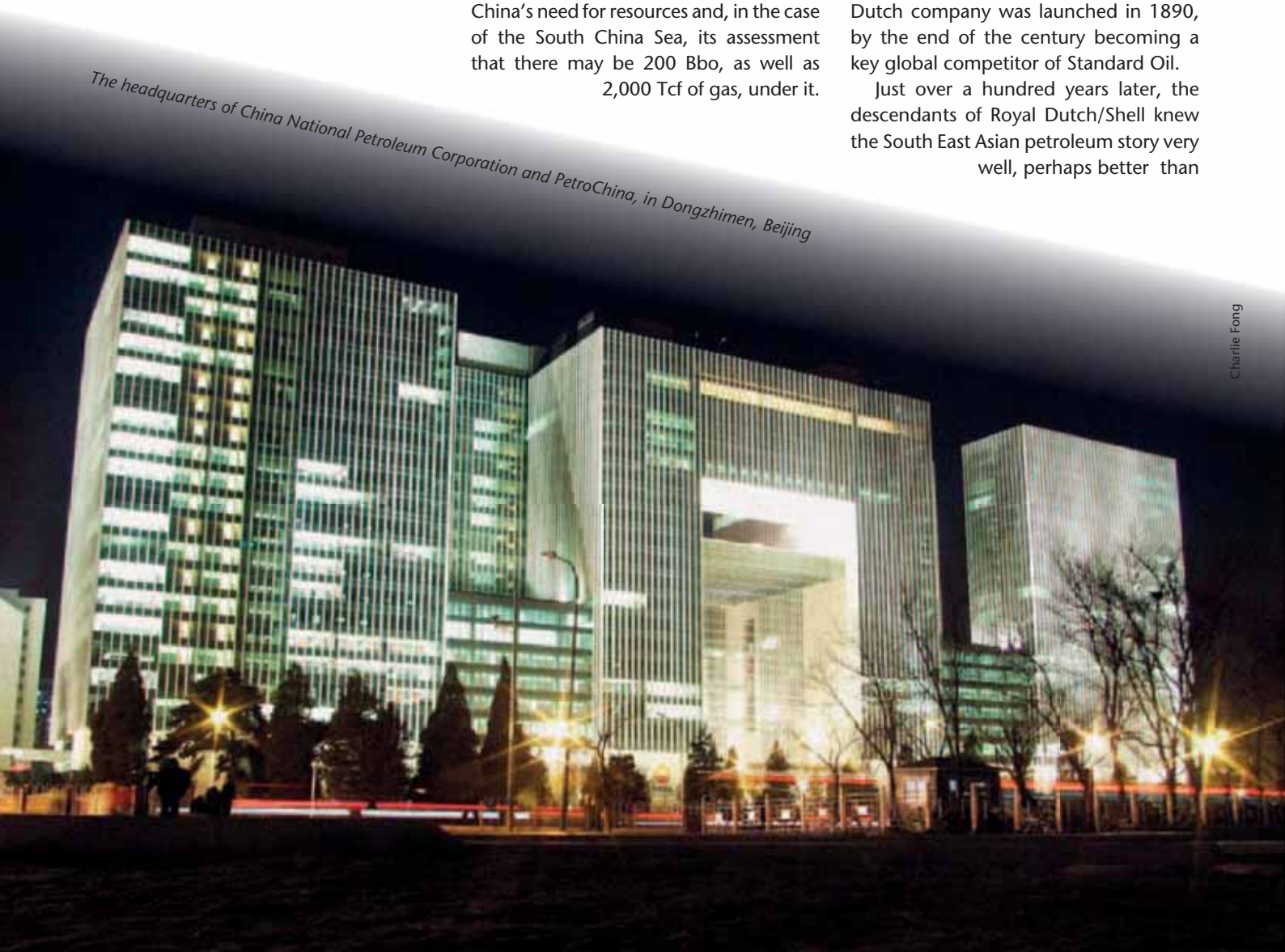
This high level of activity is based on China's need for resources and, in the case of the South China Sea, its assessment that there may be 200 Bbo, as well as 2,000 Tcf of gas, under it.

Does the history and recent experience of exploration in this region – and in South East Asia more generally – indicate that such huge resources may remain undiscovered and if so, where might they be?

## A Historical Perspective

There is a long history of exploration in South East Asia, beginning with the observation of seepages in the Dutch East Indies; by 1865, more than 50 seeps had been identified in the region. The first successful oil well was drilled in north-eastern Sumatra in 1885 and the Royal Dutch company was launched in 1890, by the end of the century becoming a key global competitor of Standard Oil.

Just over a hundred years later, the descendants of Royal Dutch/Shell knew the South East Asian petroleum story very well, perhaps better than



*The headquarters of China National Petroleum Corporation and PetroChina, in Dongzhimen, Beijing*

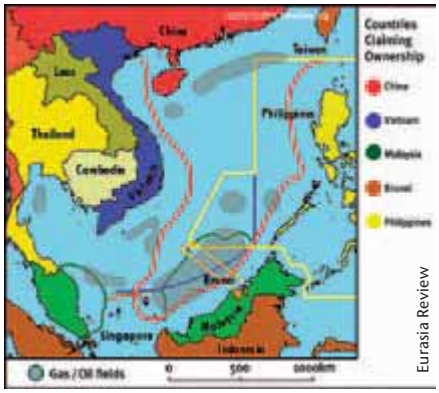
Charlie Fong

anybody. The broad ideas discussed below originate from a regional review of the oil and gas potential of South East Asian Tertiary basins, carried out by Shell during the 1990s and reported by the eminent Shell geologist Harry Doust (Doust and Sumner, 2007). As discussed previously in *GEO ExPro* (Vol. 7, No. 5) the main conclusions of this study were that petroleum prospectivity could be linked to the presence and relative development of a small number of petroleum system types (PSTs), common to the South East Asian family of basins as they pass through an early Tertiary Syn-Rift to late Tertiary Post-Rift geological history. These exhibit an almost exclusively land plant and/or lacustrine algal charge system and are characterized by rapid short wavelength sedimentary variations involving a distinct suite of depositional environments and their associated lithofacies.

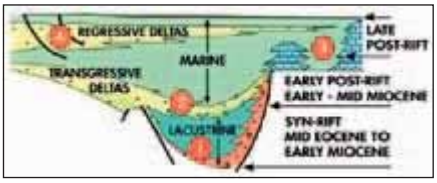
What is especially relevant is that these South East Asian PSTs are in the main thoroughly explored and have significant production histories, allowing us to ask two crucial questions; firstly, "what field sizes do such PSTs yield?", and secondly, "are there any special issues connected with them?"

In answer, Doust and Sumner believe that the Pre-Rift (pre-Tertiary basement) is only lightly explored, while fields producing from Early Syn-Rift lithofacies are oil-rich but small, with average ultimate reserves of 25 MMbo and 60 Bcfg. Fields producing from Late Syn-Rift lithofacies are oil-prone but with significant gas (2:1 ratio) and of moderate size, with average ultimate reserves of 55 MMbo and 293 Bcfg. In the Early Post-Rift, gas predominates, perhaps due to access to contemporaneous gas-prone marine source rocks, while the average field size is only 28 MMbo but an impressive 2.2 Tcf of gas. Finally, in the Late Post-Rift, average field sizes are moderate – 41 MMbo and 486 Bcfg. Potentially, contemporaneous turbidites, distal from the deltaic depocentres, offer an exciting play in present-day deep water.

As mentioned above, lacustrine source rocks are important and these provide a complication, in that the reservoired




*The South China Sea and competing maritime boundary claims. China claims 'indisputable sovereignty over the South China Sea islands and adjacent waters' based on centuries-old rights that allow its maritime border to reach almost to Borneo, bringing it into dispute with Vietnam, Malaysia, Philippines, Brunei and Taiwan.*




*Cross section showing summary from Doust and Sumner (2007) of the four main petroleum system types (PSTs) recognized in South East Asia.*

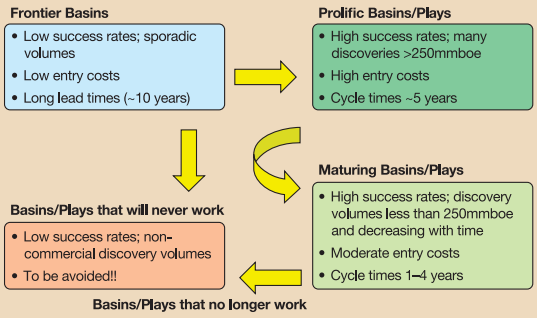
1: *Early Syn-Rift Lacustrine Petroleum System (Oil prone);*
2: *Late Syn-Rift Transgressive Deltaic Petroleum System (Oil/Gas prone);*
3: *Early Post-Rift Marine Petroleum System (Gas/Oil prone);*
4: *Late Post-Rift Regressive Deltaic Petroleum System (Oil/Gas prone)*

*Note that as shown in this cross-section, the existence of a lacustrine source rock system in the Syn-Rift is a crucial component of the working petroleum systems.*

## *The Exploration 'Life Cycle'*

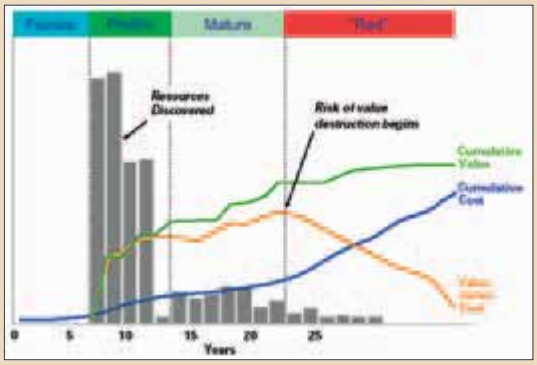
The Exploration 'Life Cycle' of exploration plays (and, occasionally, whole basins) illustrates the essential discussion about "where shall we explore?"

*A cartoon representation of the 'Life Cycle' of exploration plays. The status of any play can be considered in terms of its position in this Cycle. To illustrate, the UKCS North Sea Brent (oil) province moved over its 45+ year history from 'Frontier' in the 1960s to 'Prolific' in the early 1970s, 'Mature' in the late 1970s and in the 1980s and to 'Red' today.*




Explorers are often accused of being only concerned with volumes but, inevitably, this cycle has profound implications forvalue. In the early, 'Frontier', phase, of course, there is only expenditure with as yet no production of even significant discoveries. In the 'Prolific' phase, value creation is at a maximum, as discoveries are large (typically, 'Giant' accumulations of >250 MMboe gross), and therefore R&D costs are spread over a large number of barrels. In the 'Mature' phase, value creation can still be good but technology application and cost reduction become important in order to enhance economics. Finally, in the 'Red' phase, value destruction is probable, occasionally inevitable, success rates plunge, the very few discoveries are small, and costs escalate. Of course, it remains possible for a company to 'win' during this phase but the number of 'winners' is small, the number of 'losers' very high!

It is important to emphasize that the right level of analysis is the play level. It would be absurd to pretend that a whole region lies in the 'Red' zone, for example.




*Exploration Life Cycle: illustration of the evolution of discovered resources, value, costs and a notion of 'reward', through the cycles of exploration from 'Frontier' to 'Red'.*

crude oil usually has a high wax content. The difficulty with waxy crude is that it can have a tendency to turn solid en route from the reservoir to the processing facilities or in a pipe-line. The technology to overcome this problem, including the injection of chemicals, lighter oils and the heating of flow/pipelines, exists and has led to successful production throughout South East Asia.

## Current Trends

Reflecting on the raw data of South East Asian exploration success rates, discovery sizes and finding costs, both Wood Mackenzie and IHS have asserted* that since around 2003, the number of discoveries has been rising slowly but the resource additions have been dropping, and whilst exploration success rates are more or less holding up, discovery sizes are dropping. Average recoverable reserves are only 5–10 MMb for oil and 5–20 MMboe for gas fields; overall, gas is more prominent. Discovery costs are rising more rapidly than elsewhere and so there is competitive pressure from other regions, meaning that while exploration is just about profitable globally, it would appear that in South East Asia it is not.

Thus, this broad brush summary could be thought to suggest that much of South East Asia is either 'Mature' or in the 'Red' zone.

However, South East Asia is large, with a complex geological history and complex politics, and Longley from GIS-Pax* indicated that recent and planned activity gives plenty of encouragement at the play level. He pointed out that last two years have delivered a variety of material discoveries around the region, in 'Frontier' areas and in new plays in 'Mature' areas, by both large and small companies using old and new technologies. Results have demonstrated that significant exploration potential remains, both in accessible areas and in areas underexplored due to boundary disputes. Many already identified exciting plays will be drilled and tested in the next two years, and he sees no reason that this should not continue into the foreseeable future.

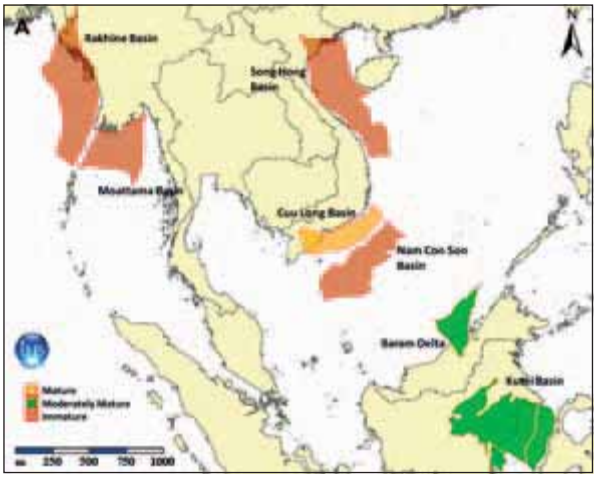
| Discovery | Date | Location | Recoverable Reserves |
|---|---|---|---|
| Paus | April 2009 | Deepwater Sarawak | ?125 Bcf and 10 MMbo |
| White Shark | March 2009 | Phu Khanh, offshore Vietnam | <100 MMboe |
| Longshui 21-1-1 | 2010 | Deepwater Quingdongnan, offshore China | ?260 Bcf |
| Asap-1 | May 2008 | Kasuri, West Papua | ?2.4 Tcf |
| Badik-1 | 2010 | Tarakan, Kalimantan | 40-60 MMbo and 100 Bcf |
| Janggrik-1 | 2010 | Kutei, Indonesia | 20 MMbo and 500 Bcf |
| Liwan | 2006–2009 | Deepwater Pearl River Mouth, offshore China | multi-Tcf and moderate oil volumes |
| Sultan | 2009 | Makassar Straits, Indonesia | 50 Bcf |

*Recent discoveries in South East Asia*

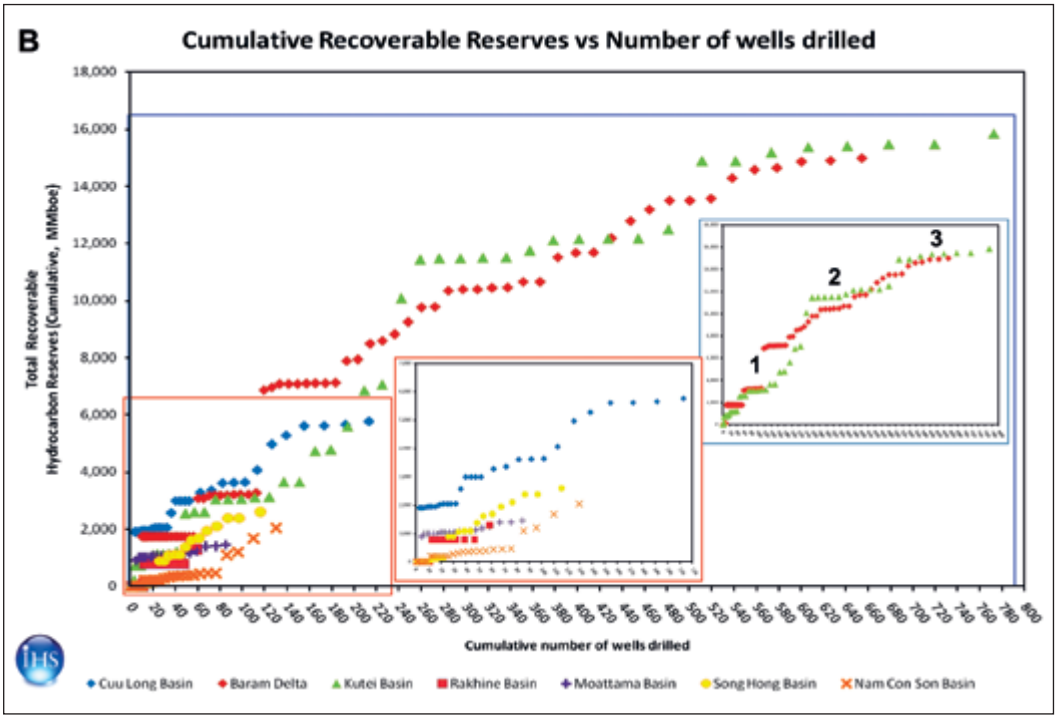
Longley

## Where are Giants Waiting?

IHS recently published an interesting creaming curve analysis of distinct plays in seven basins ranging from 'Frontier' to 'Mature', which reveals that significant potential remains for hydrocarbon discoveries in South East Asia. They observe from their data that past exploration demonstrates a




*Seven basins of South East Asia, and their creaming curves: the Baram Delta, Kutei, Cuu Long, Nam Con Son, Song Hong, Rakhine and Moattama Basins.*



preference for deltaic/regressive prograding wedge plays, while the marine/transgressive wedges, channels, and fan lobes plays have been explored only intermittently. For the latter, only the Kutei and Baram Basins have produced discoveries, most notably the Kikeh discovery, with fan lobes yet to be penetrated in Kutei. Exploration has also focused on plays close to existing discoveries and in shallower water to minimize risk. However this spatial constraint produces false plateaus in the creaming curves, as play types become locally exhausted.

IHS's comparison of these seven basins shows that the fall in exploration discoveries for the past decade is mainly because of a concentration on mature plays, combined with the neglect of other unproven or relatively less prospective plays. They suggest that significant discoveries (greater than 1 Bboe) in areas like Kutei's Upper Miocene-Pliocene play and Baram's turbidite play may be possible and that, according to a yet-to-find analysis, basins like Rakhine and Song Hong might hide around 4 Bboe in undiscovered reserves.

Based on recent discoveries and IHS's analysis, the realistic hopes for 'Giant' fields would therefore seem to be either deep water, as exemplified by the Deepwater Pearl River Mouth and some of Indonesia (Kutei; Baram), or more remote areas such as West Papua, where new play ideas and modern technology may be deployed.

Equally, it must be said that some areas, such as the Makassar Straits, have proved disappointing, dropping directly from 'Frontier' to 'Red'; while the technical approach* to some of the onshore areas, such as onshore Borneo or northern Thailand, seems to be bereft of any modern technologies such as gravity gradiometry or wireless (3D) seismic.

Returning to the theme of China's thirst for oil, perhaps we can expect Chinese NOCs to seek entry to these areas with recognized unexplored potential for Giants, while we may see the Chinese government focusing on its declared rights in the South China Sea, especially the Deep Water areas. ■

*as presented at the SEAPEX Conference, Singapore, April 2011.

*References:*

*Chan and Mair: IHS, 2011*
*Doust and Sumner: Petroleum Geoscience, Volume 13, 2007*

*The Kikeh FPSO before moving to the Kikeh field, 110 km offshore Sabah, which is the first deepwater oil production in Malaysia.*

# Does Geology Last Forever?

BÉNÉDICTE WINDLE

The Earth's resources have been exploited by humans for many thousands of years, but we need to ensure that the integrity and accessibility of important sites and landscapes in the geological heritage are preserved for future generations. Here, one group of enthusiasts from Northern England look at the issues involved and explain how they are trying to ensure that geological sites in their region will continue to be treasured and enjoyed by all.

*Peering into a coal mine shaft near Danby at the smallest coalfield in Britain.*

**The North East Yorkshire Geology Trust** is an independent, not-for-profit organization involved in geoconservation: protecting our wonderful geodiversity, including the natural range of geological and geomorphological features and processes that compose and shape the physical landscape and sharing it with as wide an audience as possible. We are similar to a local wildlife trust for rocks, fossils and landscapes. We care about our Earth heritage. Despite the expression 'solid as a rock', geology is in danger, as important sites disappear or are damaged, through threats such as unsustainable fossil collecting, coastal erosion, quarrying, infill of disused quarries and vegetation overgrowth. We want to ignite the passion of future generations for the science of geology and communicate to all the information locked in our rocks and landscapes because we are specialists in geoconservation and believe that geology should be enjoyed.

We do this by raising awareness of our rich earth heritage with a busy events programme of guided walks, talks, rock and fossil road-shows, activities in schools, 'geonaut' events using

North East Yorkshire Geology Trust


*Active geoconservation well done! A group help clear a notable geological site*

our local landscape as an open-air classroom, training sessions and field excursions. We have also published 26 trail guides in our Secrets in the Landscape series and an Earth Heritage booklet entitled 'When the Devil Came to Rosedale.'

On the 'protect' side, we undertake active geoconservation: clearing geological faces, viewpoints and sites; surveying; doing research; drawing graphic logs and management plans; recording the information uncovered in our GIS; keeping abreast of changes in the landscape and being consultees to the four local planning authorities in our area.

## Geology Taken for Granted

Our experience as practitioners of geoconservation, particularly over the last eight years in North East Yorkshire, has led us to produce a 'Handbook of Geoconservation', to raise issues that are seldom discussed and to propose a way to improve the state of geoconservation both in our region and nationally. This outlines our take on the issues that hold back geoconservation, such as the absence of a protocol, as already exists for biodiversity and archaeology, as well as site designation, the planning process, access and insurance, the lack of dedicated resources and in general, the perception that geology lasts forever.

The need to tackle geoconservation issues in a different way has arisen because geology is taken for granted, ignored even. How is it that a quarry, which owes its very existence to geology, does not automatically have geology at the core of its restoration plans? Active quarries present geologists and earth scientists with a unique opportunity to see fresh rock exposures and discover new evidence of our earliest history and yet even when faces are preserved, they are not always ramped and safely accessible. Access and insurance are discussed in our Handbook, as the burden of liability and related costs on landowners are another strong barrier to geoconservation.

Another crucial issue raised by our 'Handbook of Geoconservation' is designation. There are many UK designations, with a confusing collection of acronyms, such as FIGS (Forestry Important Geological Sites); LGS (Local Geological Sites); MCZ (Marine Conservation Zones); RIGS (Regionally Important Geological and Geomorphological Sites); or SSSI (Site of Special Scientific Interest). In terms of conservation, these designations generally create an exclusion zone around a site, and yet offer no real protection, no guarantee of a site's good condition or future existence.

In our Handbook, we question the whole process. Has designation run its course? Is there a better way to use the meagre resources available than creating new site designations? Ultimately, is designation benefiting conservation? Should a blanket designation be considered where all sites are valued? Our experience is that there are big gaps in the process, particularly with regards to newly discovered sites, and there is also an absence of protocol beyond designation.

For example, at Ardley in Oxfordshire, a site of international significance for dinosaur track-ways, designation wasn't an option until years after the site had disappeared under landfill. Mike Windle (now Director of North East Yorkshire Geology Trust) and the Oxfordshire Geology Trust, which he had founded, tried their best to save the site. They were involved too late on the project and only managed to raise the awareness of this awesome site with the general public and to protect any tracks, which may be found in future in further site extensions.

## Geoconservation Hub

We strongly believe in the need for a concerted effort to improve the state of geoconservation. Creating a one-stop shop for all geoconservation questions, which could offer unbiased expertise and liaise with all parties, would be a step in

*A Dansgaard-Oeschger Sequence in a quarry in North Yorkshire – evidence for rapid climate change.*

the right direction. To that end, the Geology Trust has designed a mechanism to improve the future of geoconservation: the Geoconservation Hub. Our independence and expertise at the coalface of geoconservation, in landscape interpretation and geology, place us well to be that hub – a centre for excellence in geoconservation.

As the Geoconservation Hub, the North East Yorkshire Geology Trust is the first port of call for landowners, quarry operators, developers, planners and other interested individuals and geologists to ensure that geodiversity is taken into consideration, evaluated and protected. It proposes a practical approach that respects business practices, accommodates development and considers the value of geology in wider terms: as a science, a source of wealth, an educational resource, the foundation of our settlements and our modern world and a source of great enjoyment in our leisure time. The Hub raises the awareness of our rich geodiversity with the general public, helping educate future generations in a better understanding and appreciation of our environment, and help broker informed and inclusive agreements, winning deals which benefit all parties involved in some way and lead to an improved condition for geodiversity and a strong protocol for better geoconservation.

These are just a few of the issues that led to the design of the Geoconservation Hub and the approach of the North East Yorkshire Geology Trust. Such a pragmatic, dedicated and inclusive approach is essential and crucial if geoconservation is to have a sustainable future. It is time to recognize geodiversity, to acknowledge its value, respect it, protect it and share it.

*If you want to know more about the Geology Trust or the 'Handbook of Geoconservation', soon to be published, please contact Mike Windle, Director of North East Yorkshire Geology Trust, on +44(0)1947 881000 or email contact@neyorksgeologytrust.com.* ■


*Geonauts on a Fossil Walk*

## 'Geonauts' Explore

Quarries often make excellent classrooms and our project 'Making the most of Geodiversity in Aggregate Quarries' (supported by the now defunct Aggregate Levy Sustainability Fund) has enabled us to demonstrate this, particularly at Wath Quarry in North Yorkshire. The Geology Trust organized with quarry operator Lafarge a brilliant field trip for primary school children from nearby villages. The heavy machinery was a definite source of attraction, as were the big crystallized ammonites and the rock samples the children took back to their school.

There is no substitute for touching the geology, or putting your finger on fossilized ripples, to get a sense of the place you inhabit. Visiting an active quarry also demonstrates where the stone we build our houses with comes from, where the sand and gravel we use for our roads originates and it creates an understanding of the importance and value of geology. This field trip at Wath Quarry certainly made school children, parents and teachers more aware of their environment, and the Geology Trust's involvement has created a whole new generation of 'Geonauts', enthusiastic and more informed about rocks, fossils and the landscapes they live in. It is also good publicity at little cost for Lafarge. Wath site manager Tony Tait said: "Lafarge has a long history of supporting education initiatives, so partnering the Geology Trust on this project came naturally. The children who visited Wath Quarry now have a greater understanding of how essential the rocks around them are to their life."


"I am so pleased with the learning that has come out of this," said the Headteacher of one of the schools involved. "Our children, and us, have 'lessons for life' from this project and it has made us more open-minded about using evidence."

The Geology Trust undertakes Geonaut Events with schools across the region as well as local groups of people of all ages. Geonaut Events are a creation of the Geology Trust. They reflect our inclusive attitude, involving people in the discovery of their local heritage and how their planet works, a holistic approach and introduction to science and the skills of a naturalist. These events are about discovering the secrets in our landscape, interpreting the clues gathered during a field trip and building a story, which is evidence-based and captivating.

Under the Patronage of:

Kingdom of Morocco
Ministry of Energy, Mining,
Water and Environment

Officially Supported by :

ONHYM
OFFICE NATIONAL DES HYDROCARBURES ET DES MINES

# SIDE

## INTERNATIONAL ENERGY EXHIBITION & CONFERENCE

Oil, Gas, Mining, Renewable Energies

**May 22-25, 2012**

**Palais des Congrès**

**MARRAKECH**






Organized by :

iec INTERNATIONAL EXHIBITIONS & CONFERENCES MAROC

**www.side-morocco.com**
**contact@side-morocco.com**

# Transiting the Northern Sea Route

The 3D seismic vessel ***Polarcus Alima*** has successfully transited from Norway to the Asia-Pacific region via the Northern Sea Route – a first in the seismic industry, and an achievement which saves considerable time, fuel, emissions and cost

**JOHN ROBERTS – Master, *Polarcus Alima***

*The view from the high tech bridge of the Polarcus Alima*

Delivered in the first quarter of 2011, *Polarcus Alima* is a high ice-class 12-streamer 3D seismic vessel built to the ULSTEIN SX134 design. She is amongst the most environmentally sound seismic vessels in the market with diesel-electric propulsion; a high-specification catalytic reactor; double hull; and advanced ballast water treatment and bilge water cleaning systems.

*Polarcus Alima* was scheduled for a series of 3D surveys in the Taranaki and Great South Basins offshore New Zealand after completion of seismic operations in the Barents Sea, north of Norway and Russia. The traditional route for the transit to New Zealand is via the Panama Canal or, for some larger vessels, the Suez Canal. The 3,000 nautical mile (5,560 km) Northern Sea Route (NSR) through the Arctic Ocean along the north coast of Russia provides a much shorter route, but it is partially covered by sea ice throughout the year and almost completely in winter.

Under the Russian Federation's 1990 Regulations for Navigation on the Seaways of the NSR, vessels sailing the route are required to hold an ICE-1A or higher ice class – a rating that is unique to the Polarcus fleet in the seismic industry. In addition, Polarcus has developed a wide-ranging set of procedures for operating in harsh environments, and was formally awarded a Statement of Qualification from DNV of its Arctic Procedures at the annual Arctic Shipping Summit in Helsinki, Finland in early 2011.

## Planning the Voyage

About a month before *Polarcus Alima* completed her 2011 summer season in the Barents Sea, Polarcus began a detailed investigation into the viability and requirements for transiting to New Zealand via the NSR, which could save substantial time, cost, and fuel. Advice was sought from expert organizations including Atomflot, a Russian provider of specialist icebreaking services and Tschudi Arctic Transit AS, a provider of transportation solutions in the region. Enquiries began with the Northern Sea Route Administration (NSRA) in Moscow, the agency responsible for managing sea traffic through the route.

Detailed study of recent and forecast ice charts over the proposed transit period indicated little risk of encountering pack ice along the planned route, and Polarcus was confident that *Polarcus Alima* was capable of completing the journey safely and efficiently. Administrative delays represented a potential challenge, as applications for the transit should normally be presented to the NSRA several months in advance of sailing. Tschudi AS assisted in getting the necessary approvals in time, so detailed planning for the journey began. A thorough risk assessment to highlight expected risks and prompt measures to mitigate the potential impact of these was undertaken. An extra Chief Mate fluent in Russian would sail as part of the crew to aid communications with the icebreaker escorts arranged by Atomflot.

All ships must be equipped with ship-to-shore and bridge-to-bridge communications equipment suitable for the waters in which they will sail. The requirements, which depend on the regional availability of suitable communications channels, are defined in four bands, and ships operating in Sea Area A4, which includes much of the Arctic region, need to make extra provision. The ship already had the appropriate HF Radio and Radio Telex systems required, but to provide extra coverage, an Iridium Communications system was fitted. Based on a constellation of 66 low-earth orbiting cross-linked satellites, this system provides voice and data communication services in all parts of the globe including poles, oceans and airways.

*Polarcus Alima* arrived at Hammerfest in northern Norway on 14 September and commenced preparations for the transit to New Zealand. Captain Sergey Minchenko of the Murmansk Maritime Agency visited the vessel in port to perform an inspection on behalf of the NSRA. All issues on the inspection check list were found to be satisfactory and the permit allowing the NSR transit to take place was issued the same day. Everything was in place for the journey to begin.

### The Northern Sea Route Transit

*Polarcus Alima* sailed from Hammerfest on September 15, 2011. Course was set towards the north end of the island archipelago of Novaya Zemlya, through the Vilkitskiy Strait and into the Laptev Sea, during which time she was escorted by NS Yamal, a nuclear powered icebreaker operated by Atomflot. *Polarcus Alima* then continued east along recommended routes, keeping in radio contact with Yamal, until on September 19 ice pilotage support was transferred to NS 50 Let Pobedy, the world's largest icebreaker. The route then passed Pevek Point, where on September 23 radio contact was made with icebreaker Admiral Makarov. The ship then sailed on to Cape Dezhnev, the easternmost mainland point of Eurasia, and was through and out of the Bering Straits into the Pacific Ocean on the evening of September 24.

Whenever air temperature dropped below zero, the heated deck walkway and railing systems on the vessel were enabled. The coldest conditions experienced were in the East Siberian Sea, where air temperatures fell to -3°C and sea water temperatures to zero. Large areas of shallow water were encountered, and even on the recommended routes, water depths as low as 15m were not uncommon. Away from the recommended routes there are large areas where charted soundings are 4 km apart, so it was essential to keep to the recommended routes to avoid risk of grounding.

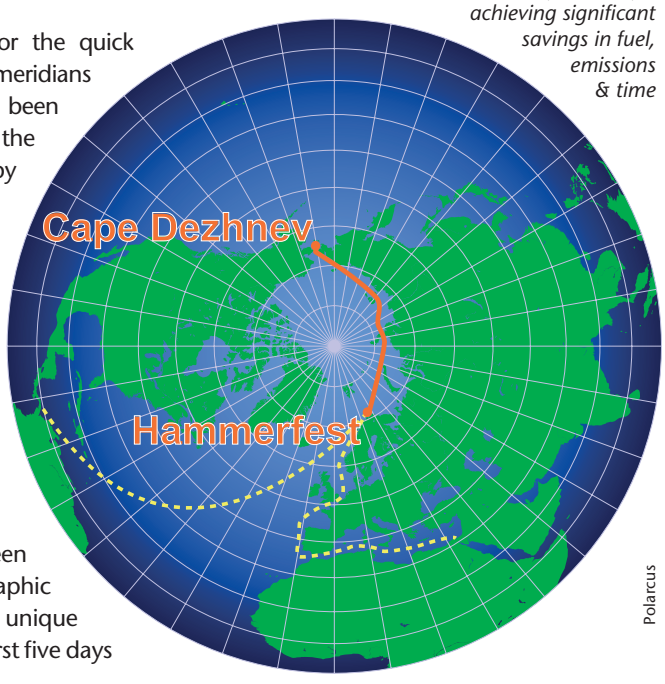
To compensate for the quick passage across the meridians of longitude, it had been planned to change the clocks onboard by one hour every day; however this proved to be too rapid for most personnel, so it was decided to ease the time change to one hour every second day and by Shelagskiy Point, sunset was at 14:00 ship's time.

The crew were keen to capture photographic memories of this unique voyage, but for the first five days there was moderate to thick fog. Groups of sea lions were sighted off Novaya Zemlya, but they quickly dispersed and it was not possible to get photographs of them. There was a marked increase in wild life when approaching the Bering Straits, including whales, but these were also too elusive to catch on camera. The best shoreward views of the passage were on September 23 when passing eight km off Shelagskiy Point, which provided memorable photographs of a dramatic and desolate landscape.

### Safe Arrival

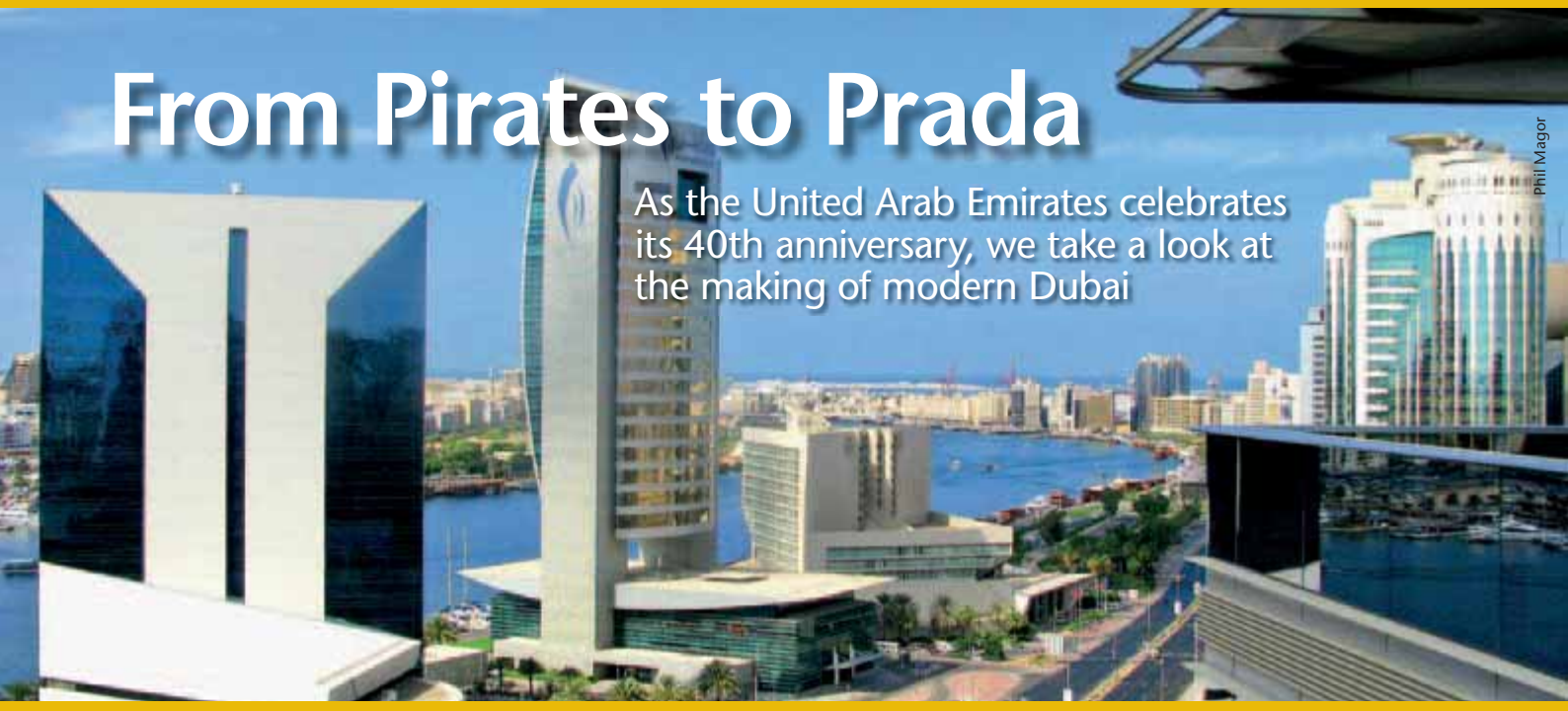
The voyage from Hammerfest to the Bering Straits was completed in nine days, and *Polarcus Alima* arrived in New Zealand on October 17. The time saved by using the Northern Sea Route is estimated at 8 days relative to the Panama Canal route and 13 days less than using the Suez Canal. "The successful navigation of *Polarcus Alima* along the NSR has been achieved through the dedication and hard work of our in-house operations personnel, the NSRA, and our crew onboard the vessel," said Rolf Rønningen, CEO Polarcus. "The result of this outstanding teamwork has been to achieve significant savings in fuel, emissions, and most significantly time during a milestone transit that effectively provides Polarcus with a viable new sea bridge between two important operational markets." ■

*The NSR took only nine days, achieving significant savings in fuel, emissions & time*




Polarcus

# From Pirates to Prada



Phil Magor

## As the United Arab Emirates celebrates its 40th anniversary, we take a look at the making of modern Dubai

SINÉAD ARCHER

With its glittering seven-star hotels, gravity-defying architecture and shopping malls complete with indoor ski slopes, Dubai has fast become the byword for resplendent consumerism in recent years. A country built upon excess and world records – tallest building, biggest shopping mall, largest man-made port – it is staggering to think that this buzzing metropolis has transformed from a small port town to economic world-player in less than a century.

### Pearls and Pirates

Although its ascent to one of the world's key business centers is a relatively recent one, Dubai's location both at the mouth of the Dubai Creek and close to the trading hubs of Iran and Bombay has always made it an attractive location to settlers and traders alike. For centuries the area's main income came largely from the pearl industry, attracting a considerable volume of cargo ships in the early 18th century. This in turn attracted an altogether less welcome band of sailors – pirates.

Between the seventeenth and nineteenth centuries, the Gulf coast became so targeted by marauding gangs that it was known as the Pirate Coast, with Arab and European pirates jostling for the lucrative cargos of the many ships passing through the Gulf. The piracy problem was further compounded when the Napoleonic Wars broke out in the early part of the nineteenth century and the British Navy, which had held a strong presence in the Gulf, were gradually deployed closer to home, leaving the Persian Gulf a veritable pirate playground.

In 1820, after several brutal attacks on their ships, including one so vicious that all crew were massacred and the ship commandeered by the pirates, the British felt something had to be done. After an aggressive response from the British Navy, which succeeded in quashing the majority of the pirate crews in the area, the 'General Maritime Peace Treaty' was drawn up, pledging British support to assist Dubai and its neighboring sheikhdoms in combating piracy, in return for enhanced trade and shipping benefits. The treaty also included clauses prohibiting slavery, thought to be the first references to the denunciation of slavery written into a British treaty.

### Tax Breaks and Oil

One factor believed to have greatly contributed to Dubai's development into the country it is today was the arrival of the Bani Yas tribe in Dubai in 1833. The Bani Yas had been the ruling tribe in Abu Dhabi for centuries, but following a family disagreement some 800 members of the Al Maktoum clan moved away from Abu Dhabi to invade and conquer the port of Dubai, with little resistance from the incumbents. Capitalizing on Dubai's profitable location and lucrative pearling resources, they quickly started to develop the town. The dynasty continues all the way through to the present-day Sheik of Dubai, and it was an Al Maktoum who introduced one of the most attractive and lucrative features of Dubai life to this day – tax breaks.

After assuming power in 1894, in a bid to attract foreign merchants and money, Sheikh Maktoum bin Hasher Al Maktoum granted full tax exemption for all foreign traders, attracting those from far and wide to the emirate town. He established the re-export industry that would contribute to the economy on a permanent basis, and struck a deal to make Dubai a key port of call for an important British shipping company. By the end of his short reign in 1906 Dubai was beginning to boom.

Sadly, the boom was short-lived. The demise of the pearling industry, which had underpinned Dubai's economy for centuries, coupled with the Great Depression, took their toll. World War II and renewed disputes with Abu Dhabi impacted further and the boom days at the turn of the century soon seemed an unlikely fairy story. It was not until the 1960s that Dubai began to regain its sparkle. A sparkle that was lent a

particular sheen by the discovery in the region of a very precious commodity – oil.

Oil certainly was a catalyst in the development of Dubai's fortunes, but many also consider the sound leadership of the ruler during the oil rush, Sheikh Rashid bin Saeed Al Maktoum, as a greatly contributing factor. After the discovery of oil in Abu Dhabi in 1958 but before it was found in Dubai, Sheikh Rashid had decided to capitalize on the commodity. With no port in Abu Dhabi, in 1963 he began a project to dredge Dubai Creek, allowing the larger vessels needed to transport oil to dock in Dubai and also enabling the gold re-export business to explode. Finally, in 1966, oil was also discovered offshore Dubai, cementing the country's fortunes – at least for the time being.

### Luxury Tourist Destination

The 1960s were a decade of great change for Dubai. The British announced their intention of terminating the 1820 treaty relationship with the Coastal states, who were given a three-year window to develop their own security plan before the British left in 1971. As a result, the United Arab Emirates (or UAE) were formed, consisting of seven sheikhdoms with Abu Dhabi and Dubai at the helm. In fact, the UAE was initially created when Dubai and Abu Dhabi put aside their centuries of differences and formed their own union, later asking the remaining sheikhdoms to join them as the United Arab Emirates in 1971; the 40th anniversary of this momentous event will be celebrated in the UAE on December 2, 2011.

Oil, as we all know, will eventually run out. However, with canny foresight Sheikh Rashid's successor, Sheikh Maktoum, was keen to maximize revenue for the country beyond the oil industry. His answer was to establish Dubai as a travel and tourist destination unlike any other, and Dubai began to develop into the extravaganza it is today. The national airline was established, some of the most ambitious building projects ever thought of were undertaken, including the world's tallest free-standing hotel, the Burj Al-Arab, and the city fast became a real-estate goldmine. Even more ambitious projects were started, included the much-maligned sea reclamation project to create a set of the world's most exclusive habitable islands.

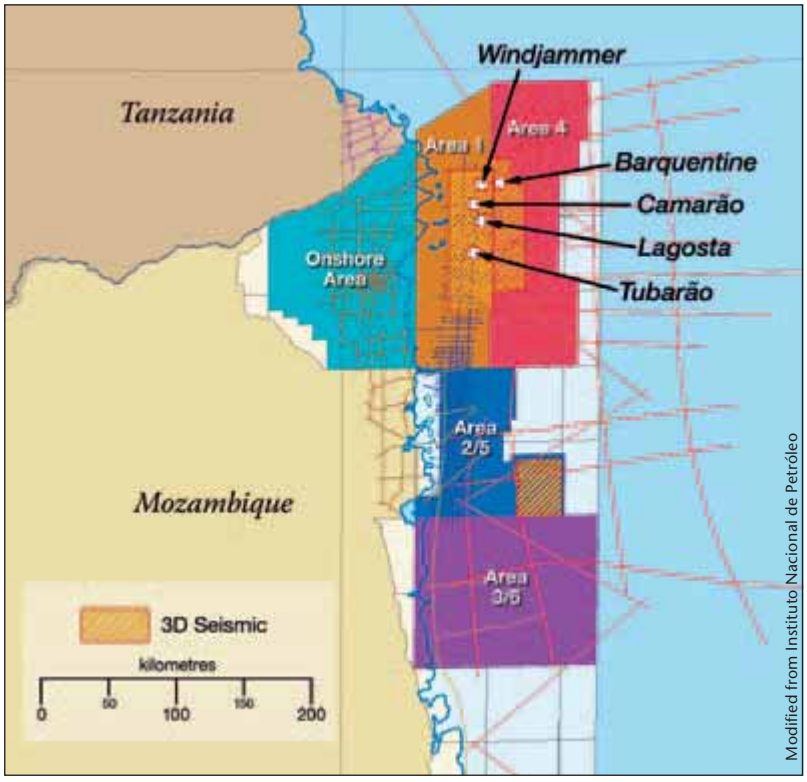
But as happened before during Dubai's stellar ascent, the good days lasted for only so long. The credit crunch did not just hit the country hard, it decimated it, spearheaded by the economy's reliance on real-estate income and foreign investment. Now with sky-rocketing debts, Dubai's future as the shining star of the Middle East looks less certain. But if the last few centuries have taught us anything, it is that surprising things happen to this little country. It is unlikely to be down for long. ■

*Dhows in Dubai creek*

Phil Magor

# Mozambique: Successful First Well

Recent discoveries by Anadarko in Mozambique have propelled that country to the fore in the hydrocarbon industry in the last year, and the first well drilled in offshore Area 4 looks set to continue the trend. The license, which covers 17,646 km² and is located in water up to 2,600m deep, is approximately 2,000 km north of the capital of Maputo. More importantly, it lies in the **Rovuma Basin**, immediately to the east of Area 1, the license in which the recent Windjammer, Barquentine, Lagosta and Camarão group of discoveries is thought to hold at least 10 Tcf of recoverable natural gas.




Originally Eni announced on October 20 that its **Mamba South-1** well contained in place reserves in the region of 15 Tcfg, reservoired in 212m of continuous high quality Oligocene sands. These results exceeded pre-drill expectations and confirmed that the Rovuma Basin, almost unexplored until last year, is a world-class natural gas province. However, drilling continued and a week later the company announced that the Mamba South field could actually contain as much as 22.5 Tcf gas in place. The well had encountered a separate pool in good Eocene sands, with about 90m of gross pay. Eni states that both sequences have been successfully cored. The well, which is located approximately 40 km off the coast of Cabo Delgado, the northernmost province of Mozambique, in water 1,585m deep, is continuing to drill towards target depth of 5,000m, after which Eni will move the rig approximately 22 km to the north to drill the Mamba North prospect.

This discovery promises to be a game changer for Eni, which is the operator of Offshore Area 4, as it is the largest operated discovery in the company's exploration history. It holds a 70% interest, with the other partners being Galp Energia, KOGAS and ENH, each with 10% shares. The company is already looking at ways of developing and exporting the gas, and with the Area 1 discoveries, operated by Anadarko, lying so close, some structure sharing could be envisaged.

The volumes of gas recently discovered should also impact on the people and the economy of Mozambique. According to the CIA Factbook, at independence in 1975 Mozambique was one of the world's poorest countries, and mismanagement and a brutal civil war from 1977 to 1992 exacerbated the situation. Since then, however, the country has stabilized and the economy has grown substantially – but over 50% of the population still live below the poverty line and the infant mortality rate is 7.9% of live births. Mozambique produces no oil and less than 120 Bcf gas per year, and while at the moment the local market for these commodities is not huge, its energy-hungry neighbour South Africa would be very happy to use any gas Mozambique chooses to export. ■

*Fishermen on the beach in northern Mozambique*

JANE WHALEY

# Argentina: Unconventional Discoveries

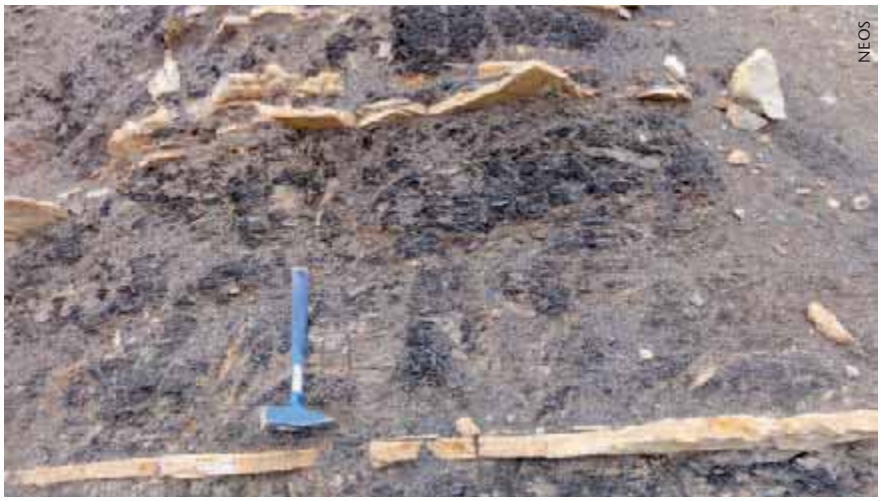

Spanish international oil company Repsol has made its biggest ever oil discovery after drilling 15 wells in the Neuquén province of western Argentina. The discovery was made by the Argentinian branch of the company, YPF, and is reported to total 927 MMboe (recoverable) of predominantly non-conventional shale oil, potentially making Argentina one of the world's leading producers of this commodity. Recoverable resources of 741 MMb of 40 – 45° API shale oil are thought to be reservoired in 428 km² of the **Vaca Muerta** Formation. YPF have already drilled 15 wells in the area, known as Loma La Lata Norte, and have reported that the wells have been flowing high quality shale oil at an initial rate of 5,000 boepd.

The Vaca Muerta Formation is one of the world's largest non-conventional reservoirs. It is a Late Jurassic to Early Cretaceous transgressive marine sequence of alternating black shales and limestones, the former being one of the principal source rocks for the Neuquén Basin. It extends to over 30,000 km² and in places is up to 425m thick.

Exploration is also in progress at another discovery in a 502 km² area of the same formation, where the well is flowing 400 boepd of 35° API shale oil. There is potential for even larger reserve estimates, as Repsol YPF has rights to 12,000 km² in the Vaca Muerta Basin, which, according to Wood Mackenzie, means that it is the world's second largest company in terms of non-conventional acreage. This discovery doubles its proven reserves in Argentina and increases by a third the amount of recoverable oil claimed worldwide by the company.

As reported in *GEO ExPro* earlier this year (Vol. 8, No. 1), YPF found 4.5 Tcf of unconventional gas in the same area in December 2010, a discovery which was considered a major breakthrough for Argentina at the time, as the country's gas reserves had fallen 51% to 13.3 Tcf, and domestic consumption had begun to overtake production. According to recent analysis by EIA and Advanced Resources International, Argentina has 774 Tcf of technically recoverable shale gas resources – the world's third largest assessed endowment, behind only China and the United States – and the Neuquén Basin contains more than half of the country's technically recoverable shale gas resources. ■

*Outcrop of the mature source rock in the Vaca Muerta Formation with parallel 'beef' bedding (light color veins) – fibrous calcite veins, the result of overpressure and horizontal compression, that grow parallel to the bedding of the shales*



# The Powers That Be

## A new book maps global energy for the 21st century

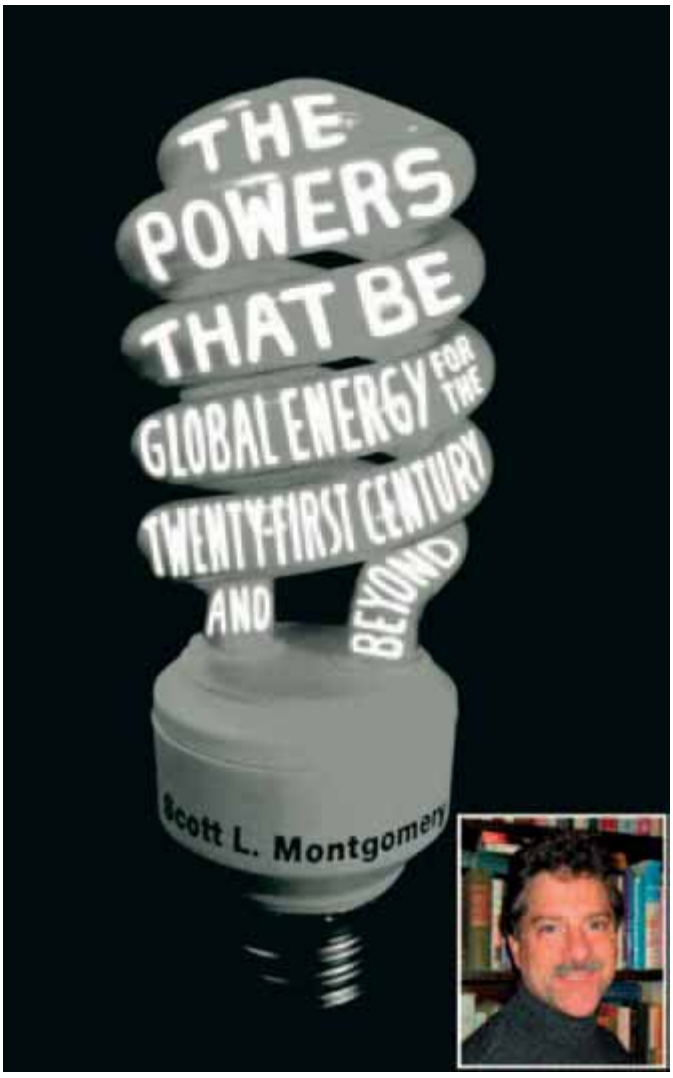
On my 'energy' bookshelf, there are dozens of books published over the past two decades. Some of them argue for Peak Oil; others refute it; still others paint a bloody picture of wars over resources. But a number of authors go beyond these debates. They try to educate the public on energy resources and technologies, show practical scenarios of global energy in the coming decades, and discuss the intelligence, investments, and efforts needed to harness energy, upon which modern civilization is founded. To this latter category belongs Scott Montgomery's new book *The Powers That Be: Global Energy for the Twenty-First Century and Beyond*. Unlike most other books in this category, which are written by journalists, economists, environmentalists, etc., *The Powers That Be* comes from the pen of an experienced geologist.

Through sixteen chapters, Montgomery has presented a comprehensive review of the current energy situation in the world and our energy options in the coming decades. The book is written in a readable style for the educated public, although the author has included only a few maps, diagrams and photographs to enhance the text.

Montgomery advises the reader to follow the book in the order of its contents; hence I will also introduce it in that manner. After an introduction, two chapters discuss the historical view and the present situation of human use of energy resources. The next three chapters are on fossil fuels (oil, natural gas, and coal), which currently account for 80% of the world's energy consumption. Chapter seven is on 'the great debate' of Peak Oil. Here we read the viewpoints of the pessimists (crude production has peaked); the optimists (no peak at all), and the realist-actionists (production 'plateau' will continue for a few decades). Then comes a chapter on nuclear power, which currently supplies 15% of the world's electricity through 436 operating nuclear plants. (Japan's Fukushima nuclear disaster is not discussed because the book was published before that.) Two chapters describe renewable energy sources (geothermal, solar and wind power), which account for nearly 2% of total energy consumption and have thus much room to grow. Hydrogen ("forever fuel or wishful thinking?") and fusion nuclear power (mimicking the Sun's engine on earth) each have their own chapter. Geopolitics of energy, technological imperatives, and climate change take up chapters 13 through 15. Concluding remarks come in the final chapter, 16. The strength of the book is that it reviews the sources, technologies, pros and cons of each energy resource, and presents a balanced discussion.

Several 'big-picture' thoughts emerge from Montgomery's study of energy for the next three decades. First, the energy sector will increasingly draw the attention of governments and industrial enterprises as energy is crucial to the world's economic growth, urbanization, power generation, transportation, food and so on. This must be good news to companies, investors and researchers as well as to educational and publishing institutions involved in various aspects of energy. Second, most of the economic growth, industrialization and urbanization will occur in the developing countries, most notably China and India. Third, no single energy resource will be able to deliver what the world needs; an energy mix depending on geographic conditions will shape the future energy markets around the world. Fossil fuels have not peaked and their production will continue to grow; natural gas, in particular, will become more significant partly because it releases less carbon dioxide, but coal is still most abundant (70% of fossil fuels) and cheapest. Every energy resource has its own challenges and prospects in terms of technology, commerciality, environmental impact, and geographic distribution. Finally, energy security requires the most important resource – the human mind. New ideas generate new technologies. Information and education must dispel people's misconceptions and myths about energy. And books such as this one help that cause.

Overall, I found this book a well-written package of information, analysis, and insight on various aspects of energy.




*Author Scott L. Montgomery holds an M.S. in geology from Cornell University.*

*The Powers That Be: Global Energy for the Twenty-First Century And Beyond* is published by the University of Chicago Press, Chicago & London, 364pp, $35

**RASOUL SORKHABI**

# The Oil Detectives

What is an Oil Scout? Is it a 'cloak and dagger' operation – or a highly qualified occupation calling for extensive knowledge of the industry and great interpersonal skills? **Andrew Melvin** of Moyes and Co. sheds some light on the business.

*Andrew Melvin was previously a Scout for Phillips Petroleum, Texaco Inc, and Energry365/ energypedia*

***What exactly are Scouts?***

Late in the 19th century when oil in the US was in demand for a lighting fuel as whale oil declined, the cost of black gold rose and it became a much sort after commodity. Scouting for information developed as oil companies and prospectors became desperate to find out if a rival had been successful and what that implied about conditions in the area. This position on information has remained in the oil companies ever since although now it has spread on a global scale.

Originally the Information Scout would roam the fields and plains of the oil provinces with a telescope and a note pad, checking on how deep the well was drilling by counting the drill pipe stems and hanging around to check on the success. As land leasing became more important secrecy levels increased – hence the need for the Scout. Oil traders were not above spreading misinformation about a well's success or failure with scouting rumors being the bread and butter of speculation. The Scout was seen as a hybrid of a cowboy and a Pinkerton detective agent as they watched and infiltrated all around them to get the important information required. It became a high risk, hard drinking profession. The individuals or small teams assigned to the companies often flourished outside the normal working environment of the industry (and in some cases still do).

***How have things changed?***

For today's Oil Scouts, life is very different, although there is a hint of the cloak and dagger glamour in finding a story before anyone else and reporting that back to the employers. The Oil Scout today will attend arranged meetings with Scouts or officially nominated personnel, who range from Geological Technicians to the CEO of the Company, and share information on recent company activity. Although new discoveries and dry holes are the talking points, the Scouts of today are more interested in the deals the companies are offering, who is farming-out or selling what acreage, or what country is about to release information on a new license round.

The other big step change is the introduction of the professional or industrial scouting agencies – organizations that specialize in information and data gathering and then sell this information back to oil companies and other energy industry associated agencies, like banks, investors and advisors. This has replaced a lot of the employed scouts. Dependent on their reputation, the agencies value authenticity and correctness of information very highly.

***What sort of information do scouts seek?***

Obviously obtaining actual well data, logs, tests completion results is useful, but this is more and more difficult to obtain as most data is stored electronically. Any type of information that will give your company the competitive advantage when exploring in a new area with the end reward of producing new reserves is important. Sometimes it all starts from a rumor.

***Why is scouting important to the industry?***

Networking can be a very under-rated art, but it is key to know the who, what, where, and whys of what is happening in specific areas to maintain competitiveness. Of course the modern scouting representative is often well qualified and knows how to disseminate information very quickly to the appropriate department.

***When did formal Scout Groups start?***

The International Oil Scouts Association (IOSA) was chartered in 1924 in USA and is a federation of district scouting organizations. It promotes scouting and the petroleum industry and publishes an annual petroleum statistical book. Since then scouting organizations have formed in many countries, varying from established centers like Houston, Calgary and London to countries with lesser involvement in the industry, like Spain and Turkey. A code of ethics and rules will apply to each group to keep control and ensure fair play and any legal requirements.

***What makes a good Scout?***

Nowadays a person of diligence and experience, observation and forward thinking with a good communication manner and an eye for an opportunity.

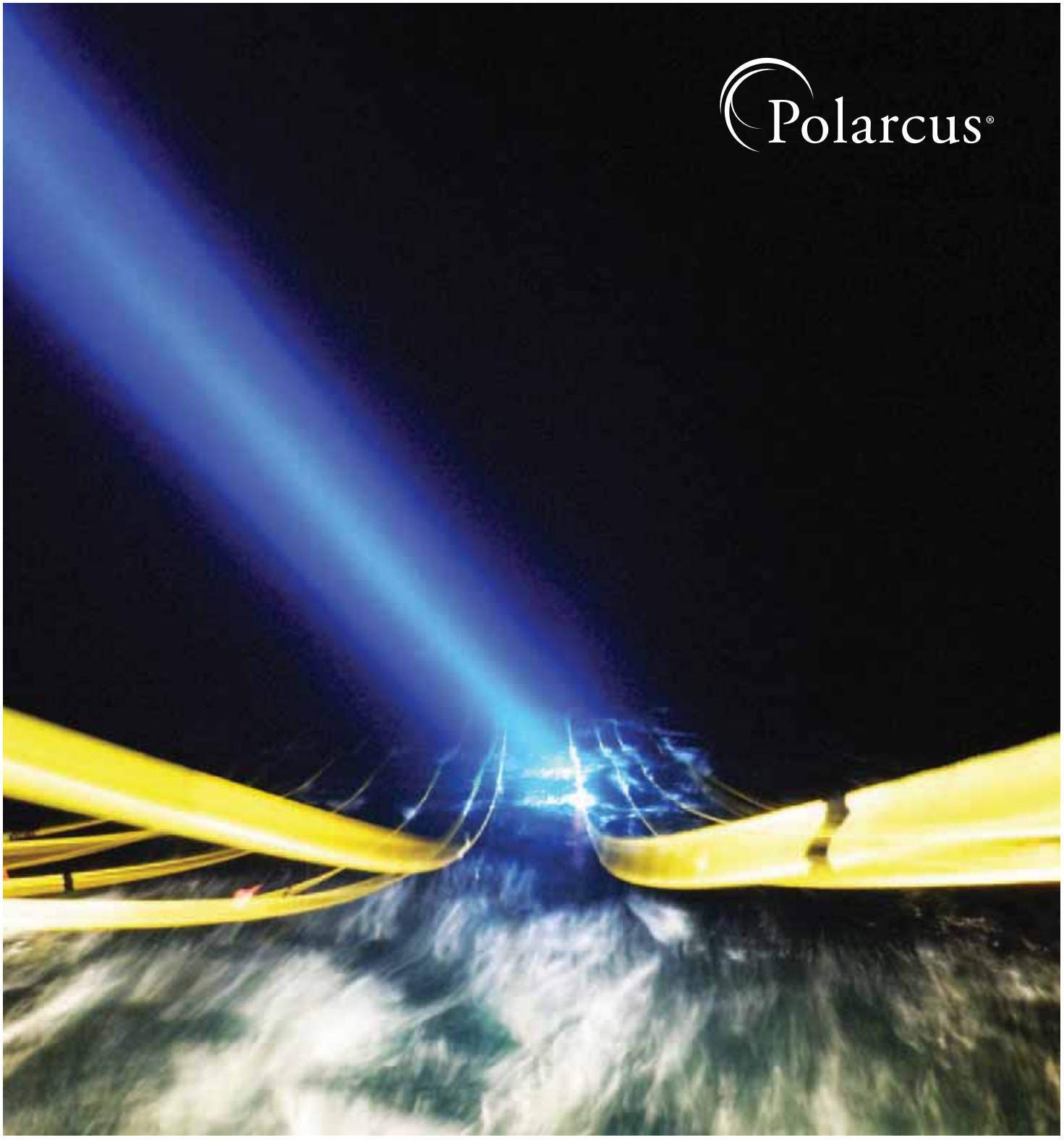
***With modern communications and technology, is there a future for the Scout?***

Over the last 20 years the oil and gas industry has embraced information technology and this also applies to scouting. In the old days the Scout would be happy to slowly put together a jigsaw of facts to build a picture of what was happening. Now, so much information is available on the internet and the user friendly news sites, along with information companies, it is much rarer to produce anything outstanding and market changing.

***Oil Scouts have been described as 'oil detectives': would you agree?***

That is one of the nicer descriptions! I think it depends on the country!

*For more information, contact Andy on amelvin@moyesco.com, or Terry Strang of IOSA on Terry_Strang@nexeninc.com* ■




# PASSIONATE ABOUT SEISMIC™

All Polarcus vessels are equipped with the latest high-end seismic acquisition, navigation and positioning technologies. Taken together, the vessels and the data acquisition systems provide complete flexibility for Polarcus to meet the entire range of possible seismic survey objectives using marine towed streamer techniques.

*Find out more, visit www.polarcus.com*

Scan the QR-code with your mobile phone and read more about our **GREEN** agenda

# Colombia Rediscovered


Ecopetrol

THOMAS SMITH

Colombia's regulatory reforms are paying dividends, with dozens of new oil and gas discoveries over the past two years – yet 'rediscovered' older fields are carrying the country to new production records.

*New drilling (two rigs pictured in the background) in the Llanos Basin heavy oil province, in this case near the Acacias production facilities, has been the catalyst for Colombia's surging production.*

As reported in a *GEO ExPro* Update article (Vol. 8, No. 3), Colombia's upstream oil and gas industry has been drilling exploration and development wells at a record pace over the past two years. This resurgence is, in part, the result of a series of government regulatory reforms making the area very attractive to foreign investors as well as prompting much larger exploration and development outlays by the companies already operating there. A second factor has been a much improved security situation. Finally, higher oil prices cannot be overlooked in making the heavy oil province very attractive.

For the third quarter of this year, Ecopetrol is reporting a new production high of 731,500 boe per day. That is an oil and gas production increase of 15.7% from the previous quarter. The average 9-month production of 716,000 boe per day broke the company record of 616,000 boe per day set in 2010. During the first three-quarters of 2011, Ecopetrol drilled 15 wells, eight finding oil. National oil production is also at a record high of 950,000 barrels per day.

The cornerstone of Colombia's oil production is from the Llanos Basin oil province that produces about 40% of the country's oil. This is where most of the country's recent production and reserve growth has occurred. As **Dr. Andrés Mora**, Ecopetrol's Instituto Colombiano del Petroleo Onshore Geological Research Leader, explains, "The heavy oil province is undergoing a resurgence of exploration and exploitation. For example, when the Rubiales Field (now operated by Pacific Rubiales Energy) was discovered in 1982, it was thought to be worth very little. Production remained very low, only 12,000 bopd were produced in 2007. At the end of 2010, production was up to 138,000 bopd and is still climbing. Most of the companies operating in the region have taken a second look. Ecopetrol has found at least five new fields in the region over the past year, increasing reserves by about 5%. In the past 5 years, other important discoveries have been focused in areas of traditional strength, which are the foothill settings (Gibraltar, Hurón, Oripaya) as well as some near-field discoveries in the Upper Magdalena region. In addition, the heavy oils in the Llanos Basin (recent Quifa and Caño Sur discoveries) represent a new frontier for us and should provide significant reserve growth."

"Ecopetrol has important technological challenges ahead," adds Dr. Mora. "While we are increasing production through faster and intense primary production, there is the need to increase the use of secondary and tertiary enhanced oil recovery techniques. In this respect, the research branch of Ecopetrol, the Colombian Petroleum Institute, is undertaking important pilot projects in the Llanos Basin using new technologies. One of the projects that we are excited about will be testing air injection to recover more oil from producing traps."

"Colombia's very attractive investment climate and improved security situation has drawn many new companies, and the established companies are spending much more on exploration and development," says Dr. Mora. "While the recent successes have been in explored areas, the real future for the industry will be the exploitation of under-explored frontier areas such as the Caribbean basins. These are a real challenge, since they are expected to hold billions of barrels of recoverable oil but little is known about them. We are now using new concepts developed in the foothill onshore settings to explore the frontier and offshore basins in Colombia where only a few wells have been drilled. Analogs from the Peruvian foothill areas, like the Camisea complex, have proven to be very productive." It should be noted that Ecopetrol aggressively increased its acreage in the Peruvian Subandes in the 2010 bidding round. ■

# A Gloomy Future

*Halfdan Carstens*

**The 2011 World Energy Outlook tells us that fossil fuels will dominate for the next 25 years. The result: a substantial increase in temperature.**

The world is rapidly locking itself into an insecure, inefficient and high-carbon energy system.

This is the truth, given that there is no radical change in policy direction, according to the International Energy Agency. There is still time to act, but the window of opportunity is closing, the agency adds.

The 2011 edition of the World Energy Outlook was released on November 9 and brings together the latest data, policy developments, and the experience of another year to provide robust analysis and insight into global energy markets, today – and for the next 25 years.

"Growth, prosperity and rising population will inevitably push up energy needs over the coming decades," Executive Director Maria van der Hoeven of IEA said when the report was presented. She continued emphasizing that "governments need to introduce stronger measures to drive investment in efficient and low-carbon technologies". The sharp rebound in energy demand in 2010, which pushed $CO_2$ emissions to a record high, certainly highlights the urgency.

The numbers presented by IEA are daunting. First of all, primary energy demand is expected to increase by one-third for the next 25 years, even with WEO's central New Policies Scenario, and a good part of this will be covered by fossil fuels, meaning that the level of $CO_2$ in the atmosphere is bound to increase. This is true even if the share of fossil fuels falls from around 81% today to 75% in 2035. Renewables, on the other hand, are expected to increase from 13% of the mix today to 18% in 2035.

The latter sounds good, but be aware that the increase in renewables is dwarfed by the increase in fossil fuels, in absolute numbers.

For example, oil demand rises from 87 MMbopd in 2010 to 99 MMbopd in 2035. Even worse, the use of coal – which met almost half of the increase in global energy demand over the last decade – rises 65% by 2035. More efficient power plants and carbon capture and storage (CCS) technology could boost prospects for coal, but the latter still faces significant regulatory, policy and technical barriers that make its deployment uncertain.

It is, for example, noteworthy that despite lots of smooth talking, not a single CCS plant for coal has been built yet.

The future for natural gas is fairly predictable, according to the World Energy Outlook. Its share in the energy mix will rise, and gas use will almost catch up with coal consumption.

In the New Policies Scenario, cumulative $CO_2$ emissions over the next 25 years amount to three-quarters of the total from the past 110 years, leading to a long-term average temperature rise of 3.5°C. However, if the new policies are not implemented, we are on a more dangerous track, to an increase of 6°C.

"As each year passes without clear signals to drive investment in clean energy, the 'lock-in' of high-carbon infrastructure is making it harder and more expensive to meet our energy security and climate goals," said Fatih Birol, IEA Chief Economist.

There is no particular reason for being optimistic on behalf of the future of the human race. ■

### Depressing News

*"While world primary energy demand increases by one-third between 2010 and 2035, and energy-related $CO_2$ emissions increase by 20%, following a trajectory consistent with a long-term rise in the use of energy, average global temperature will increase in excess of 3.5°C."*

*(IEA World Energy Outlook 2011)*

## 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.

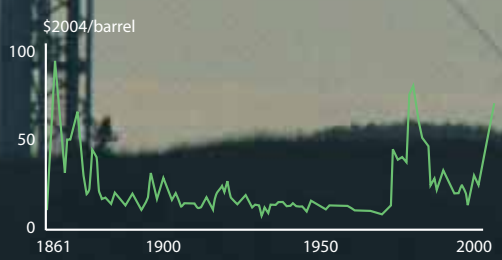
**Numbers**
Million = 1 x $10^6$
Billion = 1 x $10^9$
Trillion = 1 x $10^{12}$

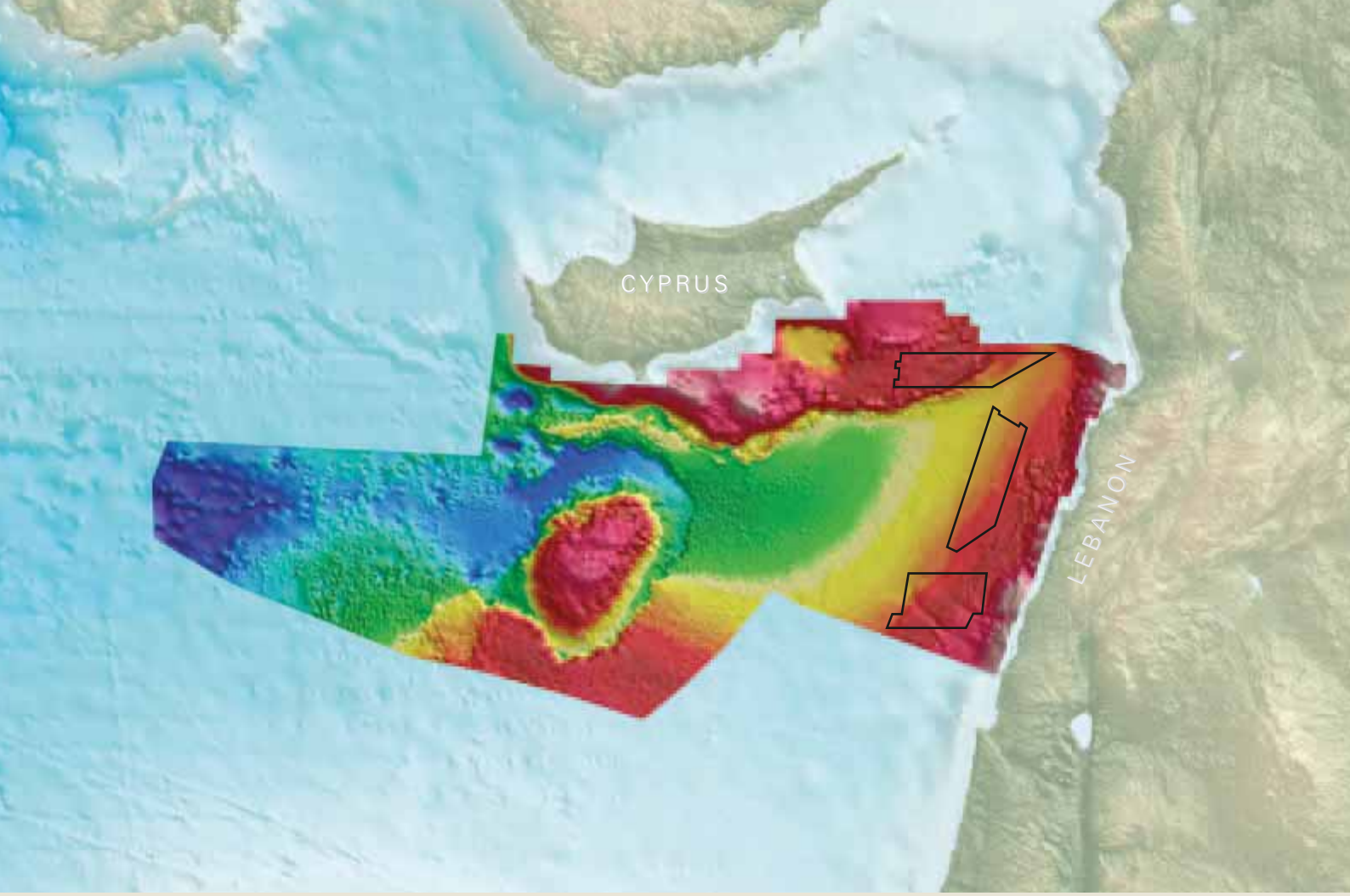
**Supergiant field**
Recoverable reserves > 5 billion barrels (800 million $Sm^3$) of oil equivalents

**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**






# MegaSurveys

## Eastern Mediterranean MegaProject

**Regional interpretation**

**GeoStreamer data**

**Subsalt horizons**

**Upcoming license rounds**

**The Eastern Mediterranean MegaProject** (EMMP) combines recently acquired PGS MultiClient and vintage data to offer the most comprehensive data coverage of this underexplored area. With both GeoStreamer® technology and 3D surveys, the EMMP interpretation of key horizons reveals structural trends, prospects and leads, providing an improved understanding of offshore Eastern Mediterranean.

**With the recent giant discoveries in the Levantine Basin, the Eastern Mediterranean offshore has become an exploration hotspot.**

**Per Helge Semb**
Tel: +47 90 61 99 61
per.helge.semb@pgs.com

**Oystein Lie**
Tel: +47 93 08 56 61
oystein.lie@pgs.com

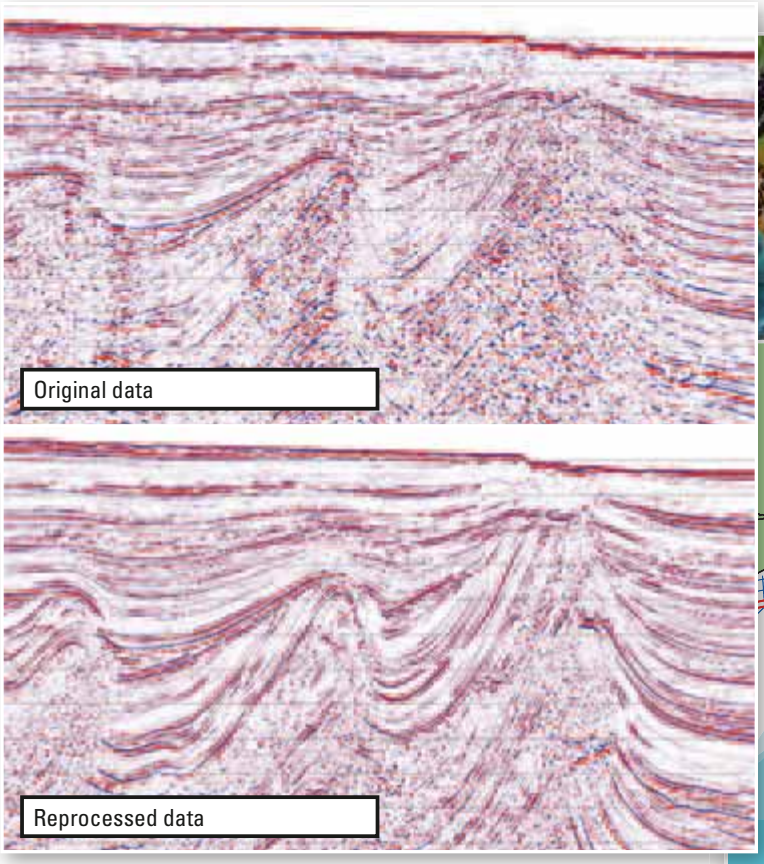
**Nicolai Benjamin Dahl**
Tel: +47 92 49 39 31
nicolai.dahl@pgs.com

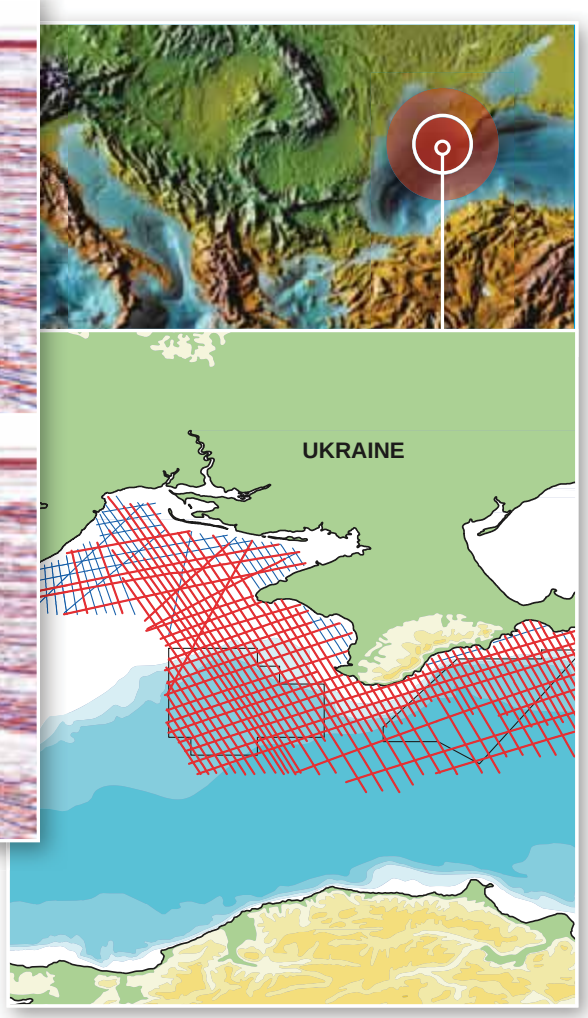
**A Clearer Image**
**www.pgs.com**

PGS

# Multiclient Services

## 17,000 km of 2D Seismic Data Offshore Ukraine,
Including 14,000 km of Reprocessed Data




### Reprocessed Data Offers Increased Resolution and Improved Imaging

Data have been reprocessed in association with the Ukraine State Geological Survey using a modern comprehensive sequence, including

- intensive demultiple processing with 2D surface-related multiple elimination
- full Kirchhoff prestack time migration
- spatially continuous velocity analysis
- relative amplitude processing with AVO products
- inversion-ready prestack data.

Petrel* seismic-to-simulation software and SEG-Y deliverables are also available.

**For more information, please contact us on**
**+44 (0) 1293 556533.**
**www.westerngeco.com/multiclient**

WesternGeco