vol. 8, no. 5 – 2011

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

History of Oil:
80 Years of Discovery

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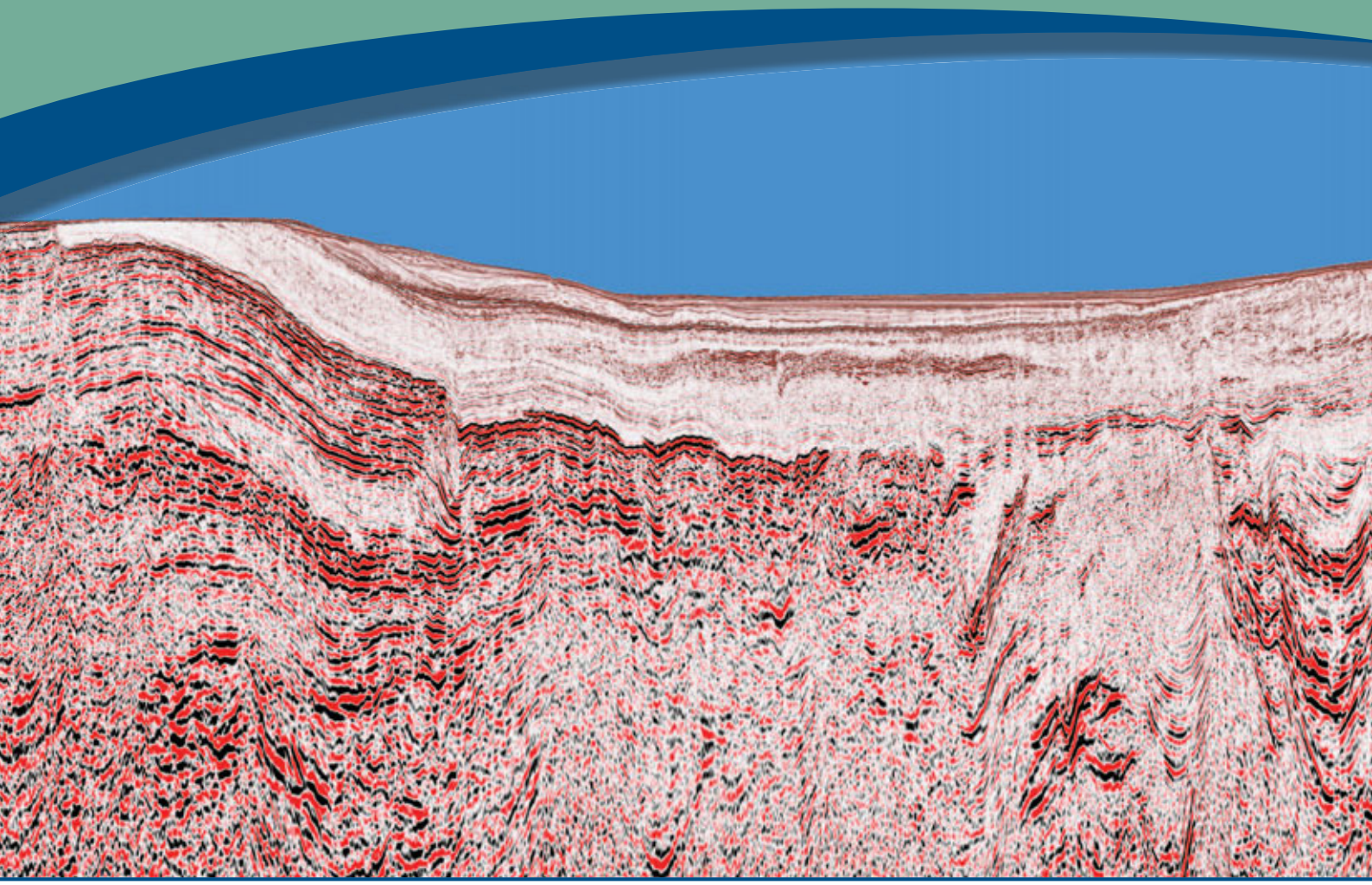
GEOSCIENCE EXPLAINED
Petroleum Systems: Following Oil Through Time

TECHNOLOGY
Integrating the Toolbox

EXPLORATION
What Next for the Russian Arctic?

GEOLOGY GEOPHYSICS RESERVOIR MANAGEMENT

Clarity in Depth



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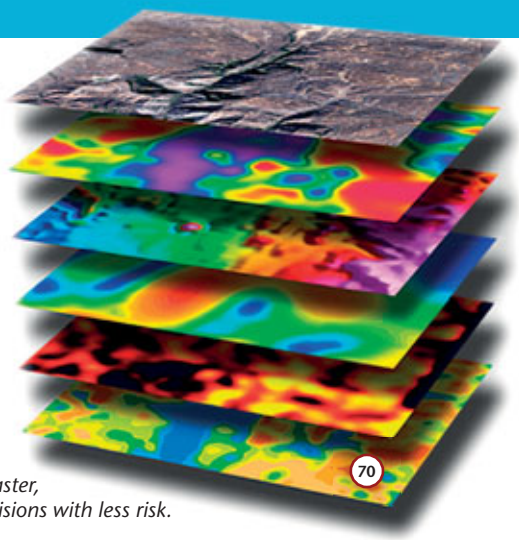

NEOS

Integrating the tool box of technologies helps exploration companies make faster, more informed decisions with less risk.

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A view of the lower sandstone-rich unit of the West Crocker turbidites in Kota Kinabalu, Sabah.

Rasoul Sorkhabi

Petrel 2011

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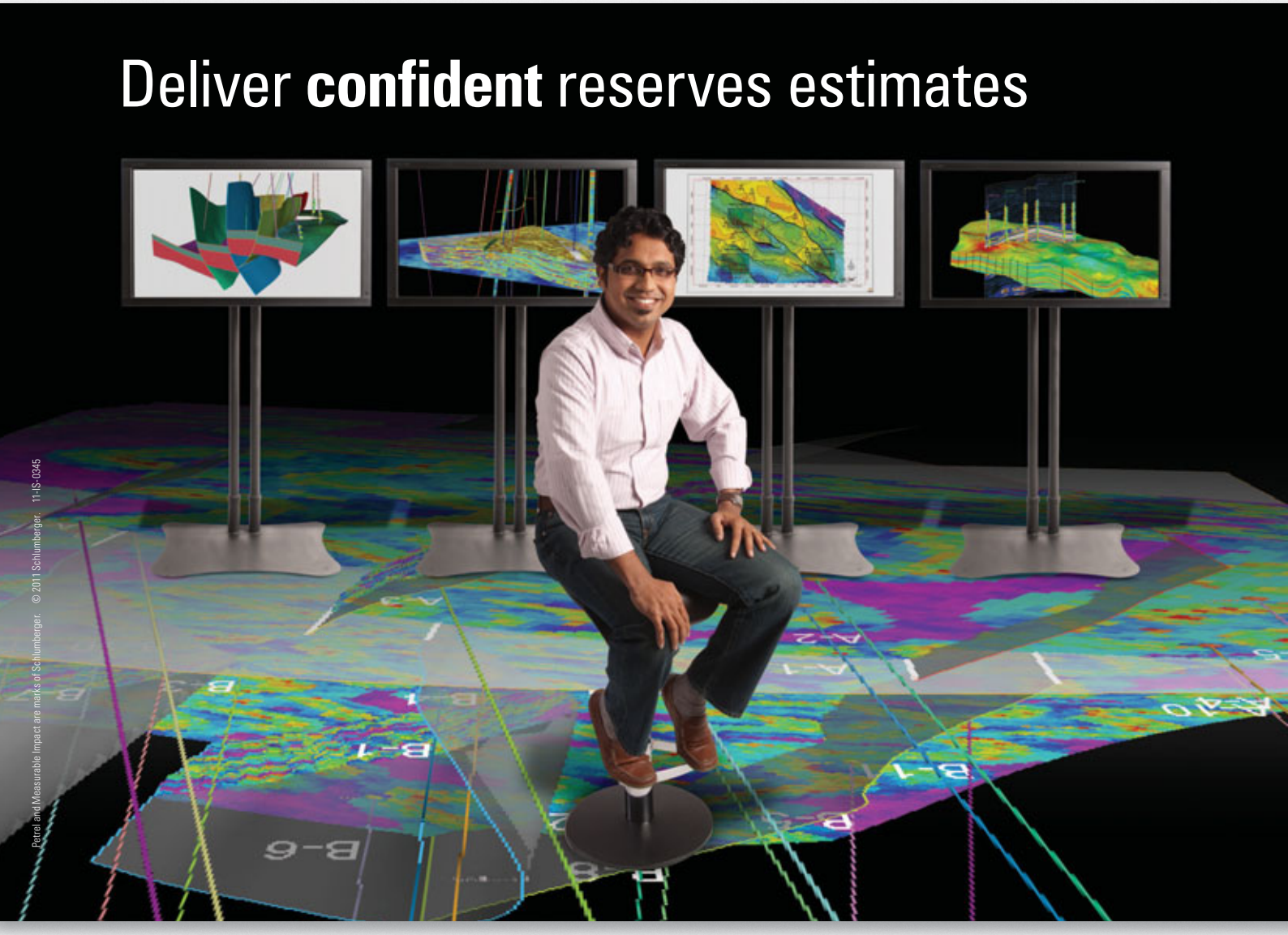

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Surprise! A Giant New Field

The oil industry is full of surprises. One of the biggest this year has been the discovery of a giant field, not in a new frontier, but in that well-worn old area – the Norwegian North Sea. As we discuss in this issue of GEO ExPro, the Avaldsnes/Aldous Major South discovery, with potentially between 1.2 to 2.6 Bbo recoverable, is possibly the largest find anywhere in the world this year – and this in the middle of a mature petroleum province in a block that has been explored since 1965.

The Transocean Leader drilling the Aldous Major South discovery in the Norwegian North Sea

So what can bring about these surprises? Technology breakthroughs are crucial, with new techniques like gravity gradiometry beginning to come into their own, particularly in hard-to-access frontier areas like East Africa. Good geoscience practice like petroleum system modelling and analysis are also vital. Vast quantities of data are now at hand for the explorationist and the important thing is knowing how to deal with this data and combine the different fragments of knowledge gleaned from it. The basic principles of geology and geophysics are unchanged, but our ability to use the tools at our disposal has improved.

Technology is important, but the human imagination remains a vital component for successful exploration. Which is why training and mentoring are so important for young people entering the profession, to develop their natural curiosity and expand their skill sets across the range of the industry. It is up to those of us who have been around for a number of years to make sure that our knowledge is spread to these newcomers. They will be the ones to either develop the future generation of tools, or use them to spot the next Avaldsnes.

JANE WHALEY
Editor in Chief

PETROLEUM SYSTEMS

The McKettrick oil seep is located in the south-west corner of California's Central Valley, 50 km west of Bakersfield. Oil seeps in this area led to the 1894 discovery of the Midway-Sunset oil field and other early discoveries. Today, petroleum system modelling, featured in this edition on page 22, is helping explorationists follow the oil to new discoveries. The Midway-Sunset field is the third largest in the United States, having produced 3 Bbo (480 MMcm) and is still in production.

Inset: Having just celebrated its 80th anniversary, CGGVeritas is one of the longest established service companies in the oil industry. We look at the developments and adventures that lead to the growth of both the company and the seismic industry.

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Will Global Slowdown Reduce Oil Prices?

THINA MARGARETHE SALTVELT, PH.D

A severe slowdown in global economic activity will cut oil demand markedly and thereby trigger a sharp fall in oil prices. During the financial crisis the Brent oil price fell by 75% to US $36.6/barrel in December 2008, from US $146/barrel in July. If we assume that the recent increase in uncertainty and the weaker economic performance of the US and the Euro zone will push the world economy into a prolonged period of low economic growth, do we expect a new collapse in the oil price?

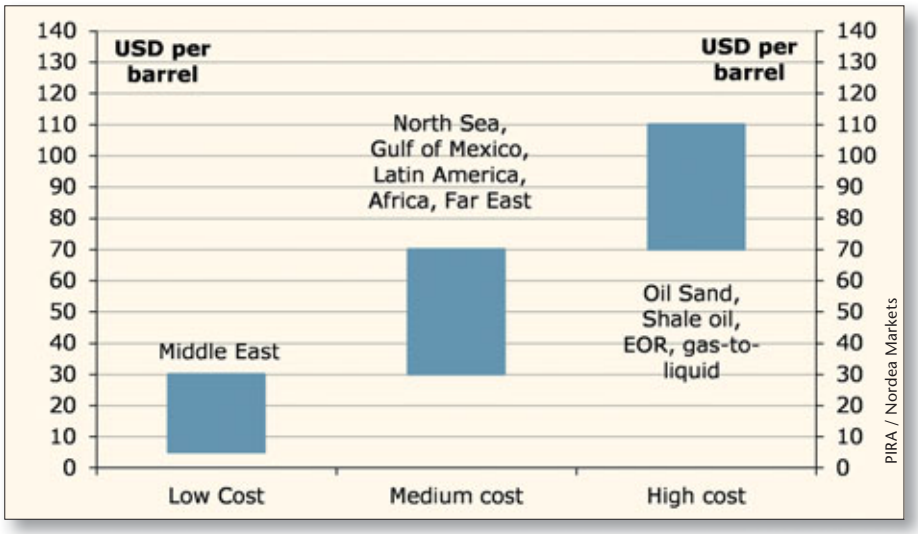
Assuming that global GDP growth will be 0.5% lower in 2011 and 2% lower in 2012 than in our baseline scenario, oil demand is expected to be reduced by 400,000 bpd in 2011 and 1.4 MMbpd in 2012. A new economic downturn will clearly trigger a sharp fall in oil demand, but in our opinion a few recent developments in the oil market may have a counterbalancing effect on the fundamental situation, thereby preventing oil prices from falling to the lows seen in 2008.

First, OPEC has not changed its official output quota since January 2009 when the cartel agreed to cut 4.2 MMbpd. The cartel does not need to coordinate new production quotas before it can start reducing its output if demand conditions deteriorate to a level where the market becomes oversupplied. Second, we expect OPEC to cut oil production at an earlier stage of a new recession cycle. Huge spending packages to try to prevent further uprising in the MENA region have in our opinion pushed up OPEC's breakeven price of oil – the price at which its budget is balanced while accommodating greater public spending.

In 2009 OPEC's unofficial oil price target was US $70-90/barrel, but we now expect this unofficial price range to have moved to around US $85-105/barrel. Saudi Arabia, the cartel's ultimate leader, needs an oil price of around US $85/barrel to balance its budgets. Third, the refilling of the emergency inventories after the IEA stock release will contribute to tightening the market. In addition, as prices drop we would not be surprised if China uses this opportunity to fill up its strategic petroleum reserves (SPRs).

How far can oil prices fall before we see cuts in oil investments? The global average marginal cost of a new project is around US $85/barrel, but it varies markedly around the world. For example in the North Sea the marginal cost averages around US $50-70/barrel compared to US $20-40/barrel in the low-cost Middle East. If the oil price falls below the marginal cost, new projects may be put on hold or cancelled. This in turn will reduce activity in the oil sector and cut demand for upstream and downstream services. Falling costs may counterbalance the drop in investments, but with a lag. ■

Marginal cost of a new barrel of oil



ABBREVIATIONS

Numbers
(U.S. and scientific community)

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

Liquids
barrel = bbl = 159 litre

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

Gas

MMscfg:	million ft^3 gas
MMscmg:	million m^3 gas
Tcfg:	trillion cubic feet of gas
Ma:	Million years ago

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

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

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

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

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

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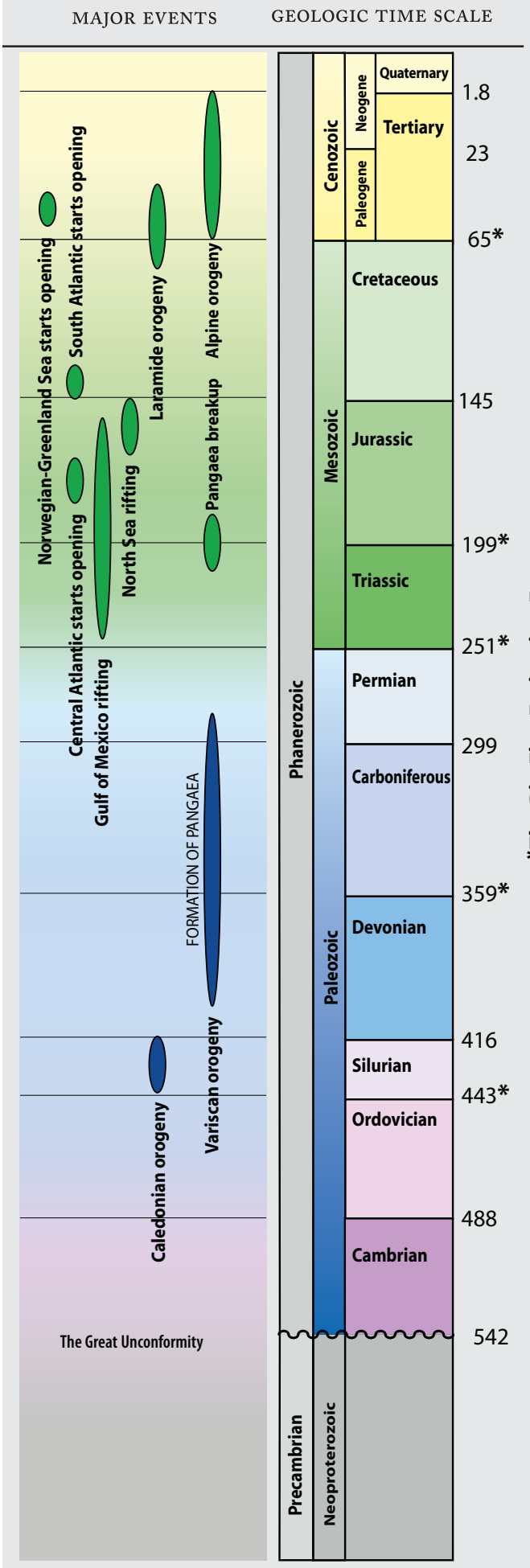
New Bid Round for Egypt

In September the Egyptian General Petroleum Corporation (EGPC) announced a new Bid Round, covering fifteen blocks located in four different areas. Seven of the blocks, comprising a total of 11,382 km^2, are in the Western Desert, a region encompassing the vast expanse of the Sahara between the Nile Valley and the Libyan border, while two, covering nearly 5,000 km^2, are offered in the Sinai, one in the centre and a second area on the south-west coast of the peninsula. On the opposite side of the Gulf of Suez three Eastern Desert Blocks are available, totalling 1,360 km^2. All this acreage is onshore, and there are also three offshore blocks available, covering 665 km^2 and located within the central part of the Gulf of Suez, which is where exploration started in Egypt back in 1906.

Egypt is a major oil producer, with estimated reserves of 4.5 Bbo recoverable (*BP Statistical Review*), but, according to the EIA, production peaked in 1996 at 935 Mbopd and is now about 660 Mbopd, which is slightly less than the growing economy requires, making the country a net importer at present. However, a number of recent major discoveries have been of non-associated gas, so Egypt's gas reserves now stand at about 77 Tcfg (*EIA*) and it is expected that this commodity will supply a continually increasing proportion of the country's energy needs. The majority of the gas has been found to date either offshore the Nile Delta – an area not included in this bid round – or in the Western Desert, where Apache are at present the largest producer of liquid hydrocarbons and natural gas in the country.

Data packages with seismic and well data for the Bid Round areas are available through the EGPC website (http://www.egpc.com.eg), where there is also additional information about the geology and petroleum systems of the different blocks. The round closes on 30 January 2012. ■

The El Q'aa Plain block is located on the coastal plain of the south-western Sinai Peninsula.



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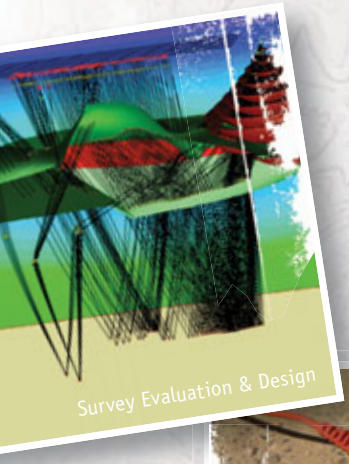

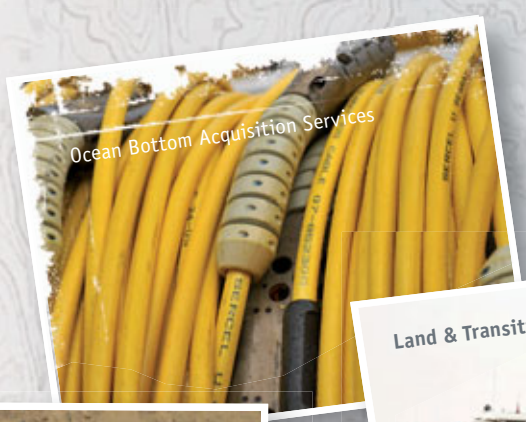

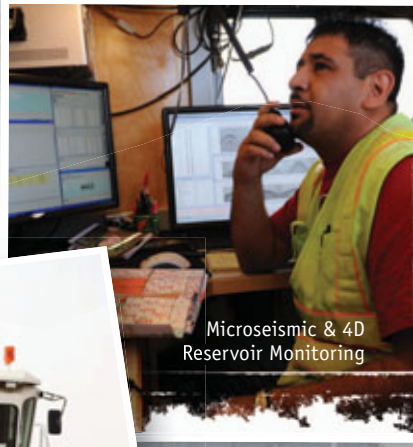

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Shale Gale Blows Eastwards

The shale gale still seems to be blowing towards Europe, despite a number of reservations having been expressed in the industry. Shell, for example, has just bought the right to drill the first 1,000 shale gas fields in **Ukraine**, a country which is estimated to have shale gas reserves of over 70 Tcf (2 Tcm) – sizable enough, although dwarfed by the estimated 200 Tcf (5.5 Tcm) reserves held by its neighbour, Poland. Ukraine is particularly keen to increase its own resource base, as it is at the moment heavily dependent on imports from Russia, from whom it imported an estimated 2 Tcf (57.6 Bcm) in 2010 alone – a major point of tension both internally and between the two countries.

Similarly, the **Czech Republic** is beginning to open its doors to companies from throughout the world interested in exploring for shale gas, including Basgas Energia Czech, a unit of the Australian-based exploration company Basgas, and the Czech unit of British company Cuadrilla Morava. However, there has been little exploratory work for shale gas in the country, and it will be some time before resources can be confirmed at present, let alone extracted. The Czech Environment Ministry emphasised that licences were only for research and that drilling based on any discoveries would not begin for at least another five years. ■

A Legacy of Exploration and Discovery

The 10th PESGB/HGS Conference on African E&P began with a packed PESGB evening lecture and ice-breaker reception held in the Royal Over-Seas League. Duncan MacGregor presented "African Rift Plays: Is the Present the Key to the Past?"; following this guests stayed for the ice-breaker reception sponsored by Tullow Oil.

Another day, another venue: The Queen Elizabeth II Conference Centre in Westminster, London, provided a stunning backdrop for the 10th Annual Africa Conference, and added to the rich atmosphere that pervaded. The sheer number of people, an 11% increase on 2009, created a lively and exciting show.

PESGB's new Executive Director Guy Elliott opened the conference and delegates prepared themselves for the high quality technical presentations that were to follow. Talks covered the whole continent, with the East African Rift and South Atlantic Play sessions proving particularly popular, but new plays in established oil-producing countries like Algeria were also discussed. Feedback was excellent, one man commenting on the superb organisation and another relaying the success of the event. One delegate said simply "great conference" and another that it had been "inspiring".

The first day of talks ended with an evening reception on the exhibition floor and when 480 people descended upon it, the room was bursting at the seams. Old friends met and swapped stories over a drink whilst a few steps away business cards were being exchanged by delegates making new contacts.

During break times, industrious exhibitors and curious delegates came together to form new agreements and generate business opportunities. 70% of this year's exhibitors were previous attendees, and you can see why. One exhibitor, typical of the 37 different companies at the show, told me, "We've had some really good business today."

PESGB and HGS would like to thank all their supporters who helped to make this event happen, particularly the organising committee and the various sponsors.

The 11th HGS/PESGB Conference will be 11–12 September 2012 in Houston, and you can find more information at www.hgs.org. ■

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Guy Elliott/PESGB

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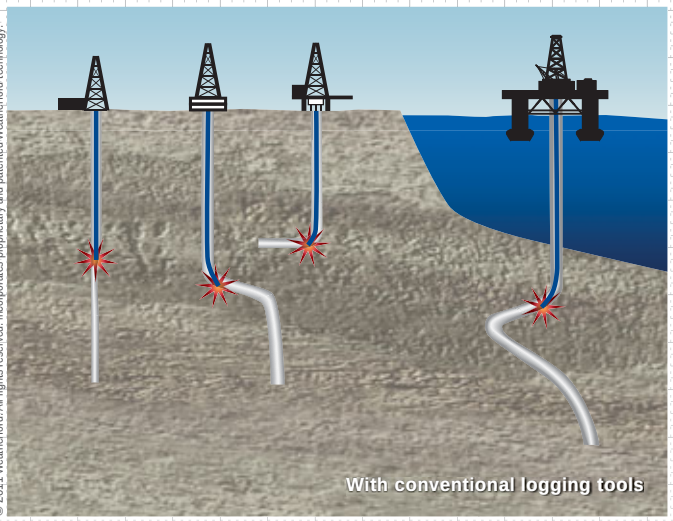

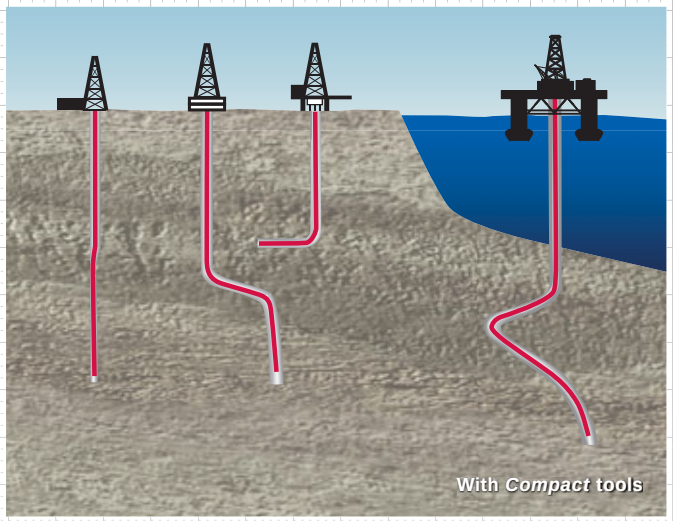

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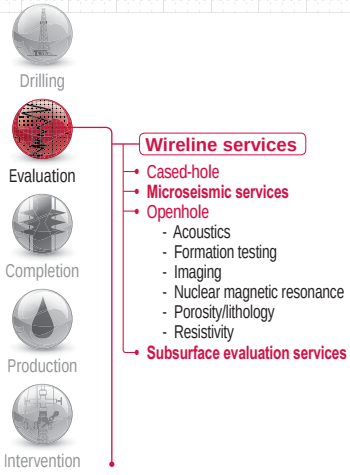

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Developing Explorers for the New Frontiers

A new unique exploration training centre at Aberdeen University aims to help explorers develop the geological inquisitiveness needed to discover new hydrocarbons.

Since the wagon trains rolled west across the fledgling United States, the term 'frontier' has always conjured geographic expansion. Whether exploring the poles, rainforests, deserts, high peaks or deep oceans, successful explorers share common mindsets and characteristics.

Hydrocarbon explorers need a unique set of thinking and behavioural qualities, the geological inquisitiveness to leave no stone unturned. And their greatest tool – the human mind.

This is the rationale behind **exploHUB**, the exploration training centre set up at the University of Aberdeen as a unique partnership between industry and academia to prepare exploration geoscientists for the challenge of discovering the Earth's remaining hydrocarbons.

Regional and Play Analysis Skills

"When it comes to the hunt for hydrocarbons, the frontiers are certainly changing," says exploHUB Director **Dr Stuart Archer**. "As the world's sedimentary basins become exhaustively explored, the term frontier means more than just a land grab for new acreage. Today's frontiers are everything from deeper and hotter plays (e.g. HPHT – high pressure, high temperature), previously unrecognised subtle stratigraphic traps, and targeting undrained compartments and previously missed pay. We also need to tackle the unconventionals, release the value in heavy oil, and exploit advances in seismic imaging and drilling technology."

Stuart knows his field. As an exploration and a production geologist for over 10 years, his experience includes exploring the Atlantic Margin, the Central North Sea, the Gulf of Mexico, production geologist on the Britannia Field and most recently on the newly discovered HPHT Jasmine Field in the North Sea's Central Graben.

"We know that most of the planet's 'easy' hydrocarbons have been found," he adds. "As a community we need to do something different to find and access the more complex reservoirs. We need a new generation of 'explorationists', equipped with the inquisitiveness, skills and creativity required to successfully discover what Earth may still be hiding from us. This is exactly what exploHUB is all about."

One example of a frontier that Dr Archer believes must be crossed is the lack of regional-scale play analysis skills. His view is that the importance of regional geology and play fairway mapping has been undermined over the years by an over-emphasis on postage stamp scale reservoir characterisation, geological modelling and prospect evaluation – causing geologists to lose sight of the bigger contextual picture and the potential to see new opportunities through regional integration. To redress this, he believes that exploration training must focus on the play fairway scale. exploHUB students will also go back to basics by actually looking at rocks on the surface – through local and international exploration field trips – to better inform subsurface interpretation.

The 2011 exploHUB exploration team enjoy a field trip on the Isle of Skye.

Training the New Crew

The challenges are not only in the science. Exploration, like other parts of the industry, is facing what has been termed 'the big crew change'. "We know only too well that we are set to lose invaluable geoscience experience in the next 15 years or so," says Dr Archer. "And here again academia has a vital role to play in working with the E&P industry to address this.

"Not only will the crew itself change – the new crew will need to change the tools in the toolbox. For example, we need to manage the technical transition from structural to stratigraphic traps, from shallow and clearly imaged targets to deeper and fuzzier targets, from conventional to unconventional resources, and from extraction to sequestration.

"This is where the 'old hand' resource is vital – and Aberdeen is, after all, home to the second largest geoscience community in the world after Houston. We must tap into the invaluable experience of these old (and not so old) timers. At exploHUB we provide an environment that feels more like a dedicated exploration team in an oil company than a classroom – with learning by doing rather than 'chalk and talk' or 'death by powerpoint'. Using industry standard hardware, software and data the trainees actively explore in an immersive team environment for a nine month period. The course represents continuing professional development and is aimed at potential explorers of all ages.

"What we are creating, above all, is a gathering place for explorers in general. We're distilling what it is to be a successful explorer, and harnessing that willingness to push back the new frontiers. Only by engendering and developing these qualities in the next generation of geoscientists will we successfully maximise the value of the Earth's last remaining hydrocarbon resources."

For more information on exploHUB contact Dr Stuart Archer on:
Tel: +44 (0)1224 273449
Email: s.archer@abdn.ac.uk or visit www.abdn.ac.uk/explohub ■

UK Quad 28

New Multi-Client 3D Data

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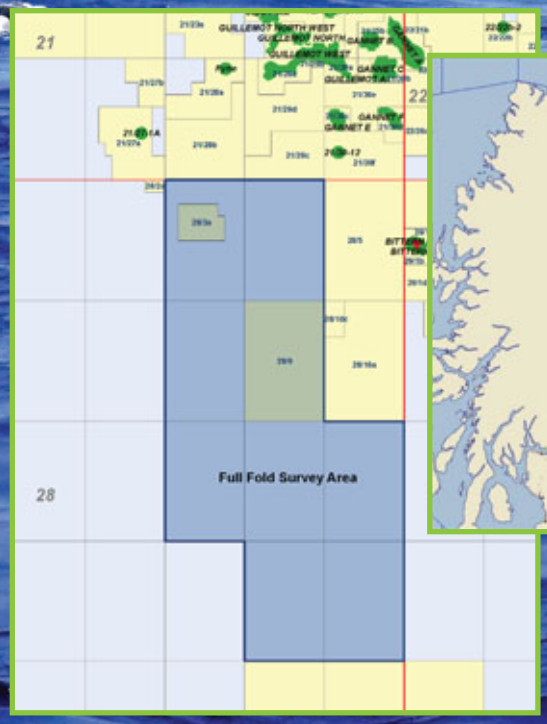
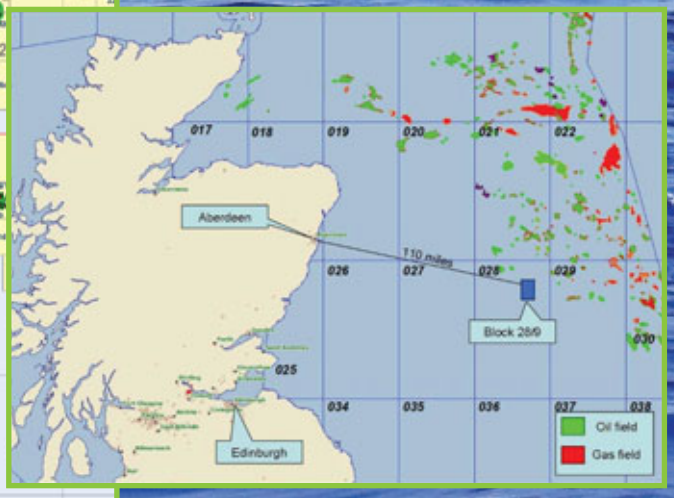
To view data sheet for the Catcher survey please scan.





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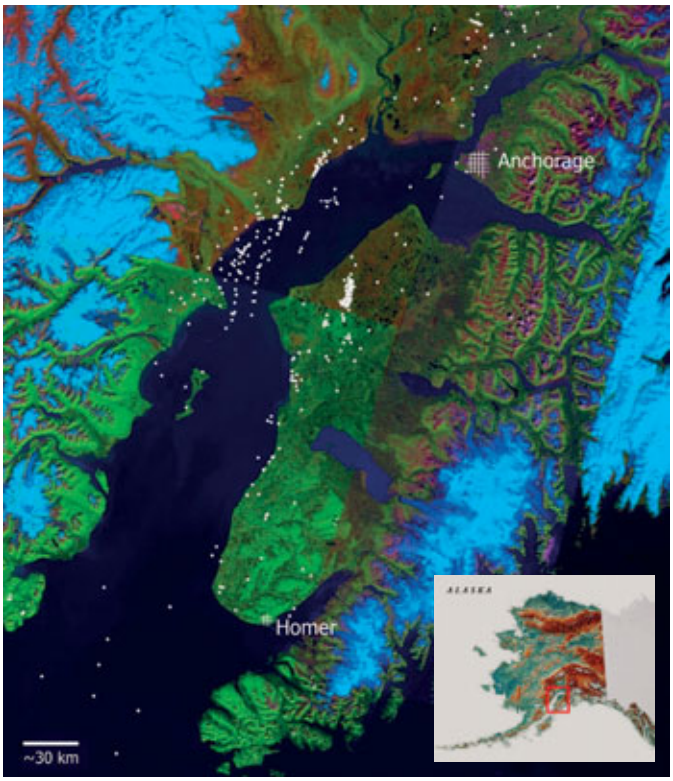
Giants Await Discovery in the Cook Inlet Basin, Alaska

Alaska's first major oil discovery was made on the Kenai Peninsula by Richfield at Swanson River in 1957 (see *GEO ExPro* Vol. 8, No. 2). This discovery led to a rapid exploration of Cook Inlet Basin that included both onshore sides of Cook Inlet and the State-owned offshore area. In all, 16 offshore platforms were installed and several large gas fields were found onshore. Oil production peaked in 1970 at 82 MMbo per year. To date, the basin has produced about 1.4 Bb oil and 10 Tcf gas.

All of the discovered oil and gas lie in structural traps along two trends roughly parallel to the basin axis – one lying east and the other lying west of the axis. Few wells have been drilled outside of these trends, leaving untested prospects along the axis of the basin and stratigraphic plays along the anticlinal flanks.

In the hope of spurring more drilling, the State is offering one of the most favourable oil and gas tax and royalty environments just about anywhere. There are tax credits of up to US $25 million per well for the first three wells drilled in Cook Inlet using a jack-up rig. The Legislature has expanded the existing gas development tax credit from 10% to 25%. In addition, there are excellent incentives for 'small' producers, gas exploration, nonconventional gas development, and gas storage projects.



Alaska Division of Geological and Geophysical Surveys

Cook Inlet oil and gas wells (shown as small white dots on this composite satellite image) are concentrated along several north-south structural trends, leaving large areas in the basin unexploited.

Large Offshore Prospects

Several large prospects extending south-west from the offshore ConocoPhillips North Cook Inlet gas field are waiting to be drilled. It had been more than a decade since an offshore rig drilled any new exploratory wells when Escopeta Oil contracted the Spartan 151 jack-up rig.

The prospects consist of Northern Lights, Corsair, Kitchen and East Kitchen. These are all anticlinal prospects on trend and down dip from known fields. Corsair is the only one of these that has been drilled. Shell, Phillips, and ARCO drilled a total of five exploration wells between 1962 and 1993. All wells encountered gas shows and some oil was tested.

The Spartan 151 jack-up arrived in Cook Inlet on August 10 of this year and Escopeta has spudded the well, just beating a deadline set by the State Legislature to take advantage of the incentive programme passed last year.

Buccaneer Alaska, a local subsidiary of an Australian independent, drilled its first well onshore on the east side of Cook Inlet north of Marathon's Cannery Loop unit. Their Kenai Loop No. 1 test flowed gas at 30 MMcfpd and the company is planning a second well this fall. Buccaneer is also hoping to purchase a jack-up rig to drill two offshore prospects in upper Cook Inlet, the Southern Cross unit and the North West Cook Inlet units.

Apache Alaska, of the Houston-based Apache Corp., started amassing existing Cook Inlet leases last year. In all, it acquired a blend of 795 km^2 on and offshore, all undeveloped. Then this year, Apache dominated the last Cook Inlet area-wide lease sale, netting 92 of the 109 tracts (5,750 km^2) sold. The sale was the fourth-largest in state history, totaling over US $11 million. Apache completed a 2D seismic programme in the Redoubt Bay area evaluating a new nodal technology. Results are encouraging and it is planning more extensive onshore and offshore programmes for 2012.

New Life for Old Assets

The major companies still active in Cook Inlet such as Chevron, ConocoPhillips and Marathon have concentrated on keeping what they have still producing. Chevron is planning a workover and gas drilling programme on its Steelhead platform. Marathon has steadily reduced drilling over the past several years but did drill an exploration well in 2010 on its Sunrise prospect inside the Kenai National Wildlife Refuge. The well "encountered a zone of interest", however the company revealed no other details. ConocoPhillips is focusing on field maintenance at the Beluga River Unit.

Armstrong Cook Inlet became the newest producer in the basin when the Denver-based independent and several partners started production from the North Fork unit, discovered in 1960. In its first year of operations, Cook Inlet Energy is restoring production from older fields it picked up from the bankruptcy of Pacific Energy Resources. Cook Inlet is also considering exploration and additional development wells to be drilled from the Osprey platform, the last to have been installed in Cook Inlet, in 2000.

Linc Energy Alaska completed its first well in October 2010 saying "three significant sand intervals were gas charged". However, Linc is primarily focused on underground coal gasification to produce synthesis gas in place from the deep coal seams which are abundant and thick in the basin. ■

THOMAS SMITH

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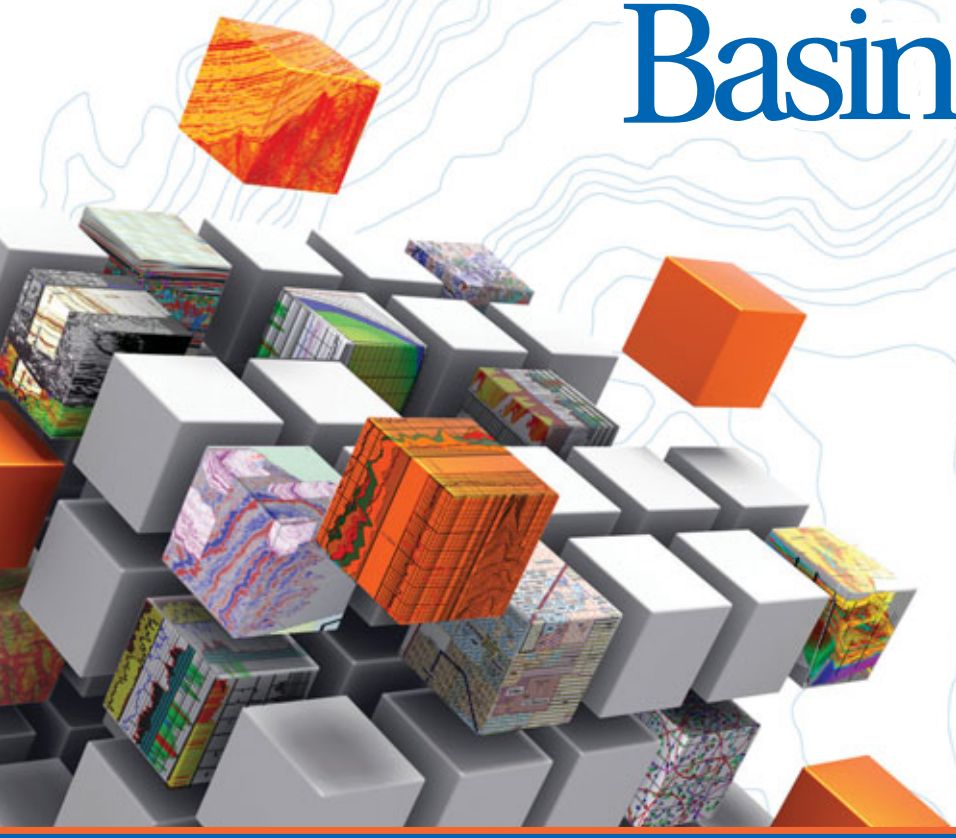

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Don't Throw Those Books Out!

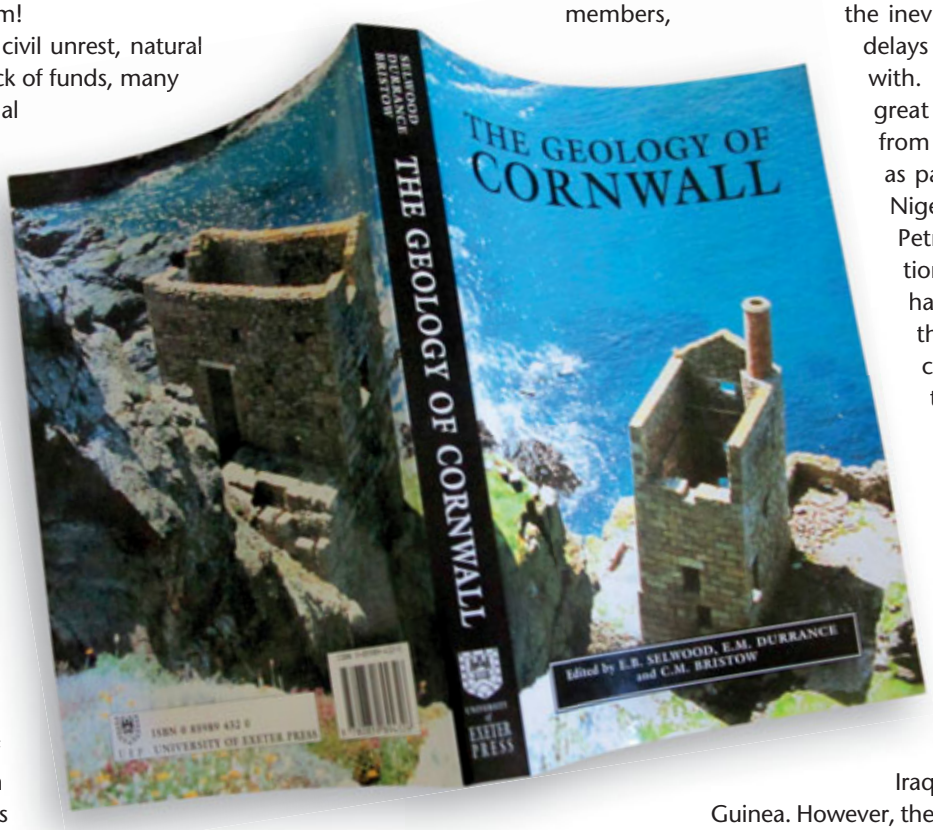
'Geoscientists helping Geoscientists!' That is the catchphrase for the organisation which has as its mission the desire to share knowledge by getting books, journals and other publications into the hands of geoscience students throughout the world

Is your company or organisation downsizing its library, merging it, or transferring its resources to an online or virtual platform? Or have you a large pile of old books and periodicals gathering dust in your attic? Don't throw them out – the AAPG would love to help you find a good home for them!

Because of war or civil unrest, natural disasters, or simply lack of funds, many libraries in educational and research establishments all around the world are in need of basic resources for use in the higher education and training which is so important to continued development for many countries. Few have adequate access to online resources. For many geoscientists in the developing world, books are a treasured luxury.

The mission of the AAPG Publication Pipeline Committee is therefore to promote and improve geoscience education in throughout the world by providing used geoscience books and periodicals at no cost to university libraries and other organisations that request them. It does this by collecting books and periodicals donated by retired or deceased geoscientists and from company libraries, and collating and storing them. The work is all done by volunteers, who sort the books, journals and memoirs into usable collections at the main depot in Houston – sometimes getting distracted for a while when they come across an old 'friend' amongst the volumes, and sit down to read!

Organisations in need of reference material contact the Publications Pipeline directly and explain the types of material they are looking for and why they need them. Libraries and establishments have also been identified and approached to see if they are in need of material by overseas AAPG members, visiting lecturers and AAPG Student Chapter members, amongst others. The Committee finds the most appropriate material, boxes it and arranges for it to be shipped out, at no cost to the recipient; the expensive shipping costs are all covered by generous donations from corporate partners, including major and independent oil companies and the U.S. Geological Survey, as well as the AAPG.



More Recipients Sought

Actually getting the boxes to the recipients can be a major logistical challenge, and the Publication Pipeline Committee are indebted to many AAPG members throughout the world, who help ensure the safe delivery and receipt of these precious materials. Without their help, many a box of geoscience literature would be sitting deteriorating in a damp or dusty customs warehouse – or even the wet quayside – for too long while the inevitable red tape and delays were being dealt with. They also get a great deal of assistance from sister or ganisations as partners, such as the Nigeria Association of Petroleum Explorationists (NAPE), who have helped deal with the arrival of several consignments to their country.

So far, over 80 tons (72,580 kg) of books and journals have been sent all over the world, to countries as far apart as Afghanistan, Iran, India, Nigeria, Argentina, Bangladesh, Iraq and Papua New Guinea. However, the Publication Pipeline Committee are interested in hearing from more universities and institutions in developing countries who may be interested in having these books and journals to augment their libraries. They would like AAPG members in far flung parts of the world to help them identify more recipients for the many publications they have in their warehouse. And, of course, they would always like more corporate partners and committee members.

If you would like to hear more about the scheme, or even, if you live near Houston, to offer the organisation some help with sorting and packing books, please contact Dr. Martin Cassidy on jo1955mar@aol.com. ■

BARENTS SEA HIGH-RESOLUTION 2D SEISMIC SURVEYS
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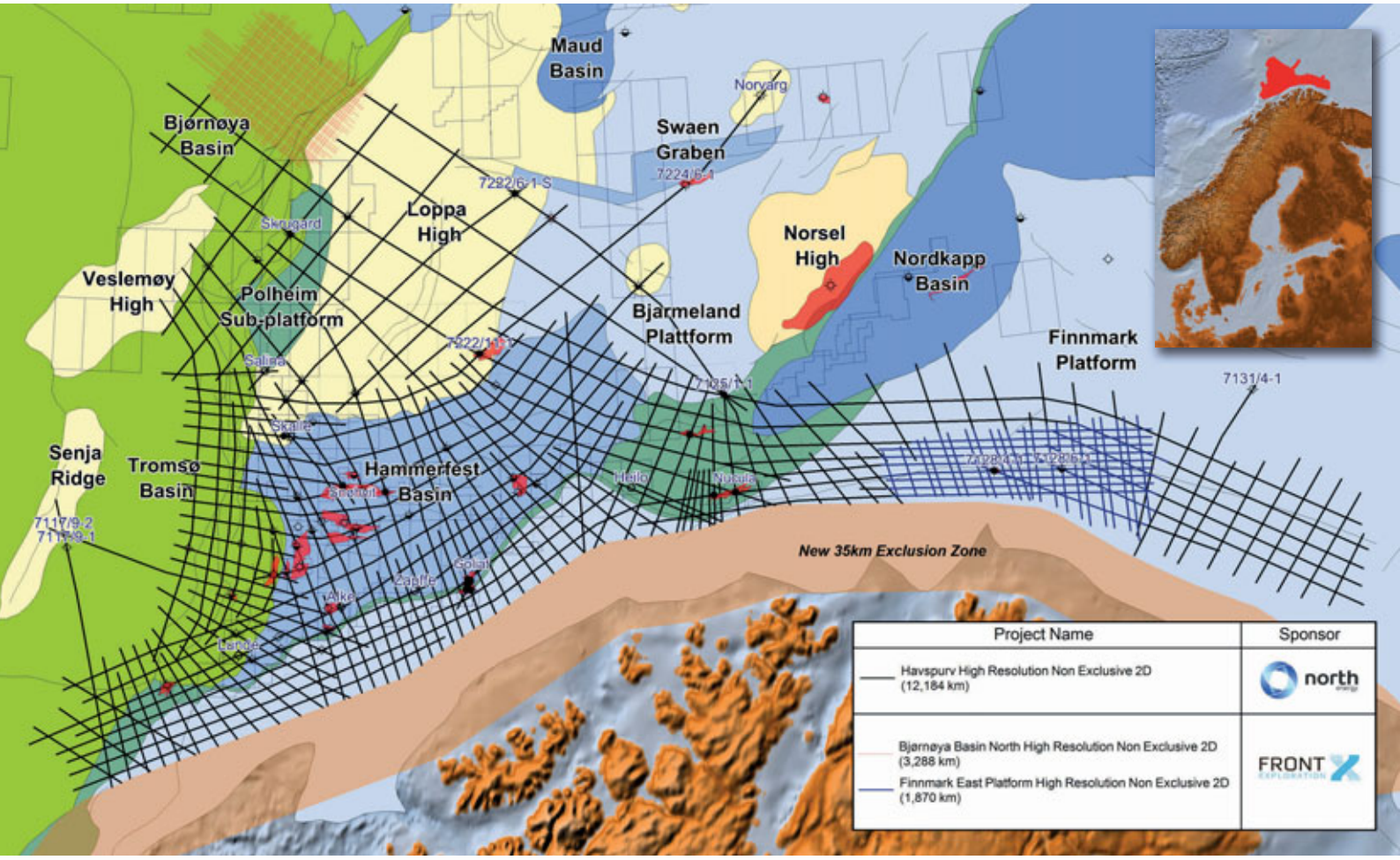

The Havspurv, Bjørnøya Basin North and Finnmark Platform East seismic surveys have been optimised to image the shallow section (<3 seconds).

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Paradigm 2011 Launched

Paradigm 2011 was released during the SEG Annual Meeting as part of a virtual online launch event. The new release is the culmination of years of research and development and is the largest synchronized release of exploration, development, and production technology in the company's history, with a rich set of geoscience and engineering applications, according to Paradigm.

"We have engineered a unified application suite, so our customers no longer need to choose between simplistic Windows-based solutions or robust Linux-based software. Paradigm delivers intuitive, easy-to-use and highly capable solutions on both operating platforms," said Paradigm CEO Eldad Weiss.

The launch of Paradigm 2011 at the SEG Meeting in San Antonio in September was well attended.

Although the Paradigm CEO introduced the new release at their SEG booth it was part of a virtual online launch event on the company website, as the number of guests who attended the launch in San Antonio represent only a minor fraction of its global user community. Videos are available online with introductions to the new release and technologies as well as a description of improved seismic and geological interpretation. ■

Five New Products for INOVA

INOVA Geophysical, the global independent land seismic equipment manufacturer, has made its most significant product launch since the formation of the company in 2010, announcing the introduction of five new products designed to infuse greater flexibility into land seismic operations.

INOVA, a joint venture between land seismic contractor, BGP, and ION Geophysical, a leading seismic solutions company, believes that its combination of pioneering land seismic technology and operational experience, together with interaction in the field with clients, has enabled it to identify gaps and needs in the market.

Among the recently launched products are two new cableless systems for land acquisition, including a new autonomous node Hawk™ SN11 recording system, based on a wireless platform without radio infrastructure. Another addition to the portfolio is the UniVib™, a smaller, more agile vibrator truck. INOVA has also equipped its ARIES® II cable acquisition system with digital sensor capabilities, so it can now support VectorSeis multicomponent digital sensors in addition to analogue geophones.

"In our highly competitive industry, our advantage comes from being out in the field with our customers," Steve Bate, INOVA's President and CEO, says. "These new products offer our customers a competitive edge through capabilities that will allow their crews to be more productive and address core acquisition issues in new ways." ■

INOVA's new UniVib truck, unveiled at the 2011 SEG Exhibition.

Geologist Turns Historian

Enthusiastic *GEO ExPro* readers will remember that our profile article in the first edition this year featured veteran geologist Joe McCall. Having spent over 60 years thinking and writing about geology, he has decided to try something new, and in his 91st year has published a history book! This is the story of his great-great-grandfather, George Pilkington, born in 1785, who, like his descendant, travelled the world, and gave vivid accounts of 19th century Africa and the Caribbean, becoming a vigorous opponent of the slave trade. A fascinating story of an amazing man. If you are interested in a copy contact Joe at joemccall@tiscali.co.uk ■

New 3D Barents Sea Survey

On July 10, 2011, WesternGeco commenced acquisition of new multiclient 3D data in the highly prospective West Loppa area of the Norwegian Barents Sea. This new survey, known as Bjørnøya Phase I 'Ice Bear', is expected to acquire 2,500 km^2 of data and will extend the existing 2D multiclient datasets previously undertaken by the company.

"The study area is located on the rim of the Bjørnøya Basin, on the west flank of the Loppa High, and includes a large downthrown terrace in the north, together with other Jurassic faulted structures, all of which have potential," said Phil Davey, WesternGeco Europe and Africa GeoSolutions manager, "Other, separate, but still promising features are seen in the south-western part of the survey area."

The survey has been timed so that the preliminary results will be available in November 2011, in preparation for nominations for the 22nd Norwegian Licensing Round. The final processed data will be available for licensing in March 2012 in advance of the applications for the Round. ■

The Geco Eagle undertook the new Bjørnøya Basin 3D survey.

Major Polish Seismic Project

GX Technology, the subsidiary of ION Geophysical Corporation, is due to undertake a large regional geological and geophysical research project covering all of Poland. The project, known as PolandSPAN™, is the result of the collaborative efforts and collective expertise of the company with organisations such as the Polish Geological Institute and the Institute of Geophysics.

Although Poland has large quantities of well and seismic data, this project is significant, as it will integrate 10,000 km of newly-acquired high-end 2D seismic data with reprocessed existing seismic data, new magnetotelluric data, and existing gravity, magnetic, and well data to create the most comprehensive and regionally extensive picture of Poland's subsurface to date. The first phase of the project, to commence later this year, will acquire new data in the area from the Baltic Basin in northern Poland through the Podlasie Depression and into the Lublin Basin of eastern Poland, focusing on the distribution of Lower Paleozoic shales, important for furthering information about the potential for shale gas. It is hoped that PolandSPAN will provide the foundation of integrated geological knowledge and a consistent seismic framework from which to build future studies. ■

New Computational Geomechanics Lectureship

A new lectureship in Computational Geomechanics has been established at the prestigious Durham University in north-east England, sponsored by the global geoscience technology group, Ikon Science. The lectureship will focus on fundamental issues in characterising reservoir performance using advanced stress analysis and fracture mechanics research. This new initiative builds on an existing relationship between Durham University and Ikon Science as the company, along with DONG (UK) Energy, currently sponsors the UK's first Chair in Carbon Capture and Storage (Professor Jon Gluyas).

Head of the School of Engineering and Computing Sciences, Professor Roger Crouch, says, "The combination of industrial expertise and engineering mechanics know-how will allow us to deliver new solutions to some of the most pressing problems in petroleum engineering and rock mechanics." ■

RPS Training Initiative

RPS Energy is a global multi-disciplinary consultancy, providing integrated technical, commercial and project management support services in the fields of geoscience, engineering and health and safety to the energy sector. It uses a large pool of in-house and external consultants so that the right solution is found for each client.

Last year RPS Energy commenced a programme of training for its consultants, aimed at increasing their awareness and core skills in the industry in key areas such as HSE (Health and Safety and Environment), which RPS Energy sees as critical in the work that they undertake in order to maintain technical quality and safe, environmentally responsible operations. Courses are also offered in 3D Seismic Survey Design and Principles of Data Processing, as well as more specialised aspects such as Explosive Remnants of War Risk Management and HSE Behavioural Safety. The company has recently gained "Approved Training Provider Status" from the Energy Institute for these courses, which have been well received both by its clients and its associates. ■

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Following the Oil Through Time


Tom Lorenson

THOMAS SMITH

Four-D petroleum system modelling allows an explorationist to understand the movement of hydrocarbons from an active source rock to a fluid's final destination in the basin, ultimately helping to reduce exploration risk.

Leslie B. Magoon doing what he has done much of his career, sampling oil from a seep, in this case the McKittrick oil seep about 50 km west of Bakersfield, California. Les has a MS degree in geology from the University of Oregon in Eugene. He worked for Shell Oil Company for 8 years and then became a research geologist with the US Geological Survey, where he developed the petroleum system concept.

Knowing where and when hydrocarbons are generated and where they finally end up seems so basic, yet it took years for the concept of the petroleum system to become an accepted practice. Now, using fast computers and innovative software, all exploration data including wells, seismic lines, geochemical data on the source rock and known hydrocarbons can be incorporated into petroleum system models. This concept provides the geoscientist with a new understanding of how a basin's rocks and fluids change over time, helping to reduce hydrocarbon exploration risks.

Leslie B. Magoon, Emeritus Scientist, US Geological Survey, Menlo Park, California, has spent most of his career "mapping fluids, collecting and analysing oil and gas samples". He first presented his work on the petroleum system concept as a brochure and poster in 1986. This was after an earlier paper on the subject was rejected by three prominent petroleum geologists, possibly not understanding his approach, who said "we already do this". With ever increasing computer power over the past decade, his original concept is now being applied to present and future petroleum provinces around the world.

What it Really Means

"Nature's distribution of hydrocarbon fluids is the petroleum system," says Les. "Deposition of sedimentary rock into a basin provides the setting and once a hydrocarbon fluid network forms, it can then be modelled as a petroleum system."

To really understand the definition of a petroleum system, it is important to break it down. Les explains, "The essential elements of a petroleum system are the source rock, reservoir rock, seal rock, and overburden rock. The two processes that are key to understanding a petroleum system are the trap formation and the generation-migration-accumulation of hydrocarbons. These essential elements along with the processes control the distribution of petroleum in the lithosphere."

"Genetically related hydrocarbons give the explorationist an idea about the correlation between the source rock and the petroleum occurrences. This can range from just having a source in the same geographic location (very speculative correlation) to a positive petroleum-source rock correlation (known correlation). As for shows, seeps and accumulations, any amount of oil or gas is proof of a petroleum system. Finally, we use the term active source rock to denote when that actually occurs, not what stage of maturity the source rock may be at today."

"The definition and a breakdown of some of these elements are needed to visualise the concept," continues Les. "We also had to refine and extend some vocabulary and create a series of graphic diagrams as a folio sheet. It is important for geoscientists to understand that generation-migration-accumulation need to be modelled at the time it happens, which we call the critical moment."

Development of the Concept

Like all science and most new concepts, the petroleum system was developed over a period of time. A foundation of principles in geology dating back to the 17th century and much more recent 20th century developments in organic geochemistry are two key disciplines necessary to formulate the petroleum system concept. Discoveries in the geosciences over the last 50 years have greatly added to our knowledge about the earth and the dynamics of the earth's systems.

It was near the beginning of this recent period of scientific discovery (1966) that Les Magoon was hired by Shell Oil Company to study source rocks in the Santa Barbara Channel, California. This was the beginning of a chain of events and experiences that would eventually lead to the concept of the petroleum system.

"When I was working for Shell, we would do source and migration studies," explains Les. "The explorationists for Shell would say to me, 'We already know there is oil here, why do we need to do more basin analysis?' This was when I started to realise that we needed a better way to look at both the geology or the rocks and the geochemistry or the fluids."

"While I was attending the AAPG Annual Meeting in Denver, Colorado in 1972, I listened to presentations by Wally Dow," says Les. "He and Jack Williams at Amoco Research presented papers on the geochemistry of oil they collected in the Williston Basin. They were able to correlate crude oils to specific source rocks, which were key ingredients in their concept of oil systems."

Les went on to work for the US Geological Survey in 1974, concentrating on oil and gas

Petroleum System:

As defined from AAPG Memoir 60

The essential elements and processes as well as all genetically related hydrocarbons that occur in petroleum shows, seeps, and accumulations whose provenance is a single pod of active source rock.
Also called hydrocarbon system and oil and gas system.

An example of a typical folio sheet showing the petroleum system map, cross section, table of oil fields, burial history chart, and events chart. "The concept provides a new understanding of independent variables – rock, fluid, time – needed to assess risk relative to petroleum prospects."

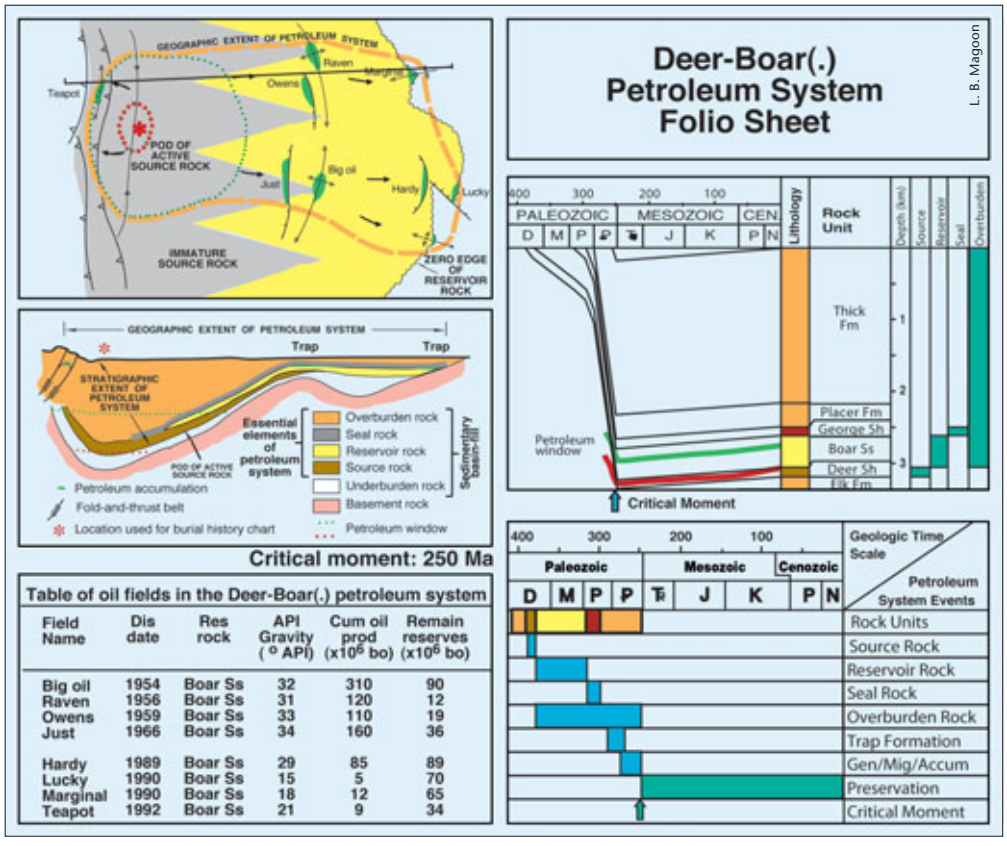
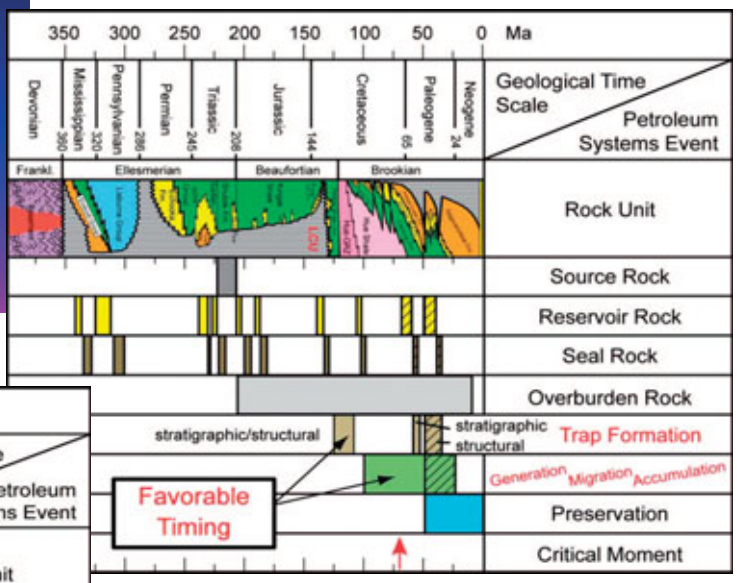


Table of oil fields in the Deer-Boar(.) petroleum system

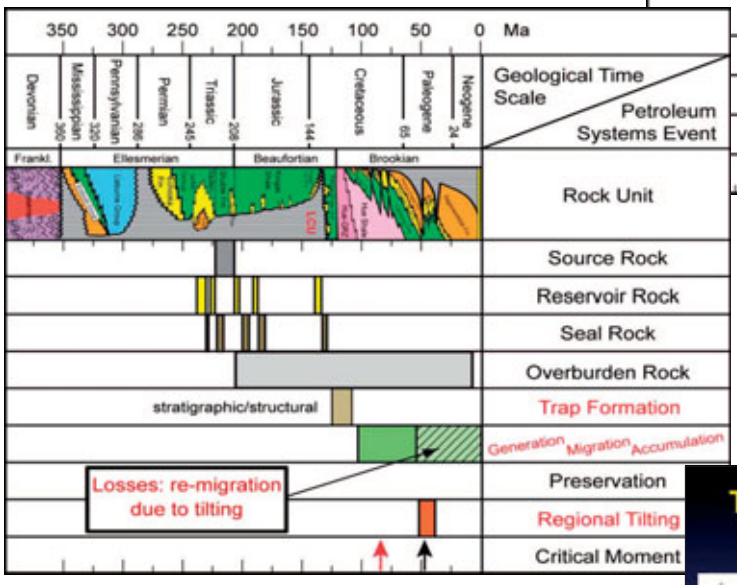
Field Name	Dis date	Res rock	API Gravity (° API)	Cum oil prod ($x10^6$ bo)	Remain reserves ($x10^6$ bo)
Big oil	1954	Boar Ss	32	310	90
Raven	1956	Boar Ss	31	120	12
Owens	1959	Boar Ss	33	110	19
Just	1966	Boar Ss	34	160	36
Hardy	1989	Boar Ss	29	85	89
Lucky	1990	Boar Ss	15	5	70
Marginal	1990	Boar Ss	18	12	65
Teapot	1992	Boar Ss	21	9	34

Location map showing the Mukluk prospect along the same play fairway as the Prudhoe Bay Field. The structure as identified on seismic is 32 km long and 14 km wide.

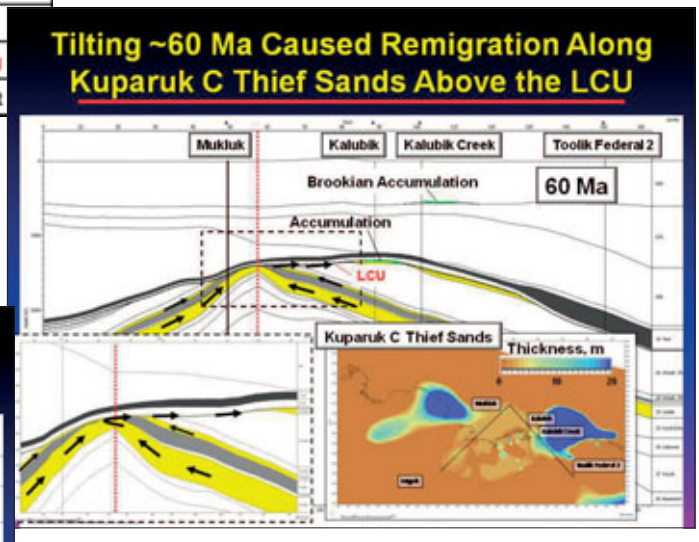
Images: Ken Peters, 2011 AAPG Pacific Section



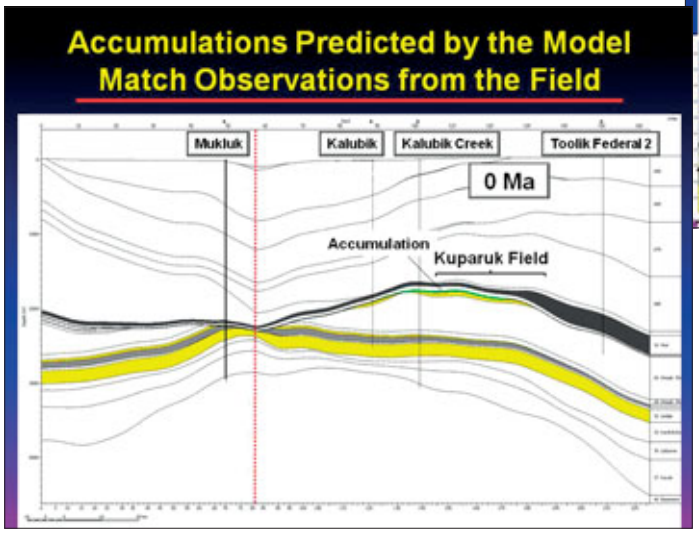
Trap formation at Prudhoe Bay preceded generation of hydrocarbons in this petroleum system, which resulted in the accumulation of hydrocarbons. The hatched pattern indicates the estimated time of eastward tilting in the Tertiary due to deposition to the east of Prudhoe Bay. The Prudhoe Bay Field tilted as well but oil was preserved because of effective seal rocks across the reservoir.



In the case of the Mukluk prospect, the critical moment is moved to about 67 Ma when regional tilting occurred. Structure formation was still favourable for accumulation until tilting, as evidenced by the oil-stained drill cuttings through the reservoirs. Once tilted, oil underwent secondary migration into the traps near the Kuparuk Field.



Present-day cross section showing that Mukluk oil migrated into the Kuparuk Field matching the model predictions.



The importance of looking at prospects through time is clearly demonstrated in this cross section. After tilting of the Mukluk structure, Kuparuk 'C' sands acted as carrier beds allowing oil to migrate south-east.

resource assessment. He quickly found that geology and geochemistry are trumped largely by statistics. By 1982, this led him to start developing a concept to help rank prospective areas.

"At first, the petroleum system concept was not well received," says Les. "It met early resistance, but others would comment 'this is important, pursue it'. I essentially started over and presented it as a series of poster sessions. The first was in 1987 at another AAPG Annual Meeting. Wally and I then organised a half-day session on the petroleum system for the 1991 AAPG Annual Meeting."

The 1991 session was the big turning point for the concept. Three years later Magoon and Dow published AAPG Memoir 60, *The Petroleum System – From Source to Trap*. The memoir, designated a classic by AAPG, is now out of print but can be purchased on CD.

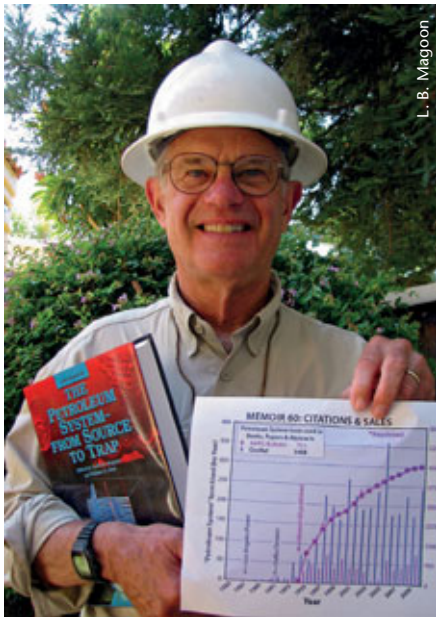
A Powerful Tool

"Using static snapshots like fairway maps fails to account for the timing of petroleum system events," says Ken Peters, consulting professor at Stanford University. "Basin and petroleum system modelling software allows us to quantify the petroleum system concept. It can explain why traps are barren or filled with hydrocarbons and is a powerful tool in assessing exploration risk."

An example from Alaska's prolific North Slope will help to demonstrate how petroleum system modelling, through the use of event charts, can be used as a prediction tool. The prospect was named Mukluk and, prior to drilling, expectations ran high. The prospect was right on trend with the Prudhoe Bay Field along the Barrow Arch Fairway. The entire structure was leased in 1982 with the total high bids exceeding US$1.5 billion. At that time, a consortium of companies headed by BP touted that it contained more than 1.5 Bb of recoverable oil (any connection to the bidding?). In 1983, the consortium built a gravel island and drilled a $120 million well; still the most expensive dry hole ever drilled.

So What Happened?

"Our models indicate that oil accumulated in the Mukluk prospect, Prudhoe Bay, and other structures along the Barrow Arch, starting about 97 Ma," says Ken Peters. "Overburden Brookian deposition (Cretaceous and Tertiary in age) occurred



Since 1986, Les has devoted much of his time developing and promoting the concept of the petroleum system. He and W. G. Dow, as co-editors, received the R. H. Dott, Sr. Memorial Award for AAPG Memoir 60, The Petroleum System – From Source to Trap.

from the south-west to north-east across the North Slope. These episodes of uplift and burial caused eastward tilting along the Barrow Arch starting at 67 Ma. Another key to our modelling was the mapping of sandstone bodies deposited on the Lower Cretaceous Unconformity. The sands served as thief zones for the re-migration of hydrocarbons."

"When modeling a basin or prospect, it is important to visualise what is actually happening through time," says Ken. "Cross sections through the Mukluk High show present-day closure as well as one drawn at 75 Ma. However, the 41, 55, and 60 Ma sections show that petroleum migrated up dip along sands (Kuparuk 'C') deposited above the Lower Cretaceous Unconformity to the south-east, towards the present-day location of the Kuparuk Field. At Prudhoe Bay, the Ivishak Formation reservoir sandstone is in superposition with shale across the Lower Cretaceous Unconformity (LCU) that trapped the oil. Had this thief sand been present, Prudhoe oil could have ended up somewhere else as well."

Reality

Donovan Krouskop, State of Alaska geophysicist, says, "The data around Mukluk was good quality and it's offshore enough that permafrost/velocity issues are not a problem. The vertical resolution of the data is the limiting factor. They (BP's geoscientists) could not see separate top and bottom reflectors of the Kuparuk sand, but would have seen an amplitude anomaly at the LCU level. I do not think that would have been enough to affect the decision to drill."

Les Magoon agrees, saying, "Mukluk would have been drilled regardless of the timing because the prospect was so large. Exploration is full of risk and some prospects just beg to be drilled because one cannot be sure any evaluation is correct (until drilled)."

These two geoscientists have pointed out that a weakness in the petroleum system concept is the inability to actually predict volumes and the secondary processes that act over geologic time. The current state of art for 4D petroleum system modelling is that it is a great tool to better understand subsurface hydrocarbon generation, migration and accumulation. Using this approach, geoscientists can better predict the pod of active source rock and the timing of petroleum generation, thermal maturity, and migration pathways to possible traps, as has been pointed out in this article.

Ken Peters addresses the concept's shortcomings this way, "Current 4D petroleum system modelling is limited in predicting volumes, compositions, and secondary processes. As seen in the Mukluk example, we can predict these things very accurately after the fact. We are hoping to address these questions with our industrial affiliates Basin and Petroleum System Modelling (BPSM) programme at Stanford University through long-term research."

Ken concludes, "Computerised 4D modelling considers the relative timing of petroleum system events, processes and dynamics of associated fluids to better assess whether past conditions were suitable to fill reservoirs and survive to the present day. Understanding the total process through time could have a major impact on economies throughout the world."

Author's Note: I first met Les Magoon during the summer of 1980 working on the Alaska Peninsula. Under his guidance, we examined petroleum seeps, source rocks, and potential reservoirs rocks in an effort to understand the overall petroleum potential of the Shelikof Strait prior to a Federal OCS lease sale. After this work, I was certainly not surprised by his future publications on petroleum system and the overall acceptance of the concept. ■

Basin and Petroleum System Modelling

Through their Basin and Petroleum System Modelling (BPSM) programme, Stanford University has the only formal university curriculum in the world offering graduate students visualisation and quantification of the geohistory of sedimentary basins and petroleum system. The programme is designed to train the next generation of basin and petroleum system modellers, devise the quantitative tools that, in combination with assessment methodology, can be used to rigorously evaluate geologic risk in various exploration settings, and to conduct basic and applied energy-focused research. Schlumberger has donated the PetroMod modelling software to the BPSM programme and technical support is being provided by their Aachen Technology Center.

Modelling of the subsurface through time (4D) has emerged over the last decade as a major research focus of the petroleum industry. Four-D petroleum system modelling has grown because it better quantifies the generation, migration and entrapment of resources. The BPSM group was started in 2008 by a group of experienced geoscientists recognising the need, from both the industry and academia, for graduates with expertise in this field.

Stanford University in Palo Alto, California, is a leading research and teaching institution.

Gary Barchfeld

Inspired by Technology

JANE WHALEY

Technology take-up and looking for new ways of doing things has been the driving force for **Kitty Hall**, one of only a handful of female CEOs in the world of geophysics.

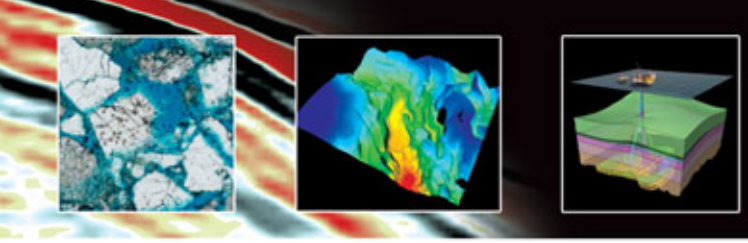
A year off between school and university had a huge effect on the career of Kitty Hall, founder of specialist geophysical imaging company ARKeX. "Before starting my degree in Geology at Leeds University, I worked for a year at Huntings, one of the pioneers of airborne geophysics," she explains. "I was only a data compiler, a fairly menial job – in fact, much of my work, such as contouring, is now done by computers – but I got an introduction to the more exciting side of the business when they sent me to work on an airborne survey in northern Nigeria. I found non-seismic geophysics an interesting and important branch of the science, so after graduating I went back to the business. This was in the really early days of computers, using arcane techniques like punched cards and large reels of tape; we've come a long way since then!"

Seeing What's Possible

Although initially working in data processing with Huntings, Kitty found herself moving gradually into the sales and marketing side, combining her technical knowledge with rapidly growing business skills. "I think my main forte is being able to use my scientific background and experience to see what is technically possible, and then working out how it can be applied to help oil and gas companies in the search for hydrocarbons."

In 1985, at the tender age of 29 and in the depths of a recession in the oil industry, Kitty and two colleagues, Andy McGrandle and Richard Gleave, branched out on their own. Their new company, ARK Geophysics – the name coming from their combined initials – specialised in both the processing and interpretation sides of gravity and magnetic surveying. "I eventually became the CEO, with Andy responsible for Sales and Richard for Technology; that was just the way our skill set panned out." Moving their fledgling company to the new town of Milton Keynes in south-east England ("not renowned in the oil industry, but they like new businesses!"), they grew fast, rapidly becoming the leading provider of non-seismic geophysics in the UK.

During the early years of ARK Kitty completed an MSc in Stratigraphy at Birkbeck College – a part of the University of London which offers evening class study. "All the other students were working in oil or service companies around London at the time, and all are now scattered around the world in senior roles. It was a great course for explorationists but I have in the ▶



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East Africa
Petroleum Province of the 21st Century?

24-26 October 2012

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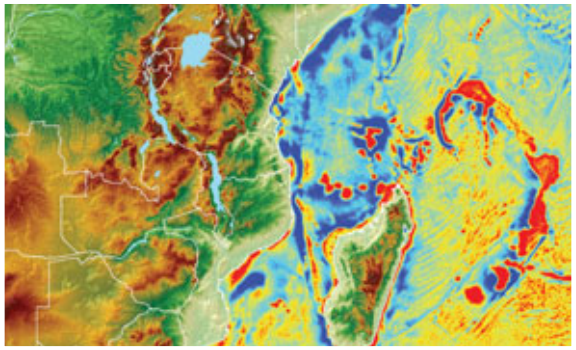

East Africa was written off as an oil and gas province for many years. The exploration campaigns of the last 5 years have changed that perception. Success onshore Uganda and offshore Mozambique and Tanzania has attracted attention around the world and made East Africa an exploration hot bed of the second decade of the 21st Century.

It is still early days but licensing activity, new seismic data acquisition and exploration wells will provide the answer about the true size of the prize in the region. There are still very few wells drilled in East Africa in comparison to the other parts of the continent. Exploration activity in Kenya, Tanzania, Uganda, Ethiopia, Mozambique and Madagascar is picking up speed and is drastically changing our knowledge of the region.

This conference will address regional geology, case studies and will discuss new and emerging plays of East Africa. The meeting will bring together experts from industry and academia, seismic contractors showing the latest data, and representatives from the NOCs.

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end had little opportunity to apply what I learned – I moved out of the technical side and into management."

"ARK originally worked exclusively in the marine area, processing gravity and magnetic data recorded during seismic surveys," Kitty explains. "We also built up interpretation and data management services. We rapidly developed our R&D arm, collaborating with oil companies to develop new software such as ARKFIELD, the first gravity and magnetic interpretation and modelling software package to be tightly integrated with the market-leading seismic packages at the time from Landmark and GeoQuest. This was back in the mid-90s, so we were at the forefront of the move towards seamless systems."

"I am particularly committed to R&D and technical developments and working out how new data types can provide new solutions," she adds.

New Developments

"Around the end of 2000, high tech instrument maker Oxford Instruments approached us with the prototype of a gravity gradiometer. This had been developed for the European Space Agency to measure the gravity field from satellites, and Oxford Instruments asked if we could help them to find an exploration application for it. We realised that this offered the possibility of dramatic improvement in the quality of gravity surveying. I consequently spent the early 2000s during the fallout of the dot com fiasco trying to raise money to set up a new company to do this – not an easy task at the time but we eventually succeeded!."

In 2004, having been CEO of ARK Geo for 17 years, Kitty left the company and started ARKeX as the only service company specialising in both building gravity gradiometers and flying gravity gradient surveys. "We decided to keep the ARK name to continue links with our clients," she explains. "However, just three years later we bought ARK Geo, to build up our processing and interpretation capability. We now deploy our gradiometer systems for both airborne and marine 'BlueQube' surveys. A particularly exciting recent new development has been the take-up of gravity gradient imaging in the shale plays in North America – we are currently flying in the Marcellus and also have a project in the Montney. We look forward to taking this application of our technology to other shale plays around the world."

Time for New Challenges

In 2010 Kitty decided to take a step back from the day to day running of the company, and resigned as CEO. "I feel my main role is as a business developer, good at the early, creative stages, and my seven years as CEO of ARKeX saw the company well established and now employing about 70 people. I remain on the Board, so I am still involved at a corporate level," she explains. "I felt it was time to try a few different things, and use my skill set in a different way – maybe even see a bit more of my husband and two daughters."

Kitty has served as a non-executive board member of Dubai-based seismic company Polarcus since 2008 (and prior to Polarcus its predecessor company, Eastern Echo). "I was interested in seeing business from a non-exec viewpoint. And while seismic is an established technology rather than the new technology world I have been used to, and is on a much larger scale from the companies I have led, there are both significant differences and similarities. It has proved very interesting."

"I also recently joined the Board of Sevan Drilling, when it separated from its parent company Sevan Marine in May," she adds. "Having always been focused on exploration, and in particular frontier exploration, it has provided an opportunity to extend my experience into the more downstream part of oil services. It is a very exciting company specialising in ultra-deepwater drilling, with a radical new design of rig."

Adaptable and Proactive

Another of Kitty Hall's enthusiasms is for the PESGB (Petroleum Exploration Society of Great Britain), which she considers serves an important role in promoting education in the scientific and technical aspects of petroleum exploration on behalf of its 5,500 oil industry members. "I've been a member of the PESGB for 26 years, and was on the PESGB Council in the mid-1990s. Now I have a bit more time I am back on the Council as 1st Vice-President, involved in organising and chairing the London evening lecture programme and public outreach events like the Stoneley Lecture."

"Having been in the business 35 years, it's interesting to see how people have grown up and changed – from young 'high livers' to responsible senior executives," she says. "The exploration sector is an enjoyable group of people to be with, and I have found that being a woman in this male-dominated business has generally been an asset rather than a hindrance; with so few of us, people tend to remember you!"

"I can't really believe how my life in business has turned out," Kitty concludes. "Like many of my age group in the industry, I have lived through and survived the downturns as well as the good times. Businesses have to float with these, and with relatively small players like ARK Geo and ARKeX you have to be adaptable, and believe in the value of your product. And you need to focus and control costs when the going gets tough, so you are in a position to thrive in the good times."

"I didn't set out to do any of this, but I believe in being proactive and taking opportunities when they appear. And I've had a lot of good fun on the way!" ■

In her spare time Kitty enjoys hill walking, particularly in the Lake District of northern England.

Halfdan Carstens

The cores smell beautiful. They are saturated with black oil in an excellent reservoir. Porosities are between 25 and 30 percent and the permeability is several darcy. Statoil's Sigrid Borthen Toven (North Sea Exploration Manager) and Silje Fekjar Nilsson (Team Leader Utsira High) have both been involved in the drilling of Aldous Major South that proved at least 800 MMbo.

A World Class Discovery

HALFDAN CARSTENS

The first oil was sampled in September last year. It took several wells and one full year of detailed analyses to prove that the discovery may contain more than 2.6 billion barrels of oil.

The discovery was announced last year. Oil had been found at about 2,000m in the Upper Jurassic Draupne Formation in licence 501. The operator, Lundin Norway, said the reservoir in Avaldsnes probably contained between 100 and 400 million barrels of recoverable liquids. In other words, it could be huge, by Norwegian standards. And it was of course good news, not only for Lundin and its partners, Statoil and Maersk, but for the entire Norwegian petroleum community who were in desperate need of encouragement following many disappointments in the last decade.

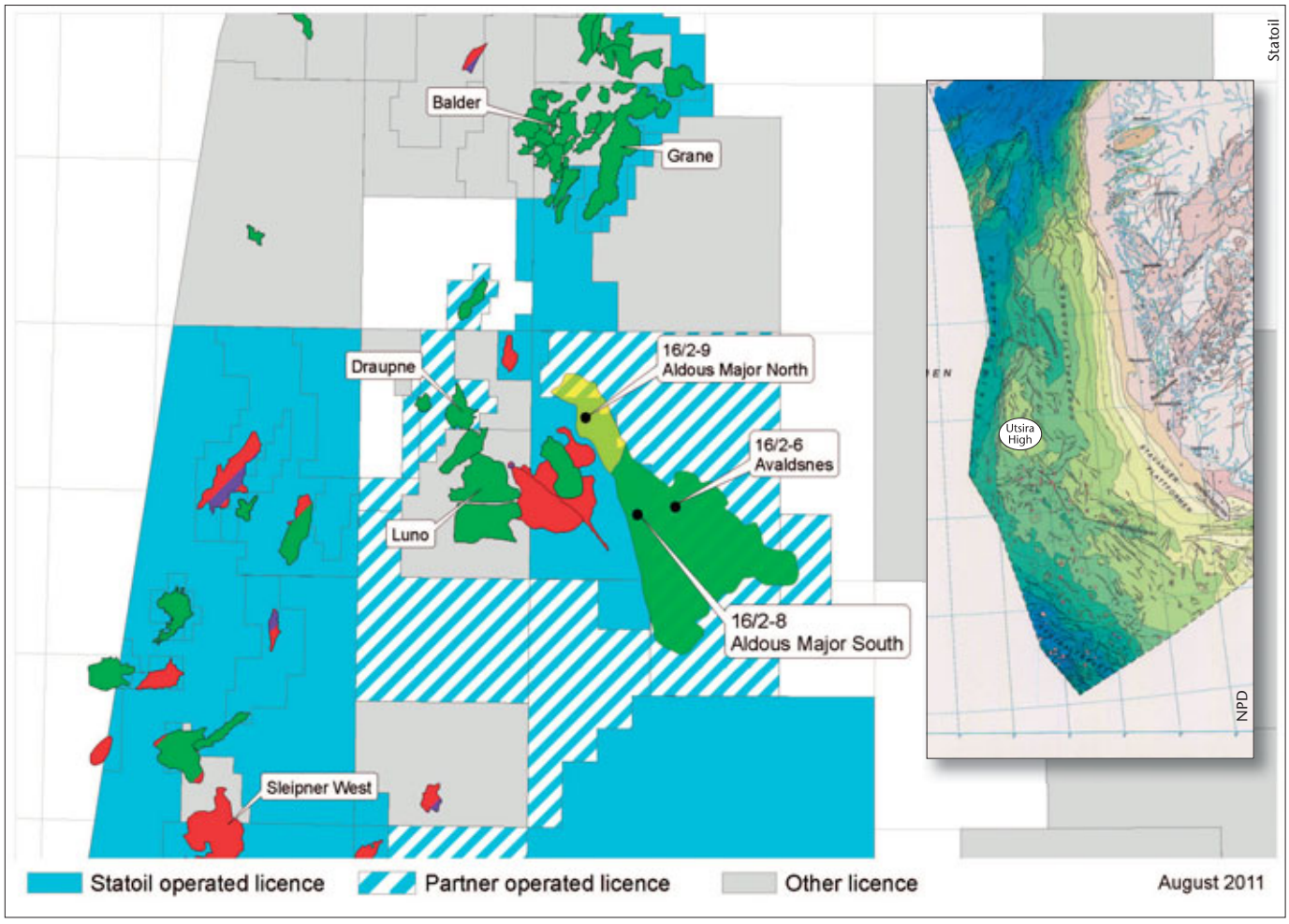
Nevertheless, most petroleum geologists working the North Sea were taken by surprise, for at least two reasons. Firstly, the presence of a decent trap was not at all obvious from the seismic data, and secondly, and possibly more importantly, the closest mature source rock is in the deep Viking Graben, down below the Utsira High, a basement ridge separating the Viking Graben from the Stord Basin, the latter having only immature source rocks.

"How could oil possibly migrate through basement rocks, or, also quite strange, could the oil have gone the long way all around the high?" Those were the questions asked by experts who had a long time ago given up on this area.

Good News – Then Bad News

Another crucial question was whether the discovery continued into the neighbouring licence to the west, operated by Statoil with Lundin as one of three partners. The seismic indicated two separate highs, one in each licence, but there was certainly no clue to whether the two were in pressure communication.

The answer came last August. And for the second time this year petroleum exploration made front cover stories in



The two wells 16/2-6 and 16/2-8 proved that Avaldsnes and Aldous Major South, respectively, belong to the same field. Aldous Major North, shown in yellow, is separated from the southern part by a major fault and does not contain a commercial discovery, as was proven in September by 16/2-9.

Norwegian national newspapers – the first time was with the 250-500 MMbo discovery of Skrugard in the Barents Sea (*GEO ExPro, Vol. 8, No. 3*). The reason was simple. It had been proved that Aldous Major South was in communication with Avaldsnes, meaning that the reserve estimate for the two fields had grown to between 800 and 1,200 MMbo. If the northern continuation, Aldous Major North, was also flush with oil, the accumulation could possibly be as large as 1.5 Bb of recoverable oil.

Well, it only took some six weeks to disprove the latter possibility. The Statoil well on Aldous Major North was quite disappointing, leaving a lot of question marks, but certainly not an increased reserve figure for the entire Aldous structure. All the same, the combined Avaldsnes/Aldous Major South was still huge and it is still the largest discovery in Norway since the 1980s.

Everybody's eyes were now on Lundin who in the meantime had drilled two appraisal wells on Avaldsnes. The company had promised an updated reserve estimate during autumn following interpretation of the well results. On the last day in September, in the early morning, the Swedish company, with a largely Norwegian crew, once again took the petroleum community by surprise. No fuss, however, just a modest press release stating a few numbers.

"The Avaldsnes discovery is estimated to contain gross contingent resources of between 800 million and 1.8 billion barrels of recoverable oil," it said.

Second to None

That's a lot of oil. In fact, if the high number is proved right, Avaldsnes will by itself rank as the sixth largest discovery on the Norwegian continental shelf, ever. But we have now already learned that Avaldsnes and Aldous Major South, despite being two separate structural highs, are connected with the same oil water contact, pressure regime, oil type and reservoir.

Statoil as operator for Aldous Major South has announced an estimated recoverable resource range from 400 to 800 MMbo. The combined Avaldsnes/Aldous Major South discoveries therefore have a resource range estimate of 1.2 to 2.6 Bb of recoverable oil.

Again, if the high number is correct, we are looking at the third largest discovery on the Norwegian continental shelf, only trailing Statfjord and Ekofisk, which each contained some 3.5 Bb when they were discovered in 1972 and 1969, respectively. Sceptics should note that the contingent resource range has been independently audited by Gaffney, Cline & Associates.

Therefore, we are now talking about a world class discovery. So far it is the biggest find this year all over the globe. It is second to none!

Lateral Continuity

The resource increase of Avaldnes is due to the positive results from appraisal wells as well as the Aldous Major South discovery well. All the wells have been cored through the reservoir section for direct reservoir properties analysis, age dating, log calibrations and analysis of the depositional system of the reservoir sands.

The Avaldsnes discovery well 16/2-6, drilled last autumn, and first appraisal well 16/3-4, drilled this summer, were both successfully tested and proved the high lateral continuity and productivity of the main Upper Jurassic reservoir sandstones. The reservoir has confirmed excellent properties in all wildcats and appraisal wells. The appraisal wells have also significantly upgraded the thickness and properties of the main prime Volgian Upper Jurassic reservoir which has had a material impact upon the revised recoverable resources.

Appraising the reservoir will continue to narrow the recoverable resource range and to assist with the development planning strategy. One well is planned to be drilled in the south-western part of the Avaldsnes discovery in the fourth quarter 2011, while three further appraisal wells will be drilled in 2012.

A Mature Province

From an exploration viewpoint it is certainly worth noting that we are not talking about a frontier province. The Utsira High is in the middle of a mature petroleum province that has been explored since 1965.

In fact, the area of the discovery was once part of licence 001, the very first licence offshore Norway. It was awarded to Esso Exploration, and the second well drilled in Norwegian waters, in 1966, resulted in an oil discovery on this acreage. It was later developed into the oil field Balder, that went on stream in 1999 producing from a 450 MMbo reservoir.

Since then several discoveries have been made, with Grane due east of Balder as the largest with some 750 MMbo of recoverable oil.

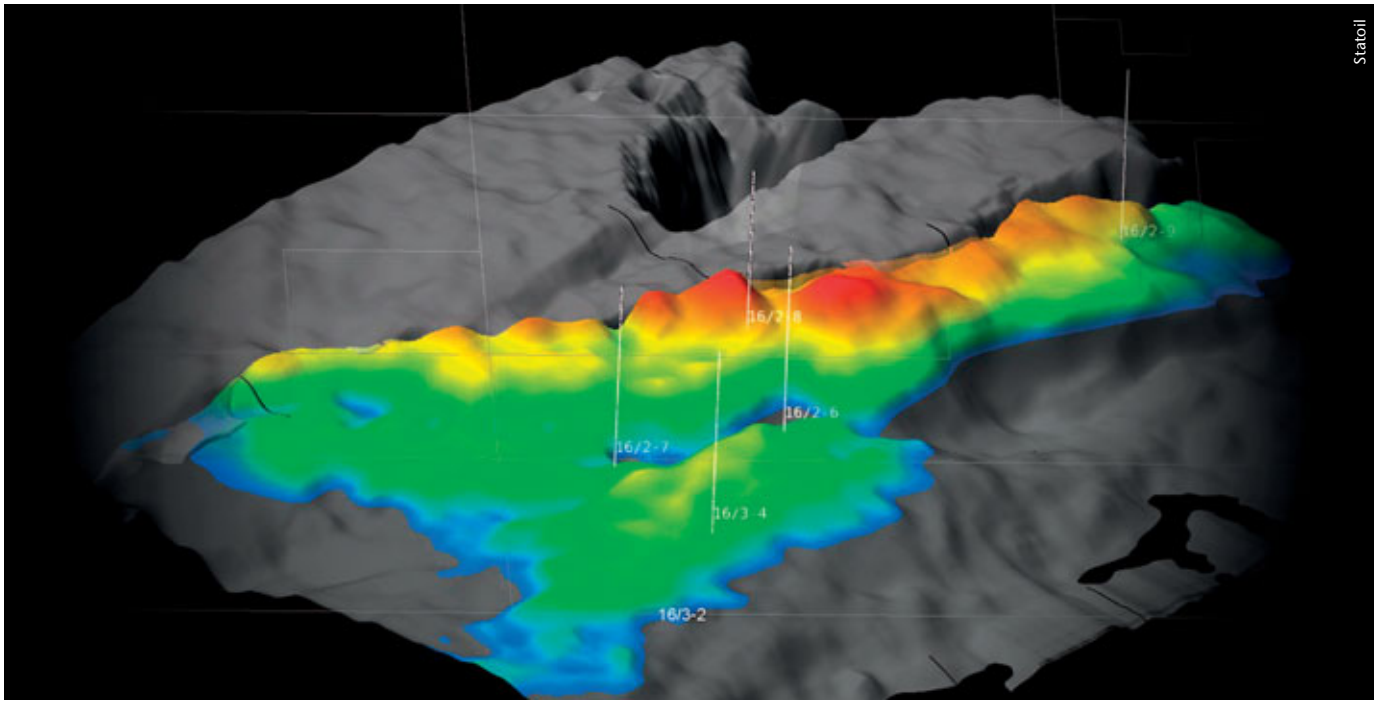

Halfdan Carstens

Hans Chr. Rønnevik, VP Exploration in Lundin Norway, has been given the credit for revisiting the greater Utsira High due east of the deep Viking Graben. Lundin surprised the petroleum community for the first time in 2007 when it made the Luno discovery in the midst of several dry wells.

Both Balder and Grane are only 30 km north of the Aldous/Avaldsnes discovery. We also know that Norsk Hydro and Elf almost made it when, in 1976, they missed the structure by only 400 metres.

In other words, the story behind Avaldsnes is a classic illustration how mature petroleum provinces may very well hide giant fields. ■

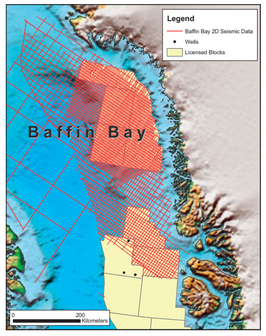
The two highs, Aldous Major South and Avaldsnes, which were explored as two separate prospects with two separate wells, have proven to belong to the same accumulation with the same oil water contact, pressure regime, oil type and reservoir. So far the highest estimate for recoverable oil is 2.6 billion barrels.



Statoil

Improved Imaging in Baffin Bay: Learning from Experience

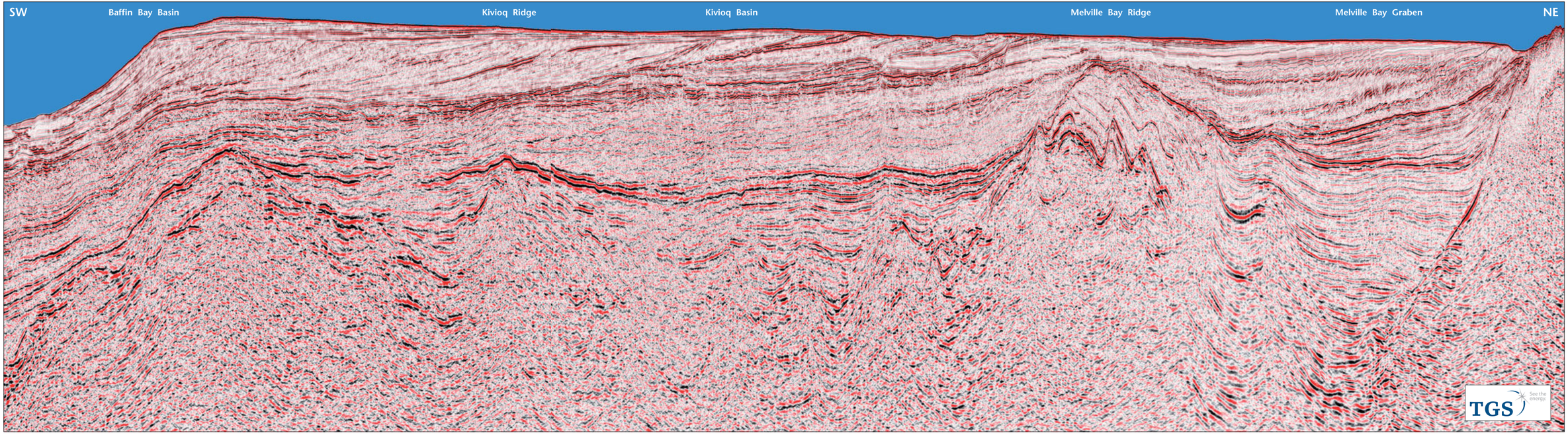
TGS' processing of Baffin Bay 2D seismic data employs innovative techniques already proven in the Atlantic Margin and has enabled TGS to launch a 31,000 km reprocessing initiative. The reprocessed data will provide a tool to enable interpreters to produce meaningful correlation in these frontier basins.



Detailed survey map

Location of the Baffin Bay data set

A 2D seismic line from the TGS Baffin Bay 2010 survey



Baffin Bay Reprocessed

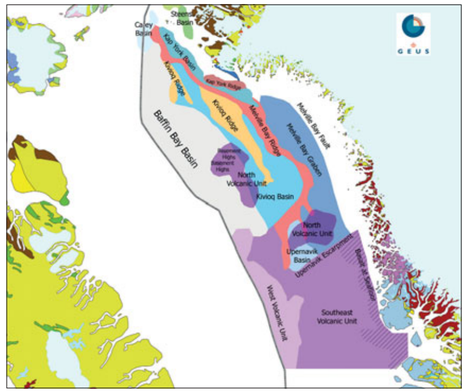
The majority of exploration focus has historically been in the central area offshore West Greenland, however since 2007 there has been increased interest in the Baffin Bay area. The 2D fold out line on the previous page illustrates the detailed level of interpretation now possible due to advances in processing technology. The new techniques described give the explorationist access to a previously unseen level of detail within the major structural features of the Greenland shelf.

WILL BRADBURY AND NICK WOODBURN, TGS

This summary focuses on the emerging petroleum province of the Baffin Bay area of West Greenland. The line shown lies a significant distance from well control (> 200 km) therefore stratigraphic understanding comes from combined sea floor sampling, onshore outcrop and offset wells. The stratigraphic section expected comprises possible Paleozoic pre-rift overlain by multiple phase Cretaceous (?) syn-rift deposition, which in turn is overlain by the post-rift Paleogene and Neogene sequences.

The line is orientated south-west to north-east and has an overall length of 275 km, stretching from the Greenland coast in the north-east, to beyond the modern day shelf break in the south-west.

The Melville Bay Graben and Kivioq Basin form the principal tectonic elements located on the shelf. The Melville Bay Graben is the most north-easterly basin on the line, while to the south-west is the Melville Ridge, which separates the Melville Bay Graben from the Kivioq Basin. The Kivioq Basin is approximately similar in dimensions to the Melville Bay Graben, and is intersected by the Kivioq Ridge extending from the north and terminating just south of the line shown. Further to the south-west the line obliquely cuts a high, separating the Kivioq Basin from the Baffin Bay Basin which then extends south-west beyond the shelf break.



Tectonic elements map (GEUS 2010)

Significant Potential

The north-north-west to south-south-east orientated Melville Bay Graben is comparable in extent to the Outer Moray Firth or the Central Graben of the North Sea and represents significant exploration potential. It is characterised by multiple phase syn-rift deposition, with sediments believed to consist of Early Cretaceous fluivio-deltaics and marine deposits and late Cretaceous turbidites. The Cretaceous succession is overlain by regional Paleocene mudstones, Palaeogene fans and Neogene mudstones. The new improved processing techniques described below allow more accurate definition of deeper structures and interaction with the stratigraphic basin fill. Fault planes, splays and hanging wall roll-overs at 5 – 6 seconds are now more clearly imaged for interpretation.

The Melville Bay Ridge bounds the Graben to the south-west and was uplifted during the early Paleogene. The upper sequence present within the ridge is interpreted to comprise a series of tilted and subsequently uplifted and rotated fault blocks containing Cretaceous age clastics.

Moving south-west along the line, the Melville Bay Ridge gives way to the Kivioq Basin. This is cut obliquely by the line and forms another regionally significant tectonic element with considerable exploration potential. The basin is divided by the southern extent of the Kivioq Ridge. To the south of the line the ridge dies out and the north-east and south-west partitions of the basin merge.

In this section the basin appears to have a Cretaceous stratigraphy comparable in thickness to that found in the Melville Bay Graben. The new processing techniques employed in the Baffin Bay 2010 survey more clearly image mid-Cretaceous and deeper levels in the Kivioq Basin. A clear distinction is seen in the deformation style present within the early Cretaceous basin fill, compared to that seen in late Cretaceous levels. The early Cretaceous is characterised by a series of tilted fault blocks and faulted anticlinal features. In contrast, the later Cretaceous deposits are characterised by comparably lower relief anticlines conforming to the deeper structural geometries. The more pervasive faulting imaged deeper in the Cretaceous does not propagate through to the younger Cretaceous levels with the exception of some of the more major faults.

To the south-west of the intervening ridge the Kivioq Basin comprises a later Cretaceous section thickening towards the north-west. A similar structural style is present here with an apparently more pervasively faulted early Cretaceous succession compared to the later Cretaceous. Again some faults are seen to penetrate from the early Cretaceous stratigraphy into the later Cretaceous although the density of faulting is much reduced.

The Kivioq Basin abuts an as yet unnamed high to the south-west, located beneath the modern day shelf break, before the line moves into the deeper water of Baffin Bay where the seismic acquisition stopped. Despite this a Cretaceous half-graben is clearly imaged at six seconds at the end of the line, indicating that there is even more to be seen.

Key Processing Improvements

Since 2009 significant improvements have been made to the processing sequence applied to seismic data from offshore Baffin Bay. These improvements are clearly visible when comparing data processed in 2010 with data processed in 2007.

These improvements are a direct result of the following changes which are summarised below in chronological order:

From 2009 onwards:

- Further optimisation of the adaptive subtraction of the SRME multiple model;
- Bubble-pulse attenuating and zero-phasing operators were designed from a data derived wavelet rather than from the modelled source signature, providing a far more superior and stable result;
- Diffraction Multiple Attenuation (DMA) has proved important for dealing with the common problem of multiple diffractions generated by iceberg drift scouring and glacial debris on the present day sea floor.

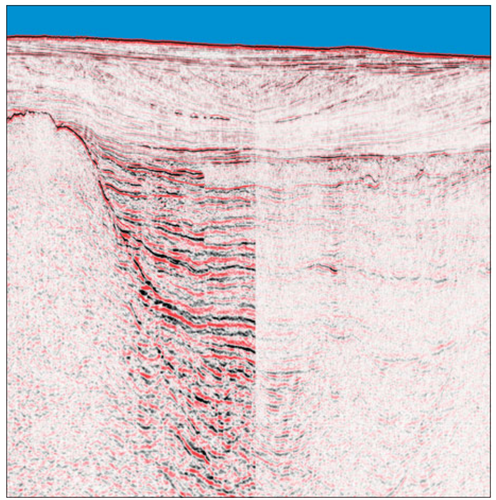
From 2010 onwards:

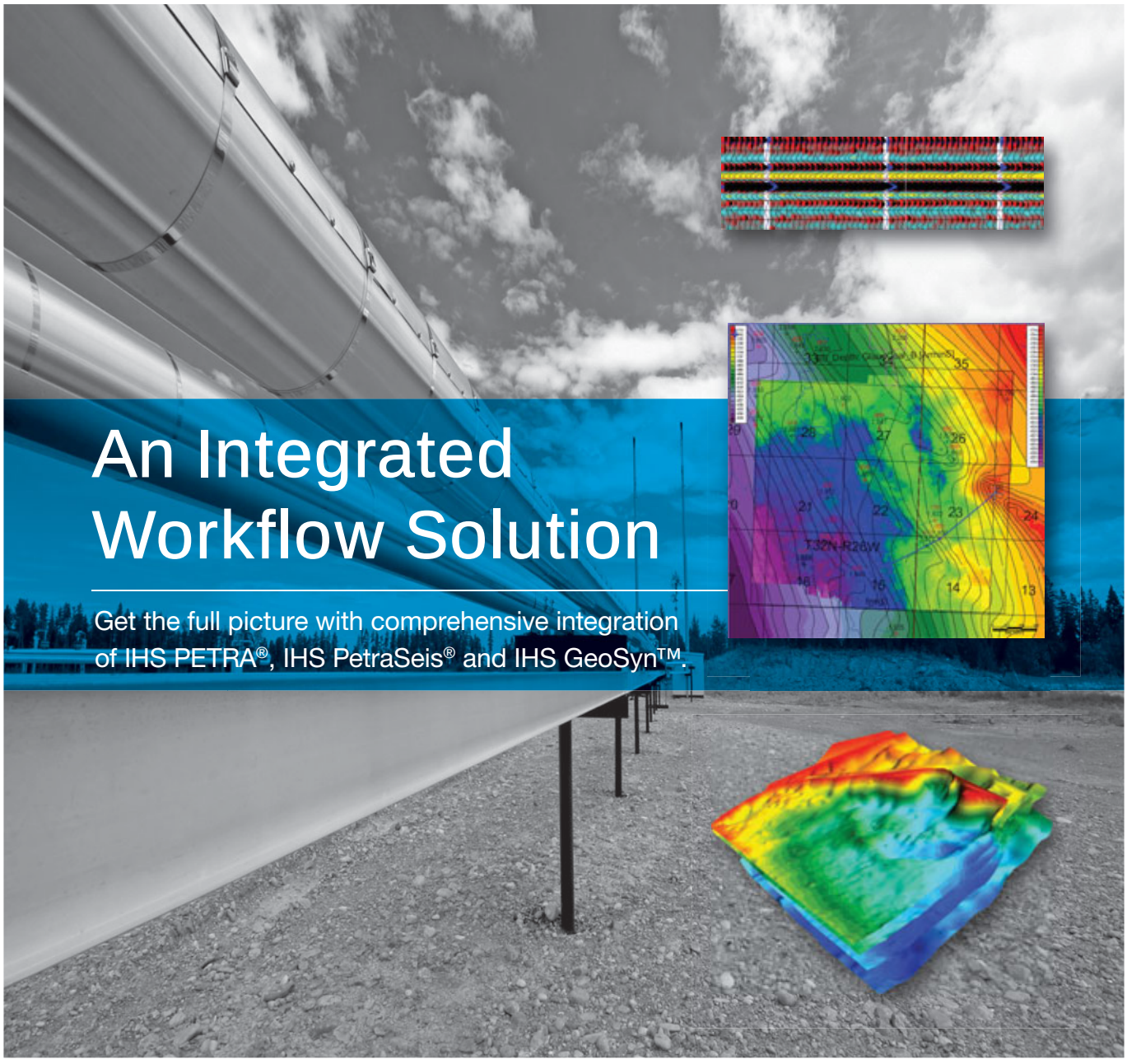
- Low frequency enhancement at the beginning of data processing. TGS has been able to demonstrate that this boosting accurately simulates the low frequency enrichment usually obtained by 'deep-tow' acquisition. Applying the boost at the beginning of processing enables all of the signal enhancing components in the flow to work on enhanced low frequency data. This, in turn, makes seismic horizons more easily identifiable in stacks, gathers and semblance plots. In consequence, more accurate velocity models can be produced throughout the processing sequence;
- Noise attenuation techniques were applied in the shot, receiver, common mid-point (CMP), and common offset domains to enhance primary signal and minimise both coherent and incoherent noise.

New Data Set

Considerable improvements have been made in the imaging of the data in Baffin Bay since 2009. This has resulted in TGS initiating the reprocessing of 31,000 km of BB07, BB08 and BB09 data. In consequence, a regional, consistent, high quality data set for the entire Baffin Bay will be available by end of 2011. For further information, contact TGS at:
Email: Greenland@tgsnopec.com
Tel: +44 (0) 1234 272122 ■

Data comparison demonstrates the clear improvement made by reprocessing the data 2010 reprocessing (left), original 2007 processing (right)





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.

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Marine Seismic Sources

PART X: SEISMIC SURVEYS AND FISH

MARTIN LANDRØ AND LASSE AMUNDSEN

The possible effects of seismic surveys on fish and fisheries have been given a great deal of media attention in Norway. In the last edition of *GEO ExPro* we reported on results from two investigations offshore Norway in 2009 and 1992, carried out to study if airgun activity affected fish distribution and commercial fisheries. For the 2009 seismic survey, the main conclusions according to the Norwegian Petroleum Directorate were that seismic shooting resulted in increased catches for some species and smaller catches for others. It appeared that pollack, to some extent, may have withdrawn from the area, while other species seemed to remain. Here, we summarise results from the Fish Rock experiment offshore Scotland.

The Fish Rock Experiment

Although behavioural studies of fish suggest that there might be some changes in behaviour associated with seismic surveying, a study by Wardle *et al* (2001) found results to the contrary. Bangs did not chase fish away, but they did cause an involuntary sudden bending of the body, or C-starts (*see box*).

The investigators used a video system to examine the behaviour of fish on an inshore rocky reef, 'Fish Rock' in Firemore Bay, Loch Ewe, on the west coast of Scotland, in response to shooting a stationary triple G. airgun (three synchronised airguns, each gun 150 cu in (2.5 l) and 2000 psi). Fish inhabiting this reef include juvenile saithe that leave for the open sea when they are about three years old, adult pollack, juvenile cod, with some flatfish, wrasse and gobies. The water depth is 10–20m.

The G. guns represent a type of gun now commonly used by survey companies in arrays and clusters for seismic survey work. The guns were fired once per minute for eight periods on four days at different positions. The peak–peak sound level was 210 dB re 1 μPa @ 16m from the source and 195 dB @ 109m from the source. We note that a 210 dB equivalent pressure would be received at about 100m below a full-scale seismic airgun array generating about 250 dB re to 1 μPa @ 1m.

Firing the G. guns had little effect on the day-to-day behaviour of the resident fish, which were not sufficiently irritated by the shooting to move away from the reef.

However, reef fish watched by the TV camera showed involuntary reactions in the form of C-starts at each explosion of the guns at all ranges tested. When the explosion was not visible to the fish, the C-start reaction was cut short and the fish continued with what they were doing before the stimulus. In one experiment, when the guns were suspended mid-water (5m depth) and just outside visible range at 16m, the fish receiving a 6 ms peak to peak, 206 dB pressure swing exhibited a C-start and then continued to swim towards the gun position, their intended swimming track apparently unaltered.

The long term day-to-night movements of two tagged pollack were observed. One of them showed little variation at the onset of and during gun firings, but was never closer than 35m from the guns. The other pollack showed detailed reactions to the gun only when it is brought close to the fish. At one onset of firing, the pollack was about 10m from the gun location. After the first firing the fish moved rapidly away from the gun by approximately 30m.

Firemore Bay on the coast of North-West Scotland was the site of a 2001 study on the impact of seismic shooting on fish.

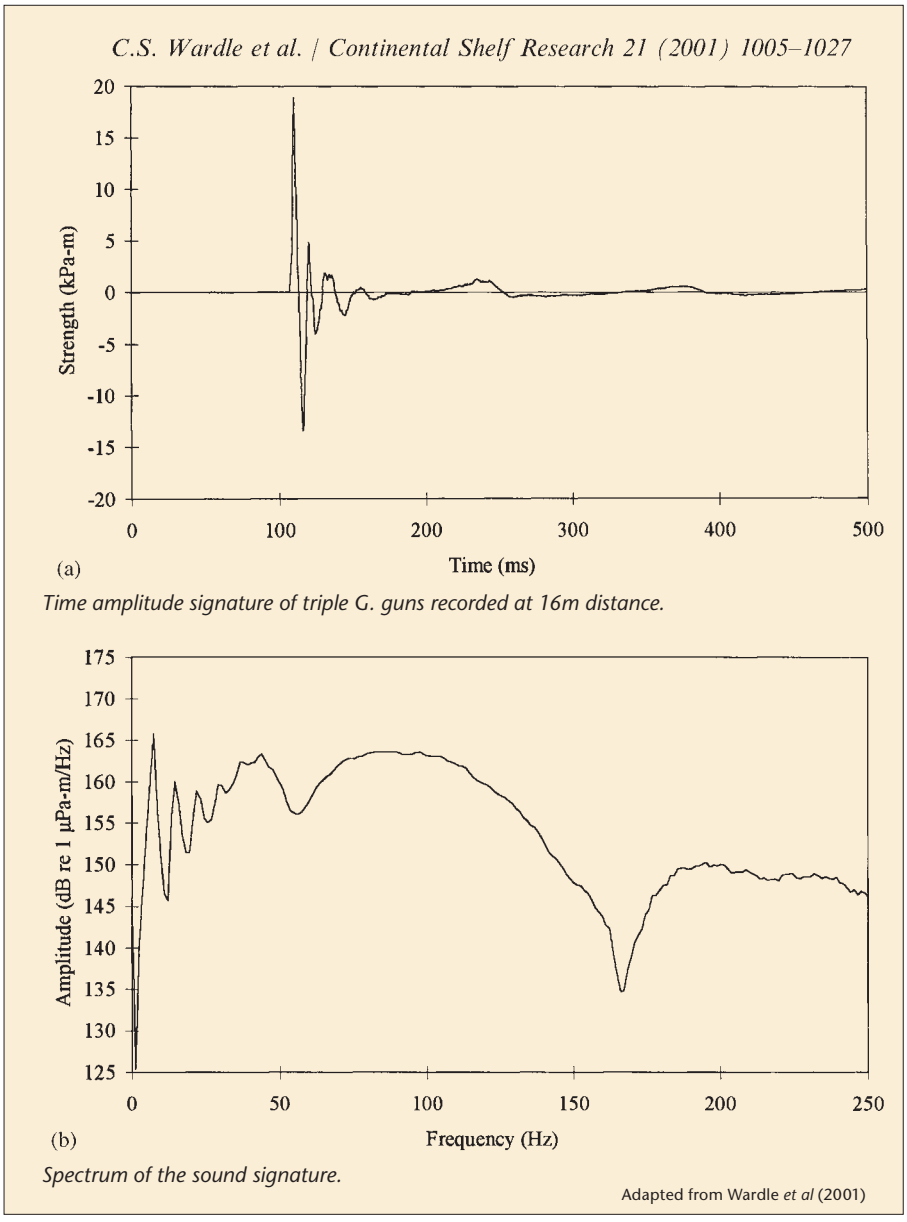
Ron Washbrook/Dreamstime.com

It is noted that the fish involved In the Fish Rock experiment are mainly inshore and reef species, closely associated with a home territory and not easily moved. In contrast, other open-sea experiments have found indications of large-scale influences resulting in apparent movements of commercial fish species, for example, making them more or less accessible to fisheries.

Startle Threshold

Fish react to manmade sound in various ways. The weakest form of response is minor changes in swimming activity where the fish change their direction or increase their speed. The most significant response on sound is an escape reaction where the fish initially show the C-start response.

Few controlled studies of startle response thresholds in different fish species and auditory groups due to sound pulses of varying frequencies have been made. It has been reported, however, that for hearing generalists the C-start response is triggered at a far-field sound pressure of 174 dB re 1 μPa @ 10 Hz, and 154 dB @ 100 Hz. These numbers indicate that the threshold

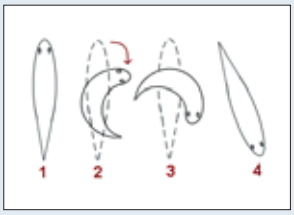


Time amplitude signature of triple G. guns recorded at 16m distance.

Spectrum of the sound signature.

Adapted from Wardle *et al* (2001)

The C-start response



When a fish receives a strong sound stimulus, or is attacked, an alarm reaction or an escape reaction is triggered. The reaction is known among scientists as the 'C-start' response, and it is perhaps one of the best-studied fish behaviour patterns. The 'C-start' takes its name from the shape the fish makes as it rapidly starts its escape from danger. The drawing shows that a threatened fish will perform two distinct movements to change direction and speed away from the threat. First, it will curve its body into the shape of a 'C' away from the source of sound. Second, it will then straighten its body from the curved position. The straightening motion allows the fish to push water off the full broadside of its body to quickly swim away from its attacker.

Field experiments have demonstrated that sound energy transmitted from air guns initiates this type of response on various fish species. In particular, intense infrasound results in escape reactions.

for triggering rapid escape responses is significantly above the absolute hearing threshold. Further, Karlsen (2010) gives startle behaviour responses for codfish starting at around 160–175 dB for a frequency of about 100 Hz. His observation indicates that their startle threshold values are around 80 dB above known auditory thresholds.

To precisely relate any startle response thresholds of fish to marine seismic activity is a difficult task since seismic sound propagation in the sea is a rather complex subject. Often, one oversimplifies the problem and assumes that sound attenuates with spherical spreading, 20 log(R), or cylindrical spreading, 10 log(R), where R is the distance from the seismic source. Spherical spreading applies to loss in deep oceans and cylindrical spreading to an ideal waveguide with perfectly reflecting boundaries at the sea surface and the water bottom. Such conditions are often encountered in the oceans for sound that strikes the bottom at angles greater than a critical angle. It follows that spreading loss in a waveguide such as the sea, with constant speed of sound, follows a spherical spreading law at short distance and cylindrical spreading at longer distance. A combination of the two spreading

Wardle et al (2001)

Images from video tape of three 30–40 cm saithe swimming towards the airgun at 16m range and about 4m from the sea bed and 10m from the surface. When the gun fires they show the typical C-start, veer off course and then continue swimming in the direction of the gun. All three saithe show the reaction in the same TV frame (Frame 2). Note the sound pulse, lasting 6ms, travels 30m during one TV frame of 20ms and the visual range is about 6m. The first three images are 20ms apart, the fourth frame is 5s later.

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laws gives for distances R greater than the ocean depth Z in metres (m), the asymptotic loss behaviour:

$$20\log(Z) + 10\log(R/Z)$$

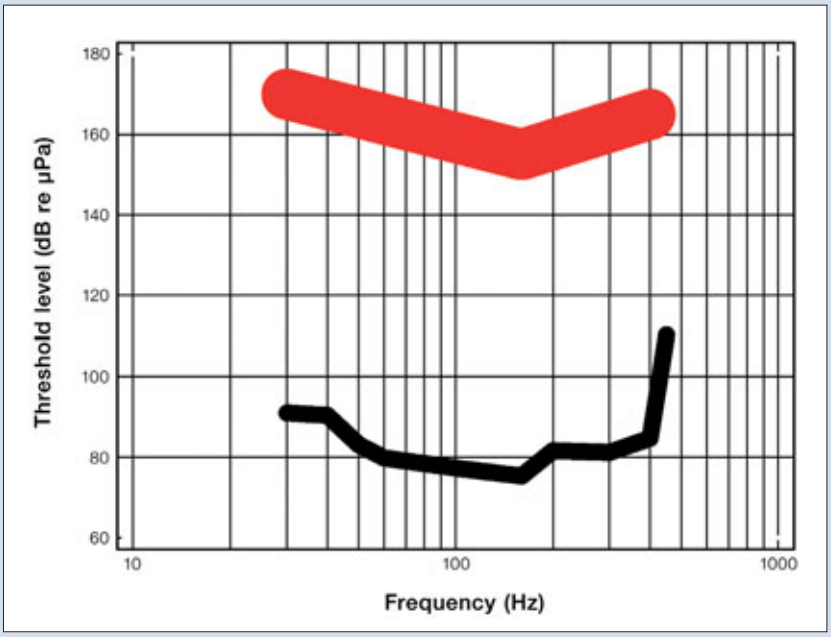
However, it is well know that the bathymetry and the composition of the ocean bottom, whether soft or hard, is important for long-range propagation. In addition, sound propagation changes with the oceanographic conditions and thereby the season. Therefore, if one wants to scientifically consider sound propagation under specified ocean conditions, one has two options: to measure or model seismic sound propagation. Obviously, it would be costly to measure sound propagation from seismic activity in the water column everywhere where seismic is acquired. The realistic alternative is to develop mathematical-acoustic simulation models which describe how sound propagates in the sea at long distances from the seismic source. Inputs to such acoustic models are source information and available geological and oceanographic information.

Simulation Models

Combined with knowledge of fish hearing and their startle thresholds, simulation models can be used to estimate the distance various fish species are affected by seismic activity. Such simulation models are under development. Among others, the Norwegian Petroleum Directorate (NPD) has commissioned SINTEF and the University of Oslo to develop an acoustic-biological model to predict the impact of seismic sound on the fish population. The ultimate goal is to develop an acoustic-biological model to use in the design and planning of seismic surveys, such that possible disturbance to fishing interest is minimised. Maybe, in the future, in a similar way as acousticians compute noise maps around airports due to airplane takeoff, underwater acousticians will be able to compute sound propagation maps in the sea due to seismic shooting?

In summary, seismic surveys may introduce a behavioural change of fish in the vicinity of the seismic source. The radius of the affected zone will depend on many variables, like the local physical conditions of the sea, the food supply for the fish and the behavioural patterns of the fish. Fish with natural habituation will be more steadfast than shoals of fish migrating through an area. Therefore it may be difficult to accurately determine the exact impact of seismic on the behaviour of fish. However, as long as their prey does not vanish, the steadfast fish will return. ■

Auditory and startle thresholds for codfish, which are hearing generalists with medium hearing ability. The audiogram (black curve) gives the faintest sounds that can be heard at each frequency. The startle response level (red curve) is assumed to be around 80 dB above the known hearing threshold. The red curve is displayed as a smoothed version of the black curve, added around 80 dB. Fish species react very differently to sound. Therefore, any generalisation about the effects of sound on fish should be made with care. The reactions of fish to anthropogenic sound are expected to depend on the sound spectrum and level, as well as the context (e.g. location, temperature, physiological state, age, body size, etc.)



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J. Dalen et al 2008 Kunnskapsstatus og forskningsbehov med hensyn til skremmeeffekter og skadevirkninger av seismiske lydbølger på fisk og sjøpattedyr: Rapport til Oljedirektoratet, Fiskeridirektoratet og Statens Forurensningstilsyn fra spesielt nedsatt forskergruppe.

H. E. Karlsen 2010 Hørsel og reaksjoner på lyd hos fisk http://www.olf.no.

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

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Modern Technology Reveals New Opportunities in the North Sea

CYRILLE REISER, EUAN ANDERSON & FRANCES MATTHEW; Petroleum Geo-Services

Although a mature basin, the use of new technologies both to acquire and process seismic data shows that the North Sea still holds significant potential

The North Sea region is regarded as a mature E&P basin, but the exploration potential is still excellent and hence there is a strong need to improve the quality of the seismic database. The use of new technologies to acquire and process seismic data has taken the level of subsurface understanding a step further and enabled the exploration of deeper, more complex and/or subtle targets. Seismic data with expanded frequency bandwidth is desirable, as it enables a better understanding of deep structure at the same time as detail is preserved in the shallower section, and the broad bandwidth offers a superior input to all inversion techniques.

Over the last few years, new acquisition methods and technologies have been introduced aiming to provide a broader seismic bandwidth, including variable inline streamer tow depth, acquisition with some streamers at different constant depths, and the GeoStreamer towed streamer.

A New Era

The first GeoStreamer towed streamer (a combination of hydrophone and vertical velocity sensor) was developed by PGS in 2007. The combination of the two sensors enables an effective removal of the sea-surface ghost by wavefield separation, allowing capture of the full bandwidth of the upcoming wavefield.

The simultaneous extension of both low and high frequencies has a major positive impact on seismic quantitative interpretation. The low side of the spectrum contributes in particular, but not exclusively, to the improved derivation of the absolute elastic properties such as acoustic and shear impedance, whereas the high side of the spectrum improves the seismic resolution and hence the detection of thin reservoir layers.

The ultimate goal of oil and gas company geoscientists seeking to find the best places to drill an exploration or production well is to be able to characterise the physical properties of rock formations in the earth before drilling. Ideally, they would like to have quantitative information regarding key rock properties such as lithology, porosity, clay content, and net-to-gross, along with information regarding fluid types, saturations and pore pressures of potential reservoirs. Historically, seismic images have stopped short of delivering this, as the seismic bandwidth was limited due to the conventional streamer design and acquisition method. Conventional

PGS

streamer acquisition, with a single type of sensor (hydrophone) and conventional towing depth, fails in most cases to fulfill the geoscientists' requirement of broader bandwidth with as much low and high frequencies extension as possible.

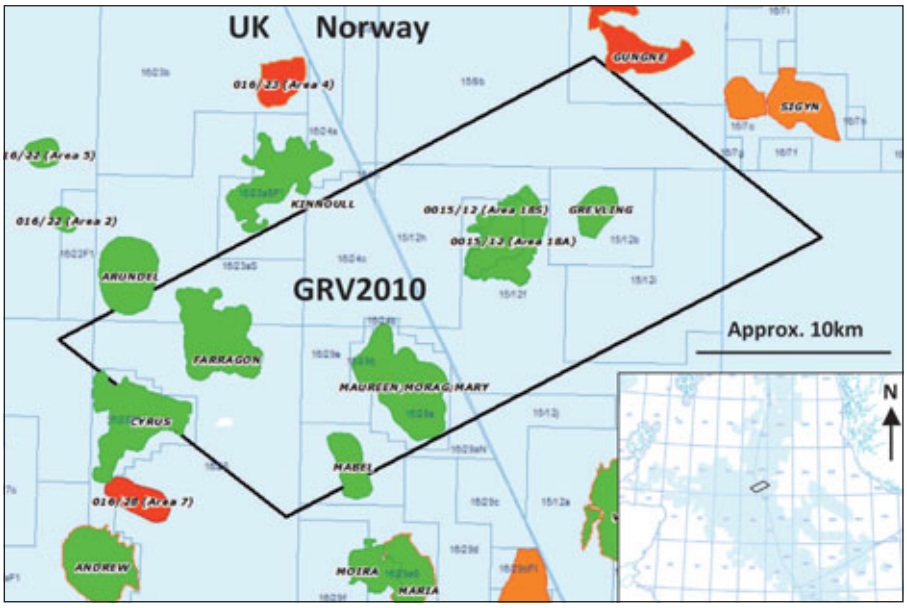
This article focuses on the enhancements seen in the mature province of the North Sea using new streamer technology, with a case study comparing conventional data against newly acquired GeoStreamer data.

Revitalising the CNS

A new 3D GeoStreamer survey (GRV 2010) shot in the Central North Sea (CNS) has helped to unlock new potential in an area which has already experienced many successful hydrocarbon discoveries. It is situated at the junction of the South Viking Graben and the Central Graben of the North Sea, and straddles both British and Norwegian waters.

Existing discoveries in the area are mainly dominated by the Paleocene play, along with some significant Upper Jurassic fields. The large Lower Cretaceous Britannia field is located in part about 10 km west of the GRV2010 dataset edge. In addition there are also some Eocene, Triassic and Middle Jurassic fields, and one Devonian field within 50 km of the Grevling area. The new GeoStreamer dataset entirely covers the Paleocene Maureen Field (now decommissioned) and the producing Paleocene Farragon Field, as well as the Middle – Upper Jurassic Grevling discovery, found in May 2009.

Upon comparing a typical section with both conventional streamer and GeoStreamer datasets, the difference between the images is easily observable.



The MC3D GRV 2010 GeoStreamer dataset is marked by the black outline, split roughly 50:50 between Norway and the UK. Conventional streamer data is available across the blue background

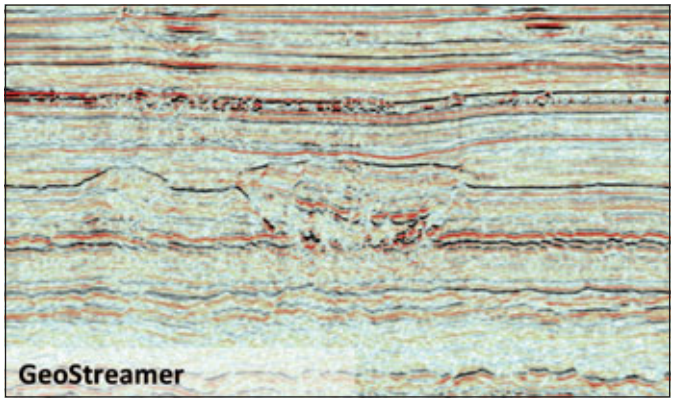
While the visible differences on the datasets are not all directly prospective, appreciation of new features adds up to a better historical understanding of the area and the geological processes that have taken place to produce the features that we can see today, and more importantly those that have shaped and created the successful hydrocarbon systems.

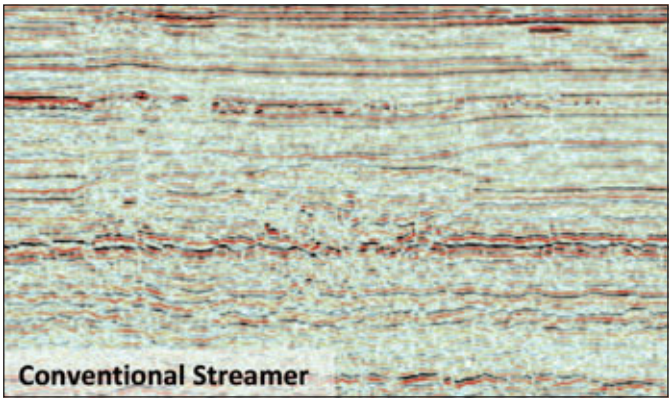
The Grevling field itself, with an estimated volume of between 40 million and 130 million barrels, makes another interesting case study. The Middle Jurassic – Upper Triassic field has a substantially improved image across the reservoir interval, providing a more reliable basis upon which to support key volumetric calculations and to predict reservoir characteristics. Not only does GeoStreamer data enable a clearer image on existing assets, but it has also proved to be successful in locating new geological features which until recently had gone unnoticed, thus opening up the opportunity to extend prospectivity to new plays.

Data Superiority

Tracking faults accurately is now more important than ever as new prospects are sought throughout the North Sea. Faults act as important trapping mechanisms, so knowing their precise positions are key to reservoir risking and categorisation. Faults appear clearer using GeoStreamer data throughout all the geological layers, meaning that faults which until now have been previously undetected will almost certainly modify current hydrocarbon expectations across all fields, existing, new, and prospective.

At first glance, the conventional streamer data appears to completely mask the Tertiary feature which is present on the GeoStreamer dataset. Interpretation based upon the conventional streamer data alone may have assumed there was no feature present, or an erosional feature rather than the injectite structure which is hypothesised.



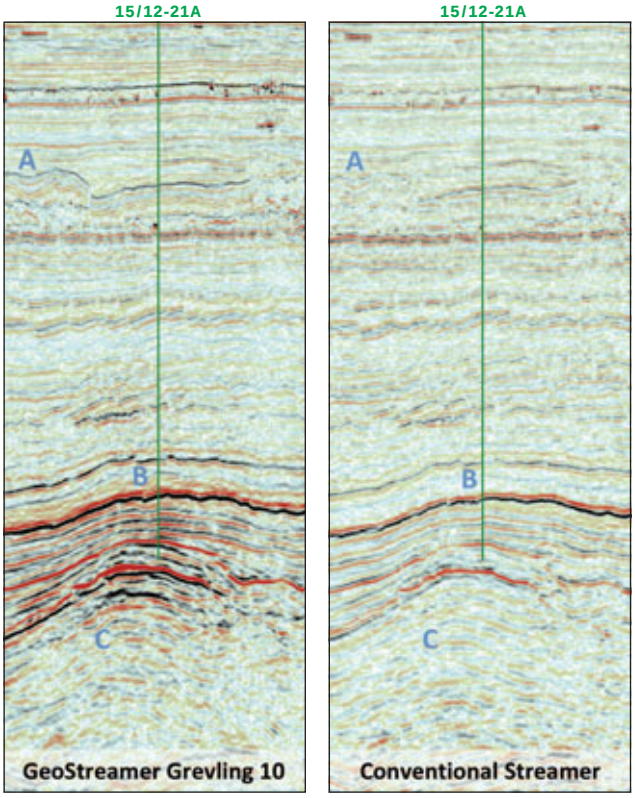


The data superiority of GeoStreamer is not limited to one geological level, but is noticeable throughout, as can be seen from the illustrations.

Revitalising the North Sea

GeoStreamer is opening up a wealth of new possibilities in the North Sea. Following a prospectivity review of this GRV 2010 GeoStreamer dataset, previously unseen features have now been identified, while existing features have been imaged more clearly. This all adds up to a better geological understanding and direction for future prospectivity, volumetrics and risking, leading to a revitalisation of this mature basin.

The industry is moving towards maximising the recovery rate of the hydrocarbons already discovered. The time of easy oil is behind us. Therefore there is an urgent need to accurately characterise very complex reservoirs, as well as being able to resolve very thin remaining hydrocarbon columns. In order to achieve improved seismic reservoir characterisation and better reservoir properties prediction away from the well, high quality broadband seismic is needed. ■

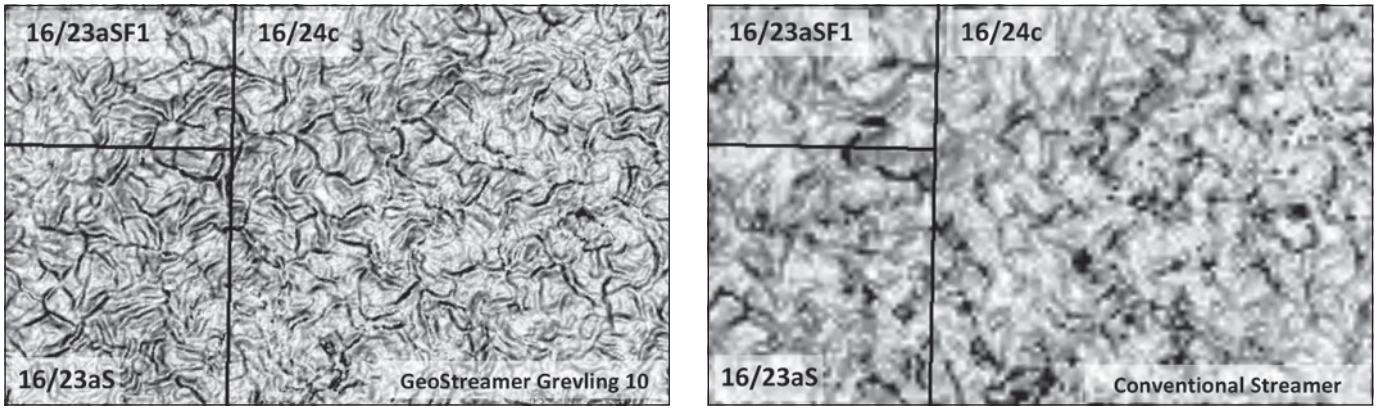


This example over the Grevling field highlights the clear differences between the datasets throughout the section. More specifically:

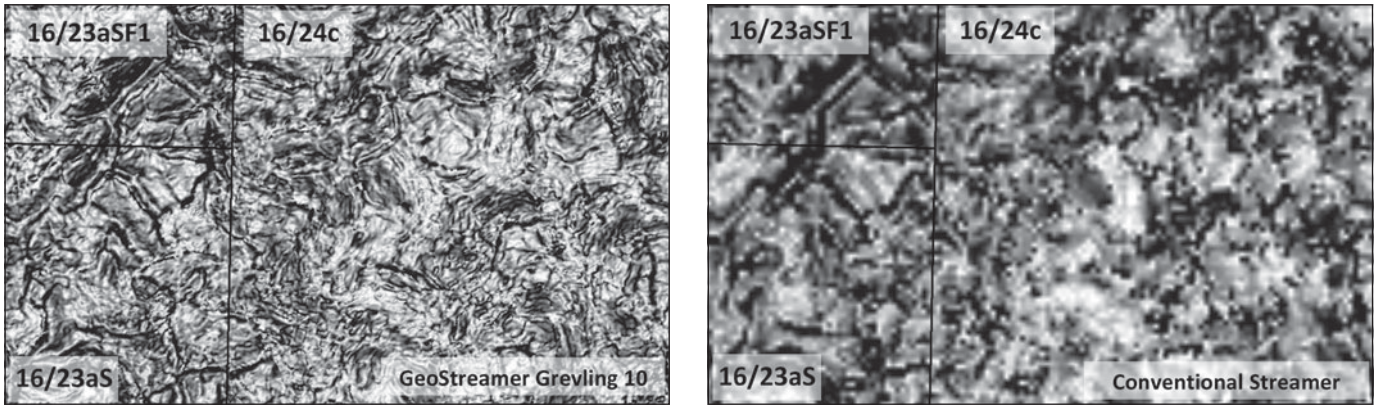
A This Tertiary feature is more observable and trackable, as in the previous comparison.

B Increased fault clarity, in particular over the Grevling field, but also noticeable throughout.

C The position of the Grevling field at this Triassic level shows clearer structural detail, enabling more reliable Gross Rock Volume calculations.



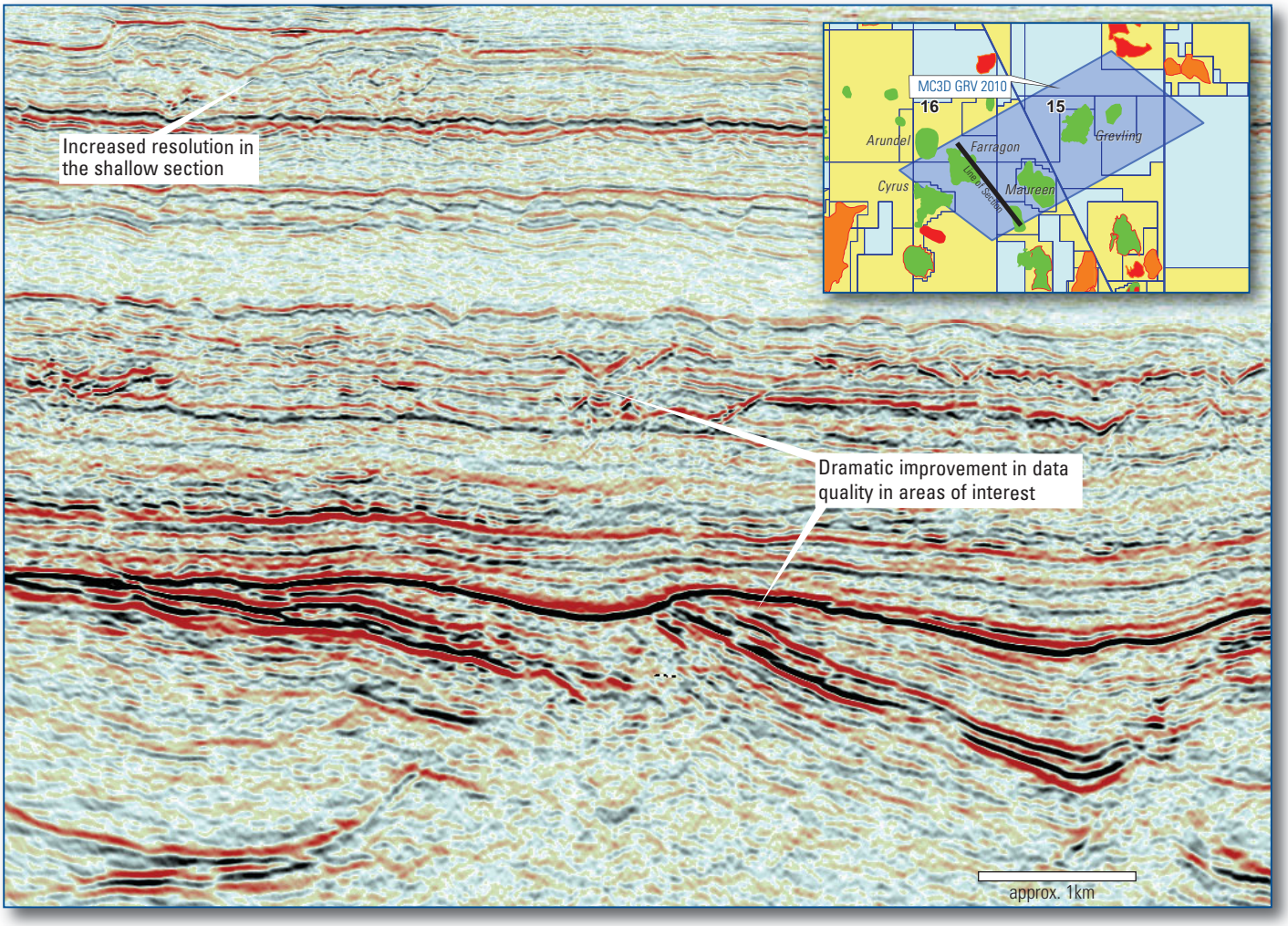
The difference between fault visibility using conventional streamer and GeoStreamer data. Polygonal faulting at the Oligocene level (1.4 seconds timeslice) is shown above, using a "Dip of Maximum Similarity" volume across the two datasets, to highlight structural anomalies. The more modern data shows a superior representation of the fault patterns with more defined edges and greater overall details, some of which can be attributed to the closer line spacing.



A timeslice at 2.0 seconds, again using the "Dip of Maximum Similarity" volume, this time within the Eocene, shows the level of detail that can be expected in comparison to older and more traditional 3D streamer acquisition. The modern data shows us a great deal of extra structural detail, which can be used to piece together a more trustworthy geological history.

MultiClient MC3D GRV 2010 : GeoStreamer® Survey

510 sq.km of newly acquired GeoStreamer data in UK Q16 and Norway Q15



An enhanced demultiple flow includes Backus Deconvolution, muted 3D SRME and Post Migration Time Domain Radon for improved short and long period demultiple.

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This GeoStreamer Broadband Seismic Dataset is now available for review & license

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Kota Kinabalu, Sabah: A Turbidite Paradise

Rasoul Sorkhabi

Kota Kinabalu is a rapidly developing city for touristic, commercial and industrial reasons.

RASOUL SORKHABI, Ph.D

Kota Kinabalu, the largest town in Sabah, Borneo, is a rapidly developing urban centre and a tourist attraction in South East Asia. To the geologist, this part of Sabah is also renowned for its outcrops of turbidites. These Oligocene deepwater sediments are among the most sand-rich turbidite outcrops in the world.

The Land below the Wind

Sabah is known as 'the Land below the Wind' because it lies below the typhoon (hurricane) belt. *Land Below the Wind* (1939) is also the title of a classic work on the cultural and natural setting of Sabah from the pen of a lady writer, Agnes Newton Keith (1901-1982), who lived there in the first half of the 20th century. Her husband Henry "Harry" worked as Conservator of Forests and Director of Agriculture for the British government of North Borneo, now known as Sabah.

Located on the north-west corner of Borneo, Kota Kinabalu (abbreviated as KK) is the capital of the Sabah state in East Malaysia. With a population of about 900,000, the greater KK is the sixth largest metropolis in Malaysia. Although its people speak Bahasa Malaysia, there are many different ethnic and linguistic groups, including Kadzan-Dusan, Bajau, Malay, Murut and Chinese (Hakka). KK has a fairly large airport that provides domestic flights (to Kuala Lumpur, Kuching and elsewhere in Malaysia) as well direct flights to overseas destinations in Brunei, Seoul, Shanghai, Hong Kong, Taipei, Singapore, Manila and Tokyo.

Seafood lovers will find numerous restaurants both in

downtown KK and along its shores which offer diverse, fresh and inexpensive seafood. The University of Malaysia Sabah, founded in 1994 in KK, has a large campus on a hill facing the South China Sea. The city has a warm, humid climate typical of the equatorial region.

Api Api to Kota Kinabalu

KK's history is a blend of ancient and colonial heritage. In pre-modern times, it was a small fishing village called Api Api ("fire, fire") after the fireflies which twinkle on local mangrove trees at night. In 1882, the British Chartered (North Borneo) Company established a settlement on Gaya Island (Pulau Gaya) offshore the present city of KK. In 1888, the British declared North Borneo (Sabah) as a protectorate of the United Kingdom. However, the indigenous people of Bajau, led by their leader Mat Salleh, burned the colonial settlement on Gaya Island in 1897, and the British then moved their settlement to Api Api. The new place was renamed Jesselton after Sir Charles Jessel (1860-1928) who was then the Vice-President of the Company which played a leading role in the early development of the city.

During World War II, Sabah came under Japanese rule, and after the war ended in 1945, North Borneo became a British Crown Colony. In 1963, the region gained self-government and joined the Federation of Malaysia. The name Kota Kinabalu then replaced Jesselton; it was so named because Mount

Borneo, with an area of 752,000 km², is the world's third largest island (after Greenland and New Guinea) and is home to some of the earliest discovered oil fields in Asia. Today, it is administered by three countries: Kalimantan (72.9% of Borneo) belongs to Indonesia; Sarawak (16.6%) and Sabah (9.8%) are parts of the Malaysian Federation, and Brunei (0.8%) is an independent kingdom. Mt. Kinabalu (4,101m), located in Sabah, is the highest summit on Borneo.

Rasoul Sorkhabi

A view of turbidites of the West Crocker Formation in Kota Kinabalu. The author, seen in the photo for the scale, is looking at a small normal slip fault that has slightly deformed the interbedded sandstone and shale beds.

Rasoul Sorkhabi

Kinabalu, a granite massif 4,101m high, is located about 90 km north-east of the city.

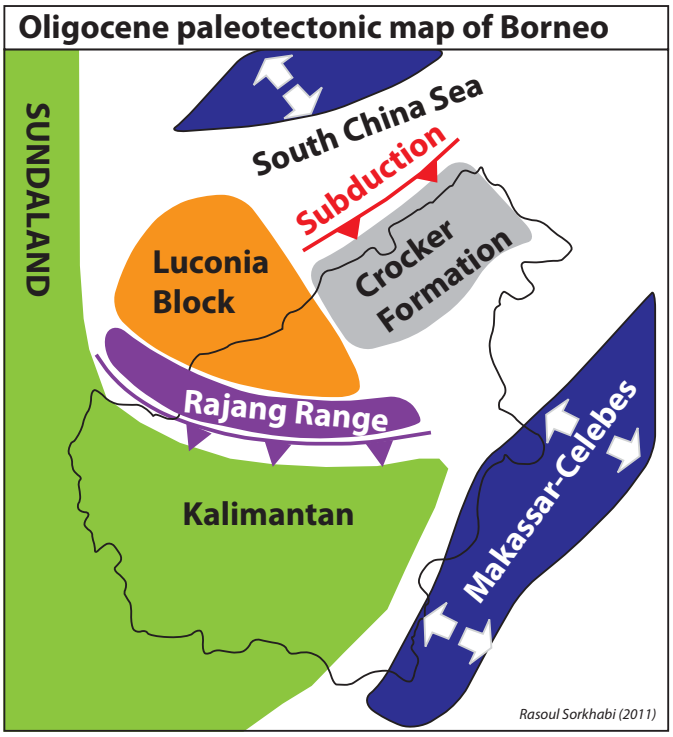
In 1976, the government of Sabah allowed Malaysia's national oil company Petronas to explore its offshore territory in exchange for royalties. In recent years, several international oil companies have also operated offshore Sabah with notable deepwater discoveries.

The Turbidites of the Crocker Range

The landscape of KK forms the foothill part of the Crocker Range. A remarkable geologic feature of this area in western Sabah is the wide distribution of turbidites of the Crocker Formation. These are interbedded sandstone and shale sedimentary rocks deposited in a deepwater basin (submarine fan) during the latest Eocene (37 Ma) through to the earliest Miocene (21 Ma).

The Crocker Range runs north-north-east to south-south-west and is deformed by a series of high-angle reverse faults dipping south or south-east; therefore, the turbidite packages exhibit repeated stratigraphy across the region, making their measurement a difficult task. The reverse faults probably formed during the Miocene, and the soft shale layers have often acted as slip planes for the faults and deformation.

The turbidites probably reach a thickness of 1,000m. Felix Tongkul, a geology professor at the University of Malaysia Sabah, who conducted his doctoral research in this area, has divided the turbidites into the lower sandstone unit (several hundreds of metres thick) and the upper shale unit



A simplified palaeotectonic map of Borneo during the Oligocene. The Crocker Formation was deposited as deepwater (foredeep) fan sediments facing a subduction zone on the South China Sea. Prior to this event, a subduction zone existed along the Rajang-Kalimantan line during the Paleocene followed by the continental collision of the Luconia Block (which had drifted away from Sundaland) with Borneo (Kalimantan) during the Eocene.

A view of the upper shale unit of the West Crocker turbidites in KK.

(about 100m thick). The lower sandstone unit is an alternation of thick grey sandstone beds and relatively thin shale beds. The sandstone is quartz rich, and the individual beds range from tens of centimetres to a few metres thick. The upper shale unit has much thinner sandstone layers and occurs as a cap rock of grey or red shale. The Crocker turbidites are also exposed on islands offshore KK, and extend offshore western Sabah below the Miocene-Quaternary deltaic sediments, but these Oligocene turbidities have not yet been explored for their possible gas resources.

The Crocker Formation turbidites sit on the Eocene Trusmadi Formation (thick dark shale beds interbedded with thin sandstone layers). The relationship between the two formations is probably an unconformity. The basement rock of this part of Sabah is an ophiolite mélange (ocean-floor subduction rocks), probably of Cretaceous age.

For turbidite lovers, KK is a paradise, as one can visit numerous sections of the West Crocker Formation, among the most sand-rich turbidite outcrops in the world, along the roads within and outside the city. If you plan to visit KK for this purpose, I recommend the following two papers for more information:

Rasoul Sorkhabi

Sabah Museum in KK offers an excellent opportunity to gain visual knowledge of the history and culture of peoples who have settled Sabah for millennia.

Felix Tongkul (1989) "The sedimentology and structure of the Crocker Formation in the Kota Kinabalu area," GEOSEA VI Proceedings, Jakarta 1987, Indonesian Association of Geologists, pp. 135-156.

Paul D. Crevello et al. (2006) "Mixed braided and leveed-channel turbidites, West Crocker fan system, northwest Borneo," in Atlas of Deep-Water Outcrops, AAPG Studies in Geology 56. ■

Facing the western waters, KK offers splendid views of sunsets over the offshore islands.

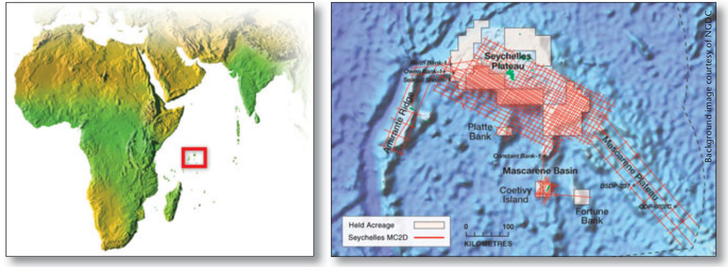
Rasoul Sorkhabi

Unlocking the Exploration Potential of the Seychelles

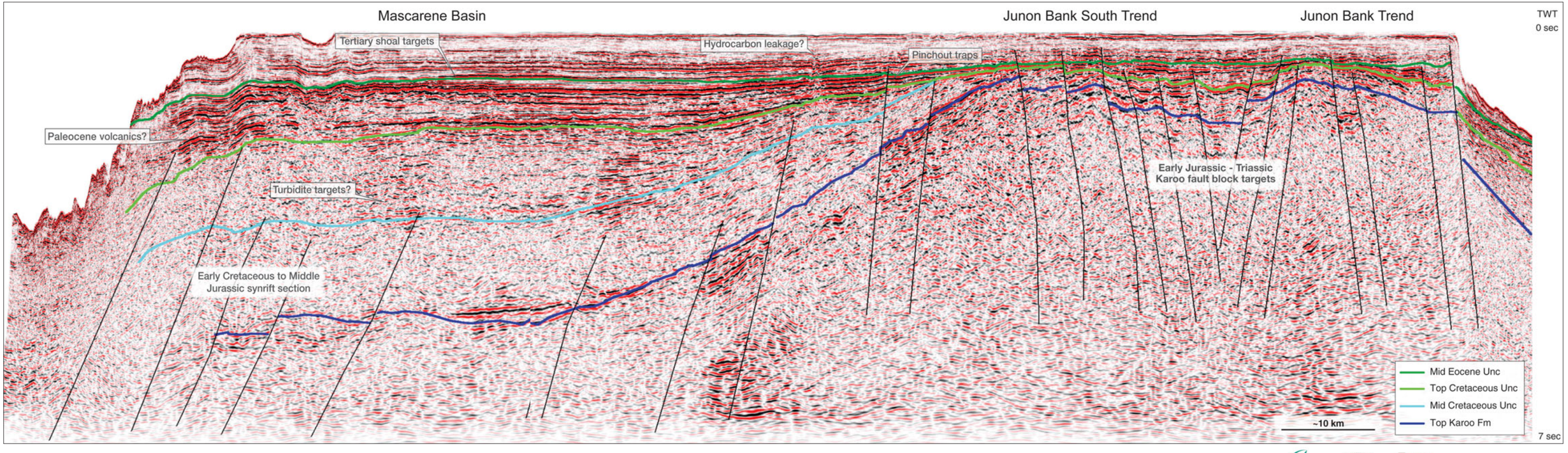
With only four exploration wells and a density of less than one well per 20,000 km^2, the Seychelles is vastly unexplored. A new 19,600 km multiclient 2D survey by Fugro and Geomahakarsa, with cooperation from the Seychelles Petroleum Company (SEYPEC), has produced a step change in seismic quality and coverage and is yielding important new insights into the geology and petroleum potential of the Seychelles.

Recent East African success, including in the deep water of Mozambique and Tanzania and onshore Madagascar has focussed industry attention on the region. With the aid of the 2010/2011 Seychelles multiclient dataset, the Seychelles is an emerging province with world class exploration potential. Multiple phases of rifting have impacted the position of the Seychelles micro-continent and resulted in a thick prospective section with numerous plays in both shallow and deep water, and attractive structural trends.

A key challenge for exploration companies has been the variable coverage and, in general, poor quality of vintage seismic data. The Seychelles MC2D, acquired with 8,000m cable length and innovative processing routines, has resulted in a significantly improved data set. Special consideration was given in preserving far offset data leading to significantly improved imaging of deeper structural and stratigraphic trends. The survey includes potential field data and a regional integrated interpretation. Extensive stakeholder alignment and community consultation was key to a successful operational component of the project. The coverage extends over prospective areas licensed by WHL Energy and Afren and previously unexplored areas, providing an exciting basis for realising the exploration potential of the Seychelles.



Project map showing Seychelles structural elements



Seychelles:
New Insights Revealed

KIM MORRISON, ExplorationEdge

The Seychelles Exclusive Economic Zone covers over 1.3 million km² and contains more than 100 islands, the largest composed of Precambrian granites and rising over 700m above sea level. It was these granitic islands, indicating the presence of a micro-continent, which drew Mobil to conduct the first exploration seismic survey in the area in the early 1970s.

In the early 1980s Amoco drilled three wells which confirmed that the Seychelles contains highly prospective Triassic, Jurassic and Cretaceous stratigraphy analogous to productive sections in East Africa and Madagascar. In Owen Bank-1 over 1,500m of a Middle to Late Jurassic syn-rift shale-dominated sequence was penetrated with good source and seal potential. Reith Bank-1 found 2,000m of a continental Middle Triassic to Early Jurassic Karoo Formation section with good reservoir quality sands and interbedded shales, while Seagull Shoals-1 penetrated a similarly attractive Karoo section. Oil and gas shows provide excellent evidence of a working petroleum system, and the new Seychelles MC2D suggests the wells may not have tested valid closures, with considerable updip potential recognised.

In a subsequent exploration phase, Enterprise Oil drilled Constant Bank-1 in 1995, reaching TD at 3,437m in Paleocene volcanics. The new data provides significantly improved imaging of the sub-basalt section near Constant Bank and potential for a large untested deep structure.

Current operators, WHL Energy and Afren are actively exploring their respective acreage and the next round of exploration drilling is planned for 2012/2013.

Petroleum System Evident

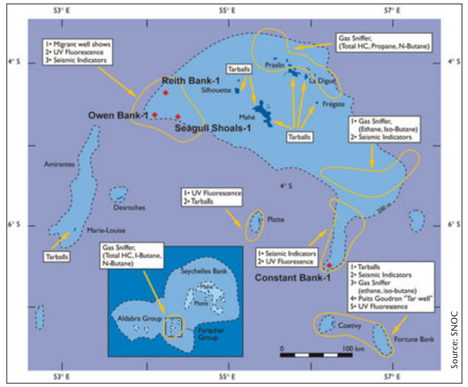
The Seychelles was originally part of the Gondwana Supercontinent, nestled between Madagascar, India, Pakistan and Somalia. As a result, the Seychelles has close similarities to geological elements of these areas.

Three phases of rifting have impacted the Seychelles micro-continent, eventually leading to its present isolated position. These are the Mid-Early Jurassic separation of Madagascar, Seychelles and India from Africa along the Karoo rift zone; Middle Cretaceous rifting related to the separation of Seychelles and Madagascar and resulting in the >3,000m Mascarene Basin section, as shown on the seismic section on page 58; and Late Cretaceous rifting of India from the Seychelles.

Airborne geochemical survey data, tar ball occurrences, seismic indicators of gas and hydrocarbon leakage and source rock data from the Amoco wells all support the presence of an active petroleum system in the Seychelles.

The tar balls have been extensively analysed, and researchers have interpreted a number of different local source rock families (Plummer, 1996). These include a locally developed Middle Jurassic open marine anoxic carbonate source rock, a Campanian or Maastrichtian – Paleocene paralic oil-prone predominantly clastic shale source, with carbonate influence, and a predominantly tropical terrestrial source possibly developed in a Middle to Late Cretaceous clastic delta.

Summary of evidence for active petroleum system in the Seychelles.



Karoo section consists of non-marine continental sands and shales, faulted against or onlapping the Precambrian granitic basement. A regionally recognised prolific lacustrine or restricted marine source rock is expected at the Permo-Triassic boundary. The Sakemena Shale in Madagascar is the source for the billion barrel heavy oil/tar sand deposits of the Bemolanga and Tsimiroro fields, while the equivalent age Bokh Shale sources the multi-Tcf gas condensate Calub Field in Ethiopia.

Rifting of Madagascar and the Seychelles from East Africa resulted in a thick Middle to Late Jurassic rift section in the region. Interbedded shales, oolitic limestone and sandstones were deposited in shelf settings, with deeper marine shales and carbonates present in basinal locations with potential turbidite sands development. The Middle Jurassic Bemaraha Formation in Madagascar contains anoxic marine carbonate and shale with excellent source potential and equivalent age formations in Tanzania and Mozambique are also recognised as high quality source rocks. Paleogeographic reconstructions show the Seychelles to be on structural and depositional trend in the Middle Jurassic and similar excellent quality source rocks are expected, which are likely to be mature for present day oil generation in the basinal and deepwater areas surrounding the banks and plateaus.

The opening of the Mascarene Basin with sea floor spreading between Madagascar and the Seychelles was a major structural event and resulted in up to 5,000m of Cretaceous sediment in areas to the south and south-east of the Seychelles, including along the Mascarene Plateau. River systems draining vast areas of India and Pakistan provide an abundant sediment source. Potential reservoir facies include shoreface and incised valley fill sands, with potential for turbidite sands in more distal locations. Cretaceous source rocks potential is recognised from regional anoxic events (i.e. Turonian) and modelling indicates significant areas where prospective source units will be currently in the oil window. Some Maastrichtian age volcanics were intersected in the Amoco wells, with clearly identifiable thinning onto structural highs on seismic data.

With the separation of the Seychelles from the Indian subcontinent in the Paleocene, the region became removed from major clastic sediment source, and the Tertiary shelf section comprises predominantly carbonates with some well-developed shallow marine sands eroded from exposed granites. Mudstone and fine-grained carbonate are expected in the deepwater setting off the main bank areas and there is seismic evidence for some turbidite sands development. The Paleocene section consists of localised volcanics onlapping onto the Seychelles Plateau.

C. Scotese 2011 PALEOMAP Project

Middle-Late Jurassic Paleogeography – separation of East Africa and Madagascar/Seychelles and regional marine source rock development

Several Major Plays

A number of plays have been identified in the Seychelles area. These include the Triassic and Early Jurassic Karoo fault block play, which comprises well developed non-marine sands sealed by Middle Jurassic – Early Cretaceous shales and fine-grained carbonates or intra-formational Karoo shales. Source is provided by Karoo shales or the interpreted regional Middle Jurassic carbonate enriched anoxic source rocks. Structural traps include large rotated 3-way dip fault blocks and horst features with closures in excess of 100 km² identified on the new Seychelles MC2D seismic.

The Middle to Late Cretaceous Mascarene Basin play consists of shallow marine and deepwater turbidite sandstone reservoirs sealed by marine shales, partially underlying Late Cretaceous and Paleocene volcanics. Sources are Jurassic oil prone carbonates and shales or Cretaceous anoxic shales. The seismic line on page 58 shows the Cretaceous section to have an attractive seismic character with both stratigraphic traps (pinchout and onlap) and structural traps (inversion, faulted and drape features) evident.

The Tertiary carbonate play involves Tertiary reef build ups or oolitic shoals sealed by fine grained carbonates and marls with charge from mature Jurassic and Cretaceous source rocks. Additional plays are provided by Middle Jurassic oolitic limestone, Tertiary turbidites in deepwater settings, and possible fractured granitic basement and fractured volcanic targets.

The Seychelles is entering an exciting exploration phase. Recent success elsewhere in East Africa has focused industry attention on the region and the Seychelles Government provides a highly supportive environment for new entrants into the country. With a number of attractive plays, large untested structures and now 19,600 km of high quality MC2D data, the key elements are in place for exploration success. ■

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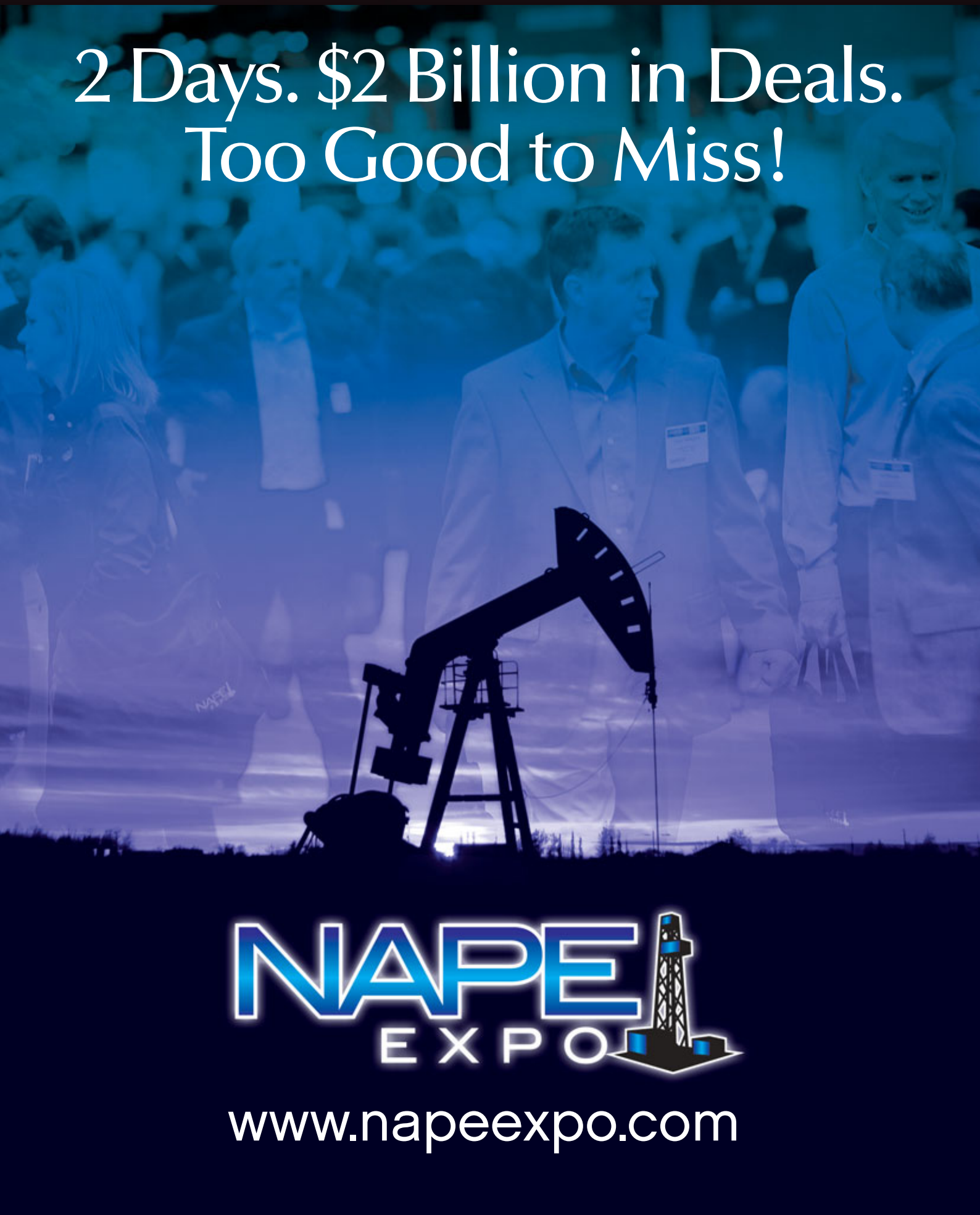
February 22-24, 2012



The Ups and Downs of Eustatic Sea Level Change:
Review and Applications

MIKE SIMMONS, Neftex Petroleum Consultants Ltd

Eustatic sea level change is a subject much debated in the literature. But what is eustasy, can it be recognised, what controls it – and why does it matter to exploration?

Most petroleum geologists will have a good knowledge of sequence stratigraphy – an important discipline that has revolutionised our work over the last 30 years. Sequence stratigraphy examines the stratigraphic geometries and associated patterns of sedimentary facies that are generated by relative sea level change. In doing so, it is a valuable tool for predicting the occurrence of, for example, reservoir and source rock facies and understanding the architecture of reservoirs. Equally importantly, it provides a catalyst for the integration of seismic and well and outcrop data as well as detailed sedimentological, biostratigraphic and geochemical studies. Put simply, many of the deepwater plays being explored for today are lowstand fans, predicted from sequence stratigraphic principles and identified on high-resolution seismic data.

Eustatic Sea Level Change

Sequence stratigraphic methodology first came to prominence with the publication of the seminal papers by Peter Vail and his colleagues from Exxon in 1977. Since then, sequence stratigraphic studies have become commonplace and the science has developed its own particular jargon to account for the countless ways in which sediments respond to sea level change. But Vail and his colleagues did not just bring

The Oxfordian Corallian succession at Osmington Mills on the South Dorset coast of England – a classic location for the recognition of sedimentary cyclicity.

Photograph courtesy Ian West (http://www.soton.ac.uk/~imw/)

sequence stratigraphy to the petroleum geologists' tool box; they reactivated an old idea that some sea level changes are both synchronous and global in nature. Such changes are termed eustatic, a term first introduced by the Swiss geologist Eduard Suess in 1888.

Following the publications by Vail and his colleagues, eustasy once again began to grow in the minds of geologists, cemented in 1987 by another paper from the Exxon school, led by Bilal Haq, which offered a clear statement of a high-resolution sea level curve for the Mesozoic and Cenozoic. Many geologists accepted this and set out to find the sea level events in their particular area, but sceptics like Andrew Miall doubted that a eustatic record could be discernible given tectonic and sediment supply influences, or that biostratigraphy was of sufficient resolution to say that sea level changes were truly synchronous. They also suggested that no viable mechanism existed to explain rapid eustatic sea level changes in the geological past. Miall's publications remain a valuable source of commentary on the validity of eustatic cycles.

So debate has raged over eustatic sea level changes and their expression for about 30 years. But why does this matter to the petroleum geologist?

Value of Sequence Stratigraphy and Eustasy

Sequence stratigraphy has now become established as a primary interpretation methodology for petroleum geologists. It helps explain the true geometric relationship of sediment packages and, because the technique is based around an understanding of the temporal and spatial relationship of sediments, we can recognise if, for example, they are physically connected – useful for estimating reservoir volume, and more effective than simple, potentially misleading, lithostratigraphic correlations. It is an effective means of combining datasets such as biostratigraphy, sedimentology, logs and seismic within one integrated framework, and is a powerful means of predicting away from known data points. The geometries of sequence stratigraphy predict what facies may be expected up, down and laterally in the depositional system, so the occurrence of reservoirs, source rocks and seals may be predicted regionally from relatively sparse datasets.

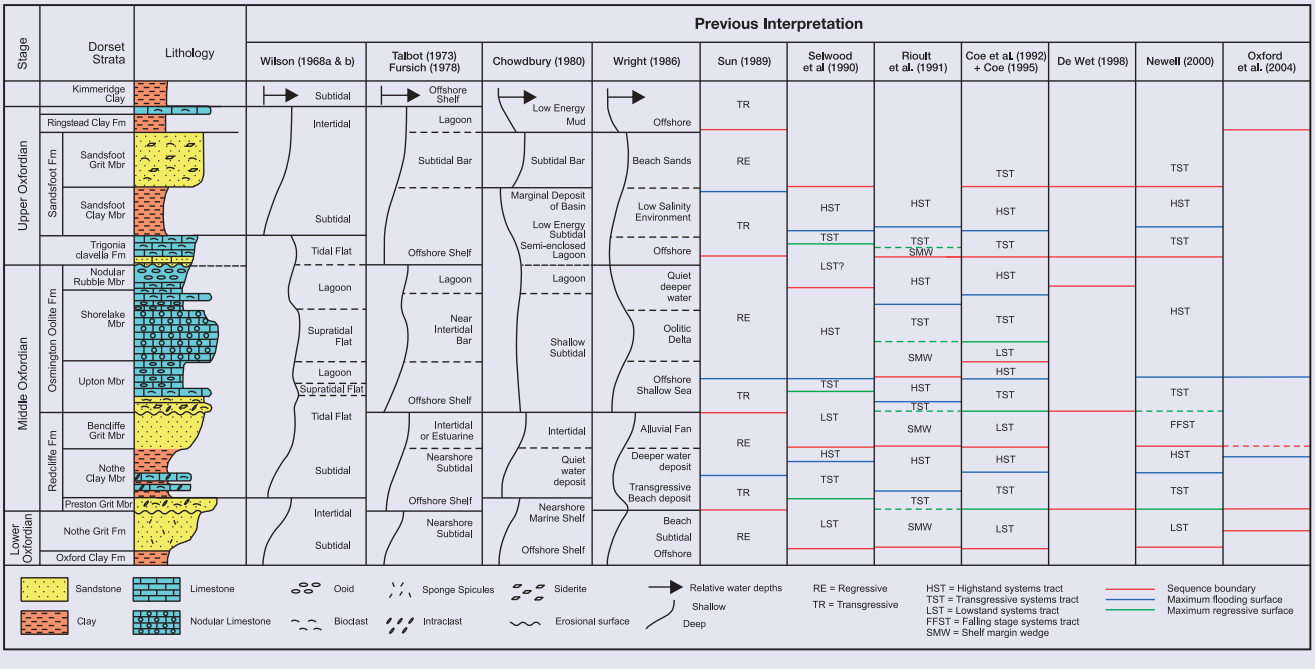
All these are valid benefits, regardless of whether a eustatic model underpins

Eduard Suess, who coined the term eustasy.

one's view of sequence stratigraphy or not. However, if a eustatic model can be applied then other powerful advantages accrue, including the development of a framework for detailed and precise correlation, mapping and isopaching, and the use of analogues and generic play concepts. Outside the direct economic benefits, an understanding of eustasy provides insight into the sedimentary evolution of the Earth and links to changes in palaeoclimate, both important for our understanding of future climate change.

But first we need to address the question of whether eustatic sea level

As an example of the variations possible in interpretation, we can consider the Oxfordian (Late Jurassic) succession of the Dorset coast of southern England, as shown in the introductory image. This is a mixed succession of clays, sandstones and limestones, in which cyclicity has long been recognised and which has been interpreted in terms of changing relative sea level by a number of workers. A comparison of these interpretations, as shown here, shows a great variation in the placement of significant bounding surfaces such as Maximum Flooding Surfaces, Sequence Boundaries and hence systems tracts. An internally consistent and robust strategy needs to be applied when attempting to develop a global eustatic model.



change can be recognised in the Earth's sedimentary record, and if so, what mechanisms drive it?

Synchronous Sedimentary Sequences

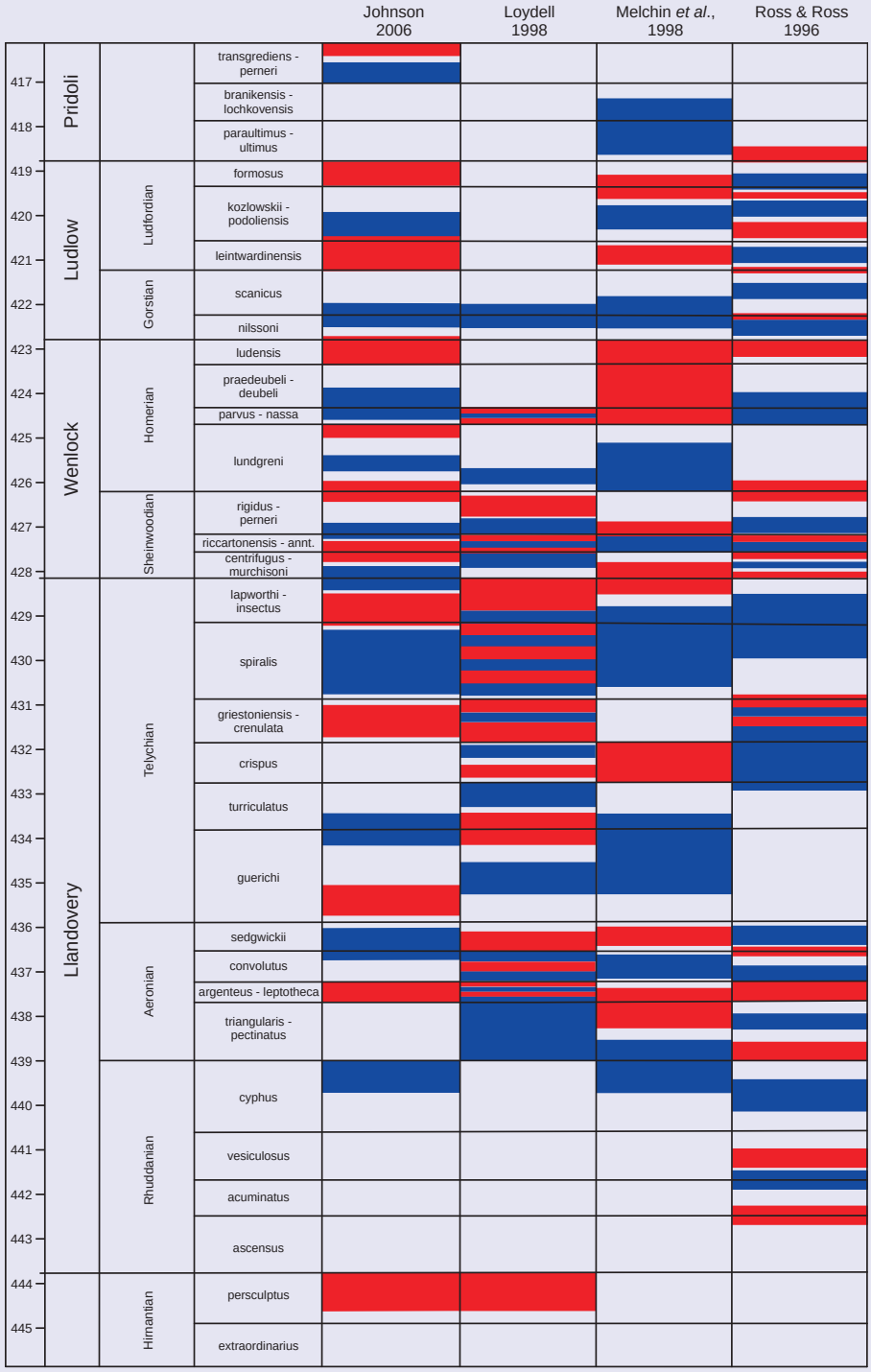
There is growing evidence that within the resolution of the stratigraphic calibration tools available (typically biostratigraphy, but also isotope stratigraphy), it is possible to demonstrate that there are synchronous global rises and falls of sea level throughout the Phanerozoic. The precision of stratigraphic calibration tools has much improved recently, so that biozonal/isotopic resolution can typically be in the order of a few hundred thousand years or less (as calibrated by orbital forcing, or "Milancovitch" cyclicity). Whilst not perfect, it suggests that a sea level event as represented by changing facies, occurring in the same or equivalent biozone in multiple locations around the world, is likely to be the same eustatic event, although expressed differently depending on the local tectonic and sedimentary setting.

Of course, to build up a eustatic model requires the examination of thousands of sedimentary sections around the globe, analysed in a consistent manner using calibrated biostratigraphy/isotopes. Such work is usually carried out in industry and has major competitive commercial advantages, hence results are rarely published in detail (in Neftex we have in the last ten years built a model which currently has over 125 global sequences in the Phanerozoic, for use in correlation and mapping).

Nonetheless, some results of sequence stratigraphic synthesis have been published. Volumes such as *SEPM Special Publication 60* or our *Arabian Plate Sequence Stratigraphy* are helpful for demonstrating the data that lies behind eustatic models. In 2008 Haq and Schutter published their model of Palaeozoic eustasy indicating the reference and ancillary sections from which the model was derived, although not their interpretation strategy or biostratigraphic calibration.

However, some eustatic models differ from each other for the same time period – not surprising as interpretation strategies vary between workers, and views on biostratigraphic calibration may differ. Therefore, as a fundamental note of caution, before considering how a succession relates to a published eustatic sea level curve or model, one should ask the question "is the sequence stratigraphic interpretation strategy used to construct this model the same as mine?" ▶

This chart compares Silurian eustatic events as described in various publications, with sea-level highs in blue and lows in red. Only major fluctuations from each interpretation are shown, with some common events detected, such as a sea level high within the spiralis Zone of Telychian time. Differences between the models may arise because the highs and lows of sea level are being picked in contrasting ways – here Loydell has used changes in graptolite diversity, whilst Johnson has concentrated on facies patterns from various tectonically stable basins.



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Understanding Eustasy

The first step to understanding the different driving mechanism for eustasy is to determine the rate and magnitude of eustatic sea level change.

Earlier estimates of eustatic sea level suggested single cycle changes of up to 400m, but more precise estimates using back-stripping (see papers by Ken Miller and co-workers) show that short term eustatic changes are typically 20–80m in magnitude.

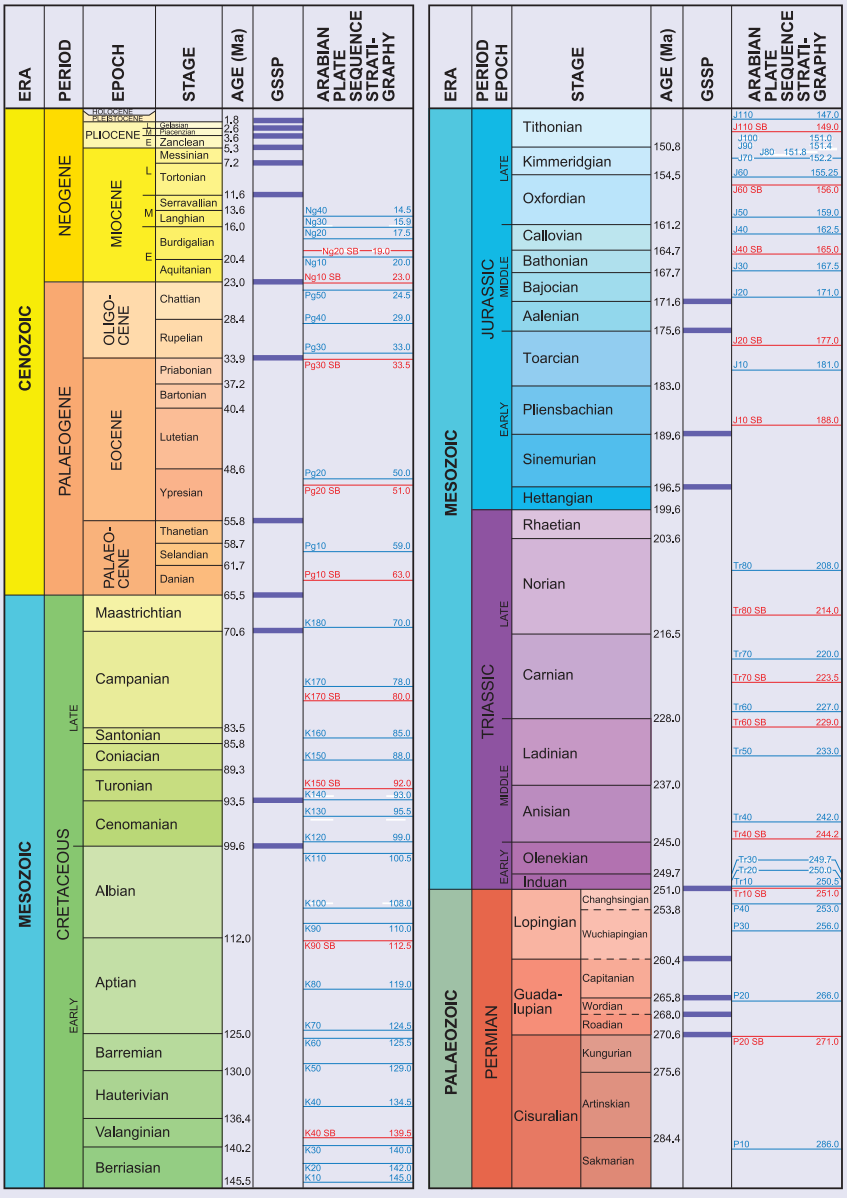
The pace of eustatic sea level change is more difficult to measure, but there are successions in which orbital forcing cycles offer a 'clock' by which to estimate pace and duration. One such is the Late Jurassic Kimmeridge Clay as exposed in North West Europe, where key sea level changes seem to relate to a major 405,000-year cycle. Orbital forcing cycles in Cenomanian chalk sequences calibrate sea level rises as taking place between 80,000–180,000 years. Thus in both the Late Jurassic and the mid-Cretaceous we can see evidence for eustatic sea level rises and falls of tens of metres over less than 500,000 years. This high magnitude and rapid pace perhaps somewhat surprisingly points towards glacio-eustasy (expansion and contraction of land-grounded ice sheets) as the main driving mechanism during this and other periods. There is certainly a strong link between sequence stratigraphy and orbital forcing in the Kimmeridge Clay and Cenomanian Chalk examples, indirectly suggesting the potential for glacio-eustasy, as it is hard to imagine other mechanisms creating climate-linked changes in sea level. Can this really be valid for Mesozoic rocks said to be deposited in "greenhouse" conditions?

There is little dispute that changes in land-grounded ice volumes have been the primary control on eustatic sea level changes over the last 30 million years. During this time there is abundant evidence for significant cycles of ice growth and destruction at the poles, with cyclicity linked to orbital forcing. Tentatively, the Cenozoic record of polar ice continues to be pushed back further into the Palaeogene with evidence for ice-rafted debris and substantial shifts in the isotopic palaeotemperature proxies. There is indisputable evidence for major polar ice in the Late Carboniferous – Early Permian, the latest Ordovician and within the Neoproterozoic. There is also growing evidence for significant glaciation affecting Gondwana in parts of the Ordovician, Silurian, Devonian and Early Carboniferous.

Rapid Climate Change

What then of the rest of the Phanerozoic? Earth history is typically divided into "icehouse" with pronounced polar glaciations and "greenhouse", when polar ice has been absent or negligible. How reasonable is it to suppose that Earth history has been dominated by these extreme states over long periods of time? It is of course undeniable that the Earth has experienced periods of extreme warming – as evidenced by crocodiles and ferns near the poles during the Late Cretaceous – but do these records prove a

The published Arabian Plate Sequence Stratigraphic Model (updated by the author and colleagues in 2007) demonstrated that over 60 sequences of various Late Precambrian – Neogene ages could be recognised and confidently correlated across the Arabian Plate (only the Permian – Recent are shown here (Blue = MFS, Red = SB)). Given the relative tectonic stability of Arabia, these sequences were considered to be eustatic in origin. It is now possible to demonstrate that these generally 3rd order sequences (with some refinements and with some key additions, as yet unpublished) occur in other parts of the globe, calibrated by biostratigraphy and isotope records. In Neftex we use over 125 Phanerozoic sequences for correlation and the generation of stratigraphically precise gross depositional environment maps highlighting, for example, potential reservoir and source rock facies.



continuous state of "greenhouse" conditions for large episodes of geological time? Or is palaeoclimate more variable than has been suspected and there have been episodic 'cold-snaps' in greenhouse times, leading to polar ice-sheet expansion and reduction, giving resultant changes in sea level? Recent compilations of palaeotemperature proxies would suggest that the latter is indeed the case.

There is a growing body of evidence to support the presence of volumetrically significant polar ice during what is commonly regarded as greenhouse times. This includes direct physical evidence within sediments, like dropstones and tillites, and proxy evidence, such as isotope records and glendonites. What is remarkable is that short-term (3rd order) eustatic sea level changes seem to show a correlation with isotope proxy records of palaeotemperature – it is hard to imagine such a coincidence without recourse to glacio-eustasy. Longer term sea level cycles can in part be ascribed to tectonic events, whilst, as argued by Bryan Lovell in a recent Presidential Address to the Geological Society, magmatic underplating of the crust could cause relatively rapid and high frequency regional sea level changes. These need to be differentiated from genuine eustatic signals.

A Consistent Framework

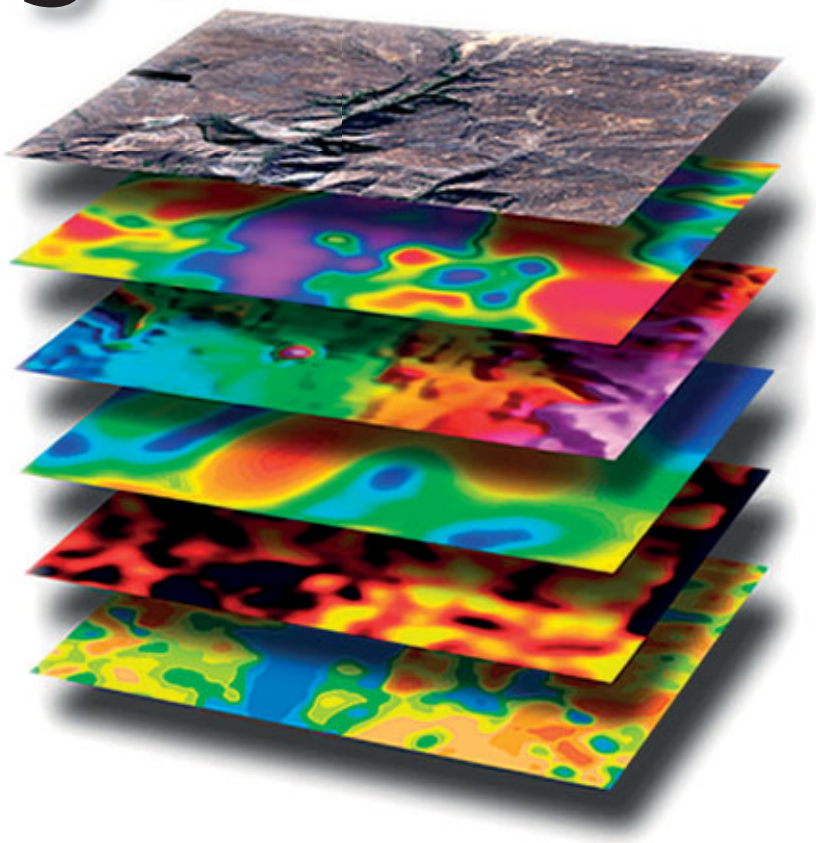
The concepts of eustatic sea level change are old ones, but improvements in the resolution of stratigraphic calibration, together with more rigorous sequence stratigraphic analysis of numerous successions worldwide, means that a consensus on a eustatic sea level model throughout the Phanerozoic is possible. Furthermore, the pace and magnitude of eustatic sea level change and its coincidence with shifts in palaeoclimatic proxy data suggest that glacio-eustasy may well be a key driving mechanism, even in supposed "greenhouse" times.

A eustatic sea level model has powerful benefits for the industry by providing a consistent framework for correlation, facies mapping and the prediction of petroleum systems components. It also provides better selection of play analogues and aids the pursuit of global plays. ■

Mike Simmons is a Director of Neftex Petroleum Consultants Ltd which specialises in the collation, integration and interpretation of large geoscience datasets using sequence stratigraphy, and the delivery of these as 2D and 3D subsurface models. He is the author of the chapter on sequence stratigraphy and sea level change in the upcoming 2012 Geologic Time Scale book and regularly presents on this subject.

Integrating the Tool Box

NEOS GeoSolutions integrates a wide range of geophysical and geological information to produce new 3D models of the earth's surface, with the aim of helping exploration companies make faster, more informed decisions with less risk.



JANE WHALEY

"I'm a data agnostic," says Jim Hollis, President and CEO of geo-solutions company NEOS. "I believe that it should be possible to integrate all data types in the constant quest to lower uncertainty and reduce exploration risk."

"Explorationists in the mining industry have accepted the concept of integrated analysis for some time now, yet the oil industry still tends to rely almost exclusively on a single measurement – seismic. In fact, more than 95% of all geophysical expenditure in the oil and gas industry is channelled into acquiring, processing and interpreting seismic data."

Pooling Data

"However, nowadays we have access to a rich technological tool box to augment our usual seismic and well data," Jim continues. "Gravity measurements, defining areas of varying density within the earth, have been vital for outlining structure, sediment thickness variations, and especially salt accumulations, helped by magnetic field measurements, which can also outline faults. Electromagnetic (EM) data – measuring the resistivity of the earth – helps identify hydrocarbons, as does the measurement of radioactive decay, or radiometrics. And the use of hyperspectral sensors, which measure reflectance of the sun's rays by the earth, can also give us further direct and indirect indications of minerals and hydrocarbons at the surface."

"It's all about understanding geology and measuring the physical properties of the earth at all depths from the surface to the source rock, and all these measurements should be used and interpreted together, not in isolation. Which tools are most relevant may vary from basin to basin, but the more measurements we utilise, the more constrained and accurate our interpretation will be. That's what we do at NEOS: we integrate a broad range of G&G data from a wide variety of sources to produce a highly constrained model of the subsurface."

Jim has long held a dream of creating methods to pool all available data to enhance interpretation – in fact he has been thinking about it since he was a student studying geophysics in California. But, until recently, neither computing capacity nor the various sensors available were powerful enough to cope with the vast quantities of data that were generated and the processing required to decipher what the measurements were telling us.

"Now, however, we in NEOS have been able to do three important things," he explains. "We have tried to identify the most important aspects of each technology and using that information we have developed better, more accurate sensors. Secondly, we have fused them together in a single airborne sensor

unit, so we can acquire all this data simultaneously. And third, we have built a data management and interpretation system that enables us to effectively bring all the information together on one platform. Our methodology ensures that each individual G&G dataset informs and constrains the others when all the measurements are interpreted simultaneously, and that is where we believe the most revealing subsurface insights can be generated."

The integration of data is not confined to freshly acquired data. Public domain data, information available for licence via third-parties or resident in client or NEOS data archives – all can be merged, the sum being bigger than the parts.

High Level Investors

Realising that accelerating computing power was the key to building an integrated model, Jim, who was COO of ION Geophysical Corporation before joining NEOS in January 2010, looked to the IT world of Silicon Valley for investment when setting up the company. He has managed to gather a number of very high level backers, including among them some of the world's best known investors and entrepreneurs, including venture capital firm Kleiner Perkins Caufield & Byers – the entity that backed pioneering companies such as Google and Amazon – as well as Goldman Sachs, Energy Capital Group and Microsoft co-founder Bill Gates.

"In addition to supplying the capital needed for our ambitious growth plans, by tapping into these networks, we ensure that our methods incorporate the latest thinking in technology, computing, neural networks and intelligent search," Jim adds. "For example, our link with Google means that we use that technology for our geospatial file management."

Introducing the NeoSphere

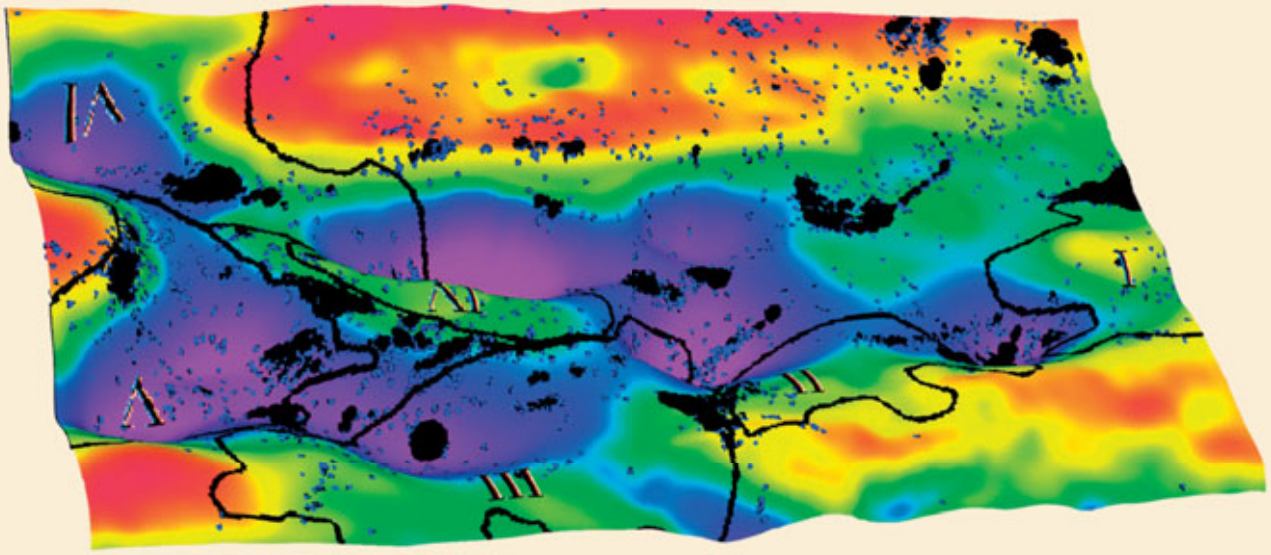
"In NEOS we have developed a proprietary data management and interpretation system, which we call the NeoSphere™, says Jim. "This is a software platform which uses a statistically driven, multivariate inversion on the data, allowing us to manage all these different types of information simultaneously and to process, visualise and interpret them within a single desktop context. It allows geoscientists to access individual geophysical datasets, test and model interpretation hypotheses, and compare their interpretations to regional well control or seismic."

"Even major companies with a vast range of expertise available find it hard to integrate information in an asset team. If you think about it, we have at our disposal data from NASA at a global level, down to the minute particles studied in geochemistry. So smaller companies

NEOS has recently completed a survey in the Ventura Basin in southern California, an area which has already yielded over four billion barrels of oil since 1861, but which many analysts believe holds still more hydrocarbons in the form of by-passed targets, deeper zones and possibly some unconventional shales. The survey, which commenced in 2011 and covered 2,800 km^2 in 60 days, acquired new airborne gravity, magnetic and hyperspectral information, including geobotanical data, which was fused with existing datasets.

The results proved to be very enlightening. Multispectral satellite data provided a quick regional geological map, and the gravity data was used to outline the basin margins and deep topography, while magnetic data identified faulting throughout the area, as well as the main boundaries delineating the area's producing fields. Hyperspectral data identified hydrocarbon seeps and also flora infused with hydrocarbons, an indirect indicator.

With a number of new opportunities identified, the application of geo-statistical techniques meant that the location and distribution of undiscovered hydrocarbon accumulations could be easily mapped and the Ventura Basin will continue producing for many years to come.



A map of basement topography drawn up from 3D gravity modelling, part of the Ventura Basin study, and overlain with producing well locations (black dots) reveals missed and potential exploration targets.

with less manpower have even greater issues, and within the NeoSphere we have built collaborative tools to help them work as teams. I feel that this technology is particularly invaluable to them, allowing them to operate more like the 'big boys'. The NeoSphere also allows geoscientists to join forces across locations through the sharing of both data and interpretations to be confirmed or challenged by their colleagues."

NEOS has a particular speciality in the rarefied science of hyperspectral analysis, looking at over 600 bands over a continuous spectral range, from ultraviolet to thermal infrared. NEOS's purpose-built hyperspectral sensor measurements, complemented by ground truthing using a 2,151 channel spectro-radiometer, ensures that unique spectral signatures can be accurately recorded and compared to the in-house spectral library containing hundreds of mineral and flora indicators known to be associated with hydrocarbons. "The hyperspectral tool can also be used to identify gas which has migrated to the surface, in much the same way as slicks and seeps can be used to identify potential oil accumulations," Jim adds.

"Our unique integrated system allows us to provide solutions to the full range of exploration requirements, starting with a review of the potential of large frontier areas at macro scale. More detailed study of a known or prospective basin involving acquisition of new gravity, magnetic and hyperspectral sensors, acquired with one of our own aircraft, can be followed by an investigation at the prospect level, flying a tightly gridded pattern at high resolution to identify potentially drillable prospects."

"Core to the company is the ability to glean from each methodology and fuse them together," he concludes. "Our aim is to bring something new to the industry by being able to do all these things simultaneously – and cheaper, faster, and, hopefully, better." ■

Jim Hollis, President and CEO of NEOS, has a long career in the oil industry, having worked in management and technology roles for Landmark Graphics, a Halliburton subsidiary, where he focused on providing geoscience software solutions. He joined Input/Output (subsequently rebranded as ION Geophysical) in 2003 and then NEOS in January 2010. He holds a BS in Geophysics from the University of California, Santa Barbara and an MS in Geophysics from the University of Utah.

NEOS generally uses the company-owned Twin Otter aircraft for airborne sensor deployment, as it offers a reliable platform capable of operating in remote, low-service locations.

80 Years of Discovery

Having just celebrated its 80th anniversary, CGGVeritas is one of the longest established service companies in the oil industry, and now employs over 7,200 people in 70 countries.

JANE WHALEY

"…the practical ability to conduct measurements covering vast expanses of terrain at a reasonable cost and to carry out uninterrupted exploration renders the geologist's conclusions much more reliable. Having obtained an overview, he can correctly extrapolate local observations made on outcrops…"

Conrad Schlumberger, 1930

Although humans have been using hydrocarbons as an energy source for centuries, the discovery of the majority of oil accumulations before the 20th century had been the result of digging or drilling near known oil and gas seeps.

So when German engineer Ludger Mintrop began experimenting with using the way sound travels through the earth to locate the position of heavy artillery pieces during World War I, he had little idea that his work would have important and more peaceable applications. But by 1924 his method of estimating the depth to geological formations by setting off an explosion and measuring the time taken for refracted sound waves to travel through rocks had already been used to discover an oilfield in Texas. At the same time, American engineer J. Clarence Karcher was working on a seismograph which could record surface-generated sound waves reflected from horizons deep within the earth, resulting in 1928 in the first oil discovery by seismic reflection.

Meanwhile, in France, Conrad Schlumberger had been experimenting with measuring the electrical resistivity of the earth since 1912, proving that electrical soundings could be used to build up a picture of the layering of strata within the earth. He undertook the first large scale petroleum survey using this method in 1923, and he and his brother Marcel founded the Société de Prospection Electrique (SPE) in 1926, specialising in using geophysical techniques to identify subsurface features. By 1927 they were experimenting with identifying changes in vertical electrical measurements through the earth – the precursors of wireline logging.

Worldwide Expansion

SPE fell into difficulties with the 1929 stock market crash, but out of it emerged Compagnie Générale de Géophysique (CGG), founded by Conrad Schlumberger in 1931. By 1932 the new company was using geophysical techniques to look for oil in West Africa, and within a decade CGG had survey teams in places as far apart as India, the Middle East, North America and Venezuela.

Sadly, Conrad died in 1936, but the techniques he had devised and the company he had nurtured continued to grow through the 30s. As with most companies in France, WWII proved taxing, and the staff was considerably reduced, but they managed to undertake surveys until 1944, when the German occupying forces confiscated their equipment.

CGGVeritas

Early geophysical surveying in Tunisia in 1957.

Liberation brought encouragement from the new French Government, and the revamped company spread back around the world, especially into those areas which had a strong French influence, the Sahara in particular. Expansion continued in the 50s, with the number of crew/months increasing by 20% per year between 1950 and 1955 alone. In 1956, the Schlumberger group withdrew completely from the capital of CGG. That same year the Sercel subsidiary was created. Initially called Société de Fabrication de Matériel Géophysique, it was renamed Société d'Etudes, de Recherches et de Constructions Electroniques (Sercel) in 1962 when it began to offer its technology to other companies.

Rapidly Developing Technology

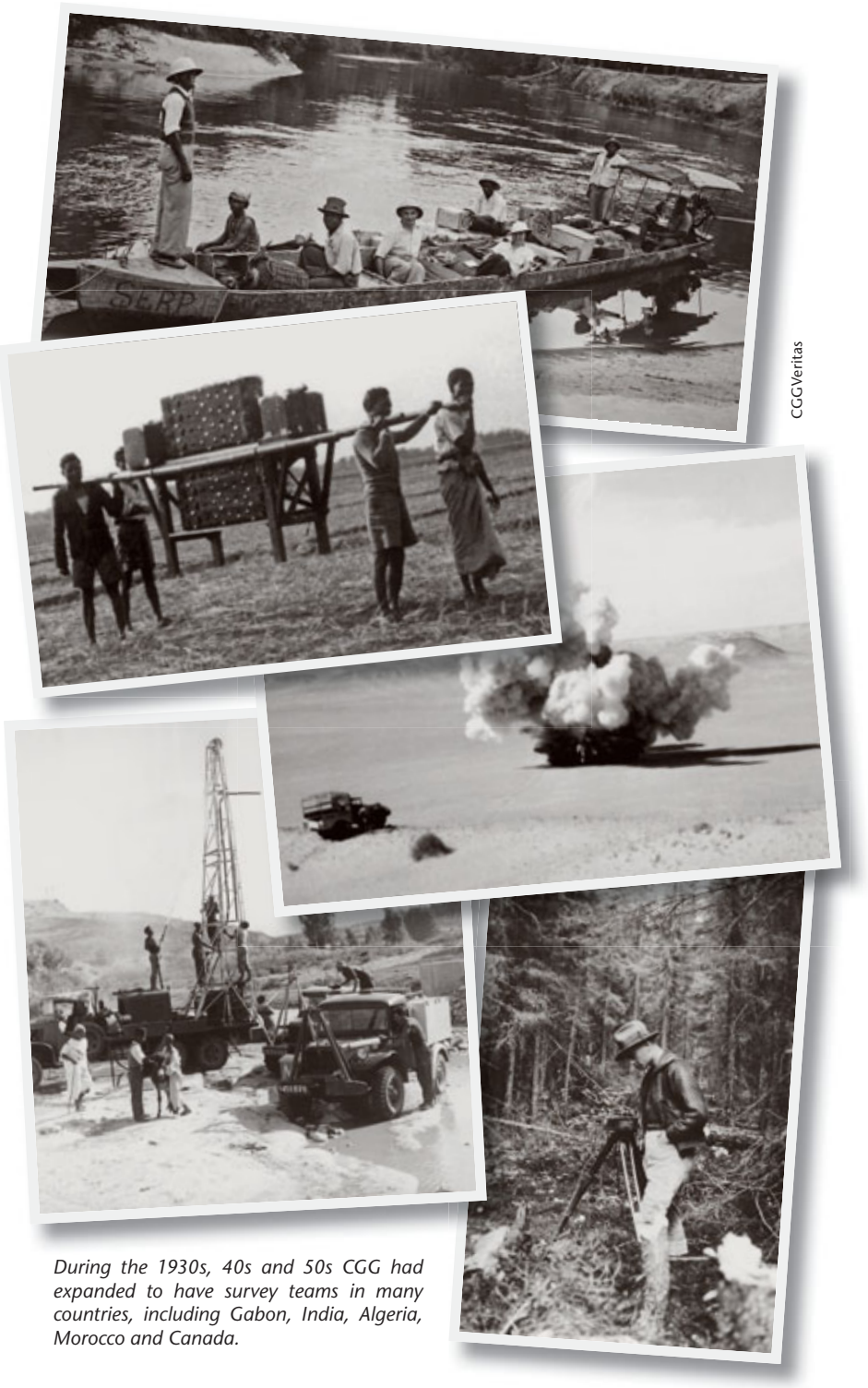
Rapidly developing geophysical techniques, including gravimetry, seismic refraction and tellurics, had been used to undertake reconnaissance surveys of many new areas in the 1930s and to identify and rank potential hydrocarbon traps. By the end of the 1940s these were enhanced by additional techniques like geochemistry, radiometry, electromagnetism and induced polarisation. By the end of the 50s airborne magnetometer surveys had become a routine reconnaissance survey method, hugely increasing the potential for developing new areas.

Seismic reflection, now a mainstay of hydrocarbon exploration, was only used sporadically by CGG until the 1950s, by which time its engineers had worked extensively on methodologies to process data by correcting the various effects of wave propagation in the subsurface. Progress had also been made with the development of non-explosive seismic sources, such as vibrator trucks – all resulting in large amounts of data in need of processing.

Geophysical measurements were recorded on photographic paper in the 1930s, but these were not reproducible until the introduction of magnetic tape records two decades later. By the early 1950s CGG had acquired an analogue computing centre for playing back field data, although there was little ability to process the data. At the same time, the introduction of the Common Depth Point (CDP) recording method significantly reduced noise (extraneous and multiple signals) by combining signals from many sensors. But the use of such intricate and involved processing inevitably required assistance and in 1954 CGG bought its first computer, moving the company rapidly into the computer age and the digital revolution.

In 1963 the concept of deconvolution – the filtering of data to eliminate distortion of the signal – was introduced, also requiring increased processing power. However, the processing of seismic data at CGG did not commence in earnest until late 1967 with the purchase of new EMR computers designed to substantially increase the subsurface image quality.

Many innovations of that time came from Sercel, which came up with technological developments, such as a 24-trace transistor amplifier, introduced in 1962, whose small size and low power requirement made a huge difference to field operations. The turning point came with the launch of the SN 328 in 1968.



CGGVeritas

During the 1930s, 40s and 50s CGG had expanded to have survey teams in many countries, including Gabon, India, Algeria, Morocco and Canada.

By 1961 CGG had four MT4 centres processing magnetic tape.

The company was constantly upgrading and improving its equipment, and in 1971, its latest product, SN 338, was at the cutting edge of data acquisition technology. Through such innovations Sercel, in the space of one technological generation, gave CGG and the industry a previously unattainable understanding and application of geophysics.

Moving Offshore

In 1960 the Schlumberger family, which in 1953 still owned 47% of CGG, finally sold its holdings, signalling the end of an era. Over the next decade the newly independent company went from strength to strength, establishing itself in new regions and getting a good foothold in US and Russian markets. At the same time, technology was moving ahead and by the end of the 60s digital recording meant that several thousand traces could be simultaneously recorded and then processed.

During the 1960s the industry gradually moved offshore. CGG's first dual vessel survey had been undertaken in 1958, with one boat as source, initially using an underwater dynamite charge but rapidly progressing to safer air or steam sources, and a second boat towing the streamer recording the seabed reflections. Single source marine exploration, with source and receivers on the same vessel, was introduced in 1964. The initial seismic vessels were converted stern trawlers, and the crew could spend up to nine months at sea – things have changed a lot since then!

CGG first experimented with 3D surveys in 1971, known then as Wide-Line Profiling, by towing three parallel streamers, but this did not come into general industry usage until the 1980s, with seismic vessels equipped with onboard processing centres undertaking 24-hour operations. Recording capacity increased, computer technology had to keep up with this, and in 1984 CGG installed the largest computer of the time, the Cray 1S, in its main processing centre at Massy outside Paris. This was able to deal with the recently developed concept of migration, which moves the seismic record to its true position.

The widespread use of 3D resulted in a race to systems which offered an integrated package of data acquisition, processing and interpretation.

Strategic Partnerships

By the time CGG floated on the Paris Stock Exchange in 1981, it had a consolidated turnover of €450 million, owned more than 100 vibrator trucks and recording units, 170,000 geophones, 1,300 off-road vehicles, seven seismic vessels and several 'supercomputers'. It had operations throughout the world and

A Challenging Life!

Life for the early pioneers of seismic surveying was not easy – not that it necessarily is for their modern equivalent. Many of the early CGG surveyors, geophysicists and engineers traversed large areas of hot mountainous terrain in places like North Africa and Oman on foot, spending up to a year away from home in gruelling climates. A long ship journey brought the early pioneers from their base in France. They then travelled on foot or camel through the desert, or hiked along poorly marked trails through the equatorial forest, or travelled in small boats up insect-infested rivers to their base camp, which usually had to be cut out and flattened from the surrounding forest or desert.

And, of course, every survey required huge amounts of equipment and supplies. Cables, drills, geophones, recording equipment; all were carried in by the crew and their local porters, as well as tents and provisions – although the pioneers were known to supplement the monotonous diet of tinned and dried food with a little light hunting. And, as for all explorers, there were constant hazards emanating from the local flora and fauna, from desert scorpions to sleeping snakes, and the myriads of biting and disease-carrying bugs and insects.

The work was also physically demanding and laborious, as a young CGG engineer in Gabon in the 1930s described. "The lines were cleared with machetes through a forest of tangled vines. The holes, 4–6 m deep, were drilled using the percussion method. We carried out an average of four shots a day. We operated with seven geophones, each weighing two to three kilos, and I was using 10 cm wide films for recording. We camped in six or seven places during this period."

This young man, like many of his colleagues, was obviously a true adventurer. Having spent many months in the field, when his time in Gabon was over, he says simply that he "returned home alone via the Sahara."

A CGG survey team enjoy a village stopover in the Atlas mountains of Morocco in the 1930s.

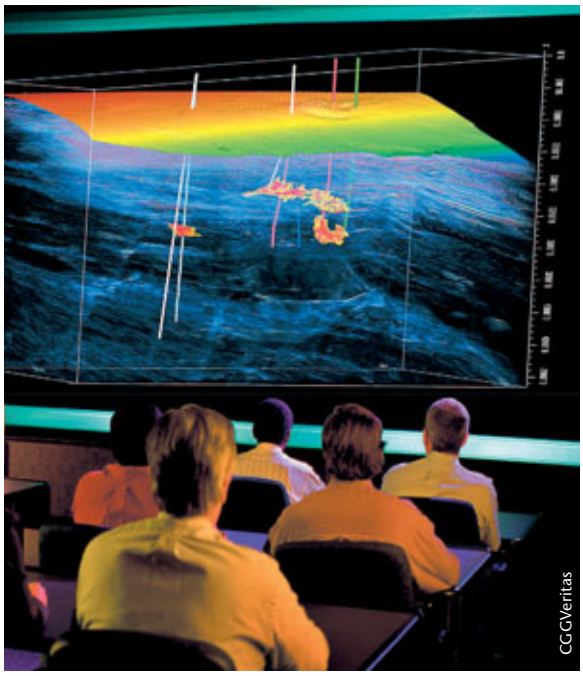
had survived a number of major industry downturns and a host of geopolitical events. Competitiveness and productivity had been key to survival, with ever greater volumes of data being acquired with minimum expense and mobilisation cost.

Growth continued throughout the 80s and 90s, despite the inevitable challenges resulting from events like major industry downturns and the two Gulf Wars. The focus was on designing the best technology for ever-changing circumstances. 3D became more important, on land as well as at sea, and with the search for oil moving into ever more complex areas, high definition depth imaging technology was developed. In 1994 CGG carried out the first 4D seismic surveys, returning to a survey area to add the dimension of time to the 3D acquisition.

Much of CGG's success can be attributed to careful strategic partnerships with other companies, both for practical operational reasons and to ensure the company had the correct skill sets. As far back as 1966, for example, ARGAS, a limited liability partnership between Industrialization and Energy Services Company (TAQA) and CGG, was created which today provides geophysical services and R&D for petroleum, mining and ground water resources mainly in Saudi Arabia. During the same year, the growth of the airborne reconnaissance surveys had been led by Geoterrex, a combination of CGG and Canadian Terra Survey. Strategic alliances with Russian and Chinese companies in the 70s and 80s allowed CGG to make substantial inroads into those countries. Similarly, in the 90s, a joint venture with Total gave CGG expertise in integrated reservoir studies.

CGG and Veritas Join Forces

In 1965 six engineers and geophysicists sharing the then revolutionary vision of bringing digital computing technology to the geophysical industry, got together in Houston to form Digital Consultants Inc. – each contributing $334 as starting capital. Before long they were undertaking their first surveys, on and offshore, using state-of-the-art computers that allowed multi-trace, multi-task programming without tape output, and by 1969 they had reformed as Digicon and were on the US Stock Exchange. This new company remained at the forefront of technology, deploying the first digital marine seismic streamer in 1979 and initiating commercial depth migration the same year. In 1981 Digicon employee John Sherwood invented the key DMO (Dip Move Out) data processing technique.



Veritas set up the first new generation Data Visualisation Centre in Houston in the 1990s.

Meanwhile, by 1978 Veritas Energy Services, established in Calgary four years earlier, was revolutionising processing speeds through the use of FPS (Floating Point Systems) processing units. In 1982 it processed the industry's first-ever 3D seismic survey, in Canada, and ten years later launched the 'SAGE' data processing system, probably the most advanced production processing system available at the time.

In 1996 Digicon and Veritas combined as Veritas DGC Inc., and the new company proceeded to set records by towing the industry's first 12 km streamer and setting up the first visualisation centres. Over the next few years it extended its capabilities further through acquisitions like Time Seismic Exchange, a land seismic data library based in Canada, and Guardian Data Systems, a data archiving and transcription company in Australia.

In 2005, the year of its 40th anniversary, Veritas also acquired the Hampson-Russell seismic interpretation software group. In 2006 CGG notched up 75 years in the business; the following year these two well established companies joined forces to create CGGVeritas, a leading global geophysical services and equipment company. Since then, the combined company has gone from strength to strength, financially, technologically and operationally.

All showing that innovation, research, sharing, teamwork and commitment can bring great rewards. Here's to the next 80 years! ■

The Oceanic Sirius*, the latest vessel to join the CGGVeritas fleet, was christened in October this year.*

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How can we explore the Russian Arctic Shelf?

The Arctic is often referred to as 'the next global frontier' – but is it possible to explore at reasonable cost?

DAVID BAMFORD

Western oil and gas technical journals as well as ordinary newspapers wax lyrical over the hydrocarbon resources of the Arctic, typically referring to it as the next global frontier. Huge resource estimates are bandied about – the USGS has suggested as much as 400 Bboe remains to be discovered, with over 80% of that thought to lie in offshore fields.

Of course, onshore Arctic exploration has a significant history, notably in Alaska and West Siberia, and there has been intermittent exploration in the Barents, southern Kara, Chukchi and Beaufort Seas.

Nevertheless, a significant part of the Arctic is represented by the largest shelf on Earth, the Eurasian epicontinental shelf, of which the major portion, amounting to some 3.5 million km^2, is in the Russian Arctic – an area roughly equivalent to 700 offshore Angola deepwater blocks or 152,000 Gulf of Mexico deepwater blocks! The area is, to a large extent, sparsely explored due to its harsh environment, high cost of operations and forbidding logistics.

From the efforts of Soviet scientists and their successors, we know that the Eastern Barents, Kara, Laptev, East Siberian and Chukchi Seas contain over 40 sedimentary basins, and we have a reasonable idea as to their stratigraphy, sedimentology and structural geology. The Russian Barents and the southern Kara Seas represent the most explored petroleum provinces with large proven resources. In contrast, the North Kara is virtually unexplored, and there is only sparse seismic data over the other areas.

Drachev, Malyshev and Nikishin (2010) give an excellent overview of the tectonic history and petroleum geology of the Russian arctic shelves, and I have no intention of repeating what they say here.

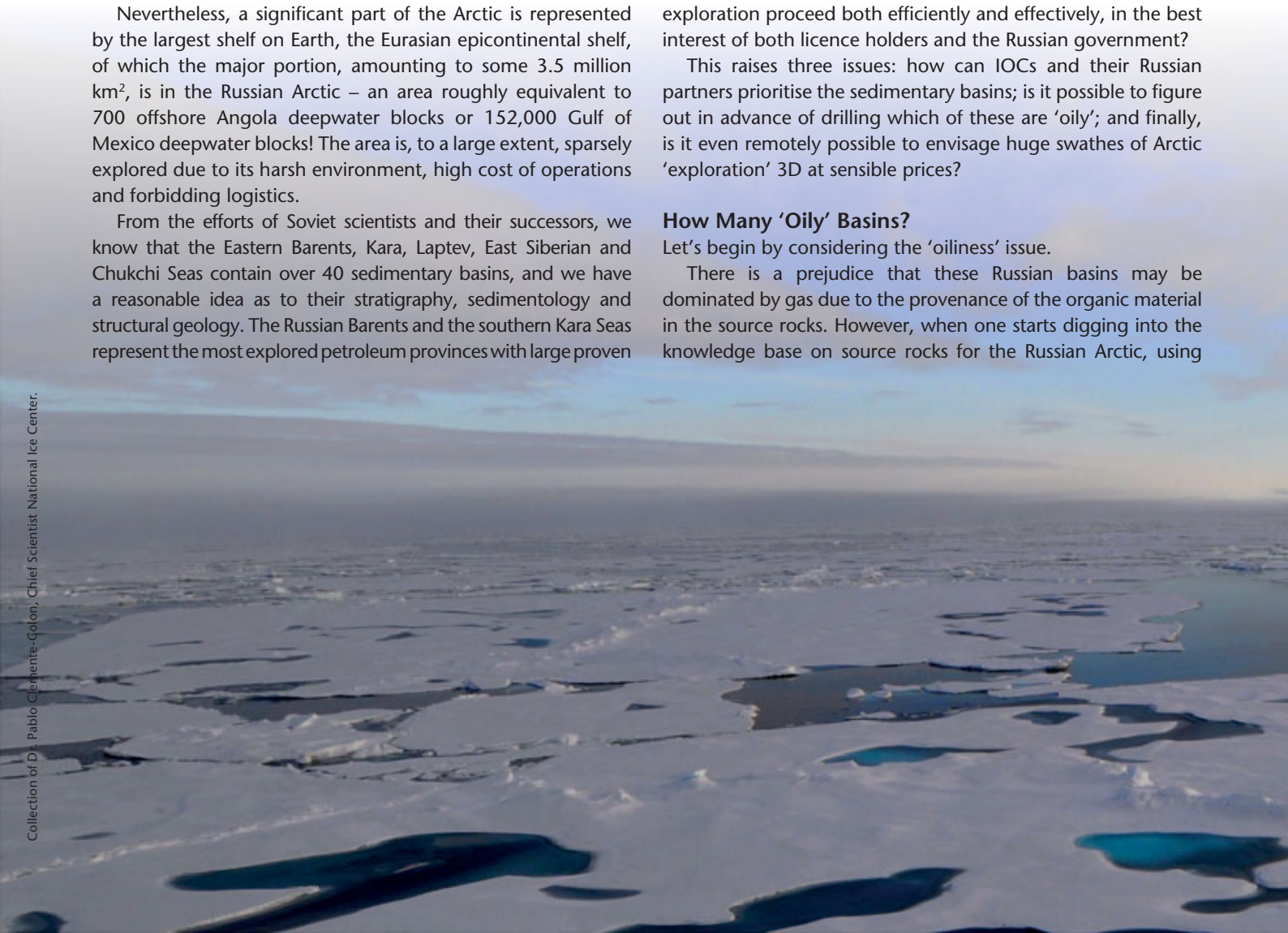
However, building on the current knowledge of the petroleum geology, let us put politics to one side for the moment and assume that western IOCs will participate in exploration of the Russian Arctic. The question then arises – how can such exploration proceed both efficiently and effectively, in the best interest of both licence holders and the Russian government?

This raises three issues: how can IOCs and their Russian partners prioritise the sedimentary basins; is it possible to figure out in advance of drilling which of these are 'oily'; and finally, is it even remotely possible to envisage huge swathes of Arctic 'exploration' 3D at sensible prices?

How Many 'Oily' Basins?

Let's begin by considering the 'oiliness' issue.

There is a prejudice that these Russian basins may be dominated by gas due to the provenance of the organic material in the source rocks. However, when one starts digging into the knowledge base on source rocks for the Russian Arctic, using

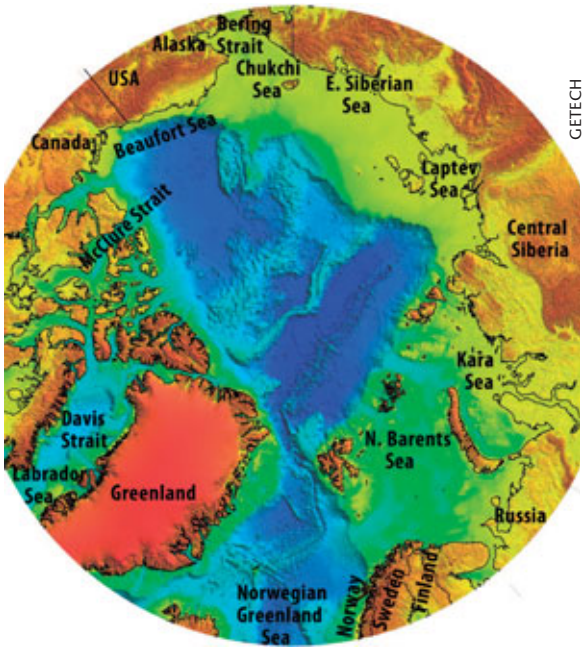


Collection of Dr. Pablo Clemente-Colon, Chief Scientist National Ice Center.

compilations by for example the USGS, Bernstein Research and the aforementioned review by Drachev *et al.*, it quickly becomes apparent that actual data is generally absent. Thus, for example, in the Laptev Sea, one may freely speculate, unconstrained by any hard facts, that there may be present Paleocene and Mid-Eocene marine shales or Lower Cretaceous and Paleogene syn-rift sediments, or for the Russian Chukchi Sea that there may well be analogues to the prolific petroleum systems of the Arctic coast of Alaska.

The areas where there is actual positive evidence of working source systems are the East Barents Sea, where there are Triassic organic-rich gas-prone coal-bearing shaly sediments, and the South Kara Sea where there are Bazhenov bituminous shales, the main source rock of the West Siberia Basin, which may have generated significant gas plus possibly oil at the basin margins.

It is not surprising therefore that the current actions of western IOCs seem oriented towards either a fresh look at the Barents Sea or accessing the South Kara Sea – the target of BP's ill-starred venture with Rosneft (and where ExxonMobil stepped in recently). It's difficult to see other areas opening up rapidly given the absence of source rock indicators.



GETECH

The Arctic Ocean covers an area about one and a half times the size of the United States. Seismic vessels, drilling rigs and tankers can access it via the Bering Strait between Alaska and Russia, the Davis Strait between Greenland and Canada, and the Denmark Strait and Norwegian Sea between Greenland and Europe.

What About Seismic Acquisition?

IOCs have got used to exploring with vast amounts of 'exploration' 3D seismic. For example, the nearly 50,000 km^2 of deep water and ultra-deep water Angola are covered 'wall-to-wall' with 3D, enabling Total, BP and others to enjoy a success rate of >90% in Blocks 15, 17, 18, 31 and 32. In Angola, this 3D typically costs around US $3,000 per square kilometre.

Broadly speaking, the Arctic presents two problems related to seismic acquisition – the ice itself and the limited time that the ice is open. Two companies have stated that they are addressing this issue:

ION Geophysical have been working in the Beaufort and Chukchi Seas, developing methods that work in and under the ice. They have shot very long offset seismic under the ice, which necessitates a very stable acquisition platform with no surface features, gun floats or tail buoys. This, together with the fact that an ice breaker sails the line ahead of the seismic boat, sets up very complex noise patterns, so completely new algorithms have been built to be included in the processing system. In addition, ION employ scientists who specialise in forecasting Arctic ice conditions, and also others who create ideal survey designs for these extreme conditions.

Polarcus have focused on building survey vessels with the capability to operate in Arctic sea ice, meeting extremely demanding ICE classification systems that specify hull construction, propulsion requirements, winterisation systems etc. They are also paying great attention to environmental issues such as sound mitigation and reduction of fluid emissions.

Now these are great technology ideas, great innovations, but with the best will in the world I cannot see either of these two companies being able to shoot vast tranches of exploration 3D at a cost of US $3,000 per square kilometre; five or ten times that, perhaps?

My point is that this displaces what has been the basis for efficient and effective offshore exploration since the mid-1990s and makes me wonder whether Arctic exploration can in fact be

Petroleum Geo-Services (PGS) has an ongoing programme in the Russian Arctic.

undertaken at reasonable cost? If we go back to exploring with 2D seismic, then we face drilling US $100 million wells at a risk of 1 in 4 or worse – not what we want to do!

How Much Data?

What data and knowledge do we have at the moment? For most of the basins, there is a reasonable understanding of stratigraphy, sedimentology and structural geology. Long wavelength gravity and magnetic data is available, as is a certain amount of 2D refraction and reflection data, the latter of which can be supplemented to some extent. Perhaps the next stage of geophysics should be to fly extensive Full Tensor Gravity (gravity gradiometry) surveys, which experience onshore, for example in East Africa, has shown can be a reliable tool for defining significant leads in a basin (see *GEO ExPro* Vol. 8, No. 1). Integrated with existing knowledge, this approach is capable of producing a basin-by-basin lead inventory.

The next step in the exploration process would then be to shoot 'postage stamp' 3Ds over the most interesting leads, to mature them into prospects; drilling could then follow.

I hope I don't make this sound too simple? Getting to grips with potential source rocks and generating a reconnaissance exploration database is an expensive, extensive and detailed project which is beyond any one company and needs to be commissioned by the Russian government prior to licensing rounds.

And there is one final issue that we need to face.

Environmental Questions

The Deepwater Horizon tragedy set shock waves around the industry at large. North American academics and other experts have pointed out that a similar spill in Arctic waters could be devastating, with ice possibly hampering any spill responses for months. Many of the problems are logistical. Apart from having only a few months to do any remedial or clean-up work, airfields are remote, weather can ground flights and workers for weeks at a time, and it would probably be impossible to bring a large number of boats to the Arctic – up to 1,000 were used in the Gulf of Mexico clean-up.

Few companies have the resources to do what BP did in the Gulf anywhere, let alone in the Arctic. Shell has described what they believe is needed, saying that for its proposed offshore Alaska drilling programme, it has a three-tier Arctic oil-spill response system, consisting of an on-site oil-spill response fleet, near-shore barges and oil-spill response vessels, and onshore teams, the last able to respond within one hour.

Clearly this is a major undertaking and cost.

Both Greenpeace and the WWF are very exercised by the prospect of a major Arctic spill, for which they claim that no oil company is adequately prepared, painting a picture of relief wells unable to be completed in a single drilling season, oil trapped and moving under ice, and so on. Not only has Greenpeace targeted rigs that are currently drilling offshore Greenland but also 'polar bears' have broken into an oil company's head offices in Edinburgh.

© Polarcus Limited

Delivered in 2010, Polarcus Asima is an ultra-modern, high ice class, 12 streamer 3D/4D seismic vessel, purpose-built for Arctic work.


Cairn

Supply vessels in the harbour at Nuuk, part of the support team for Cairn's Greenland exploration drilling. The company's work in the Arctic has made it a target for environmental activists.

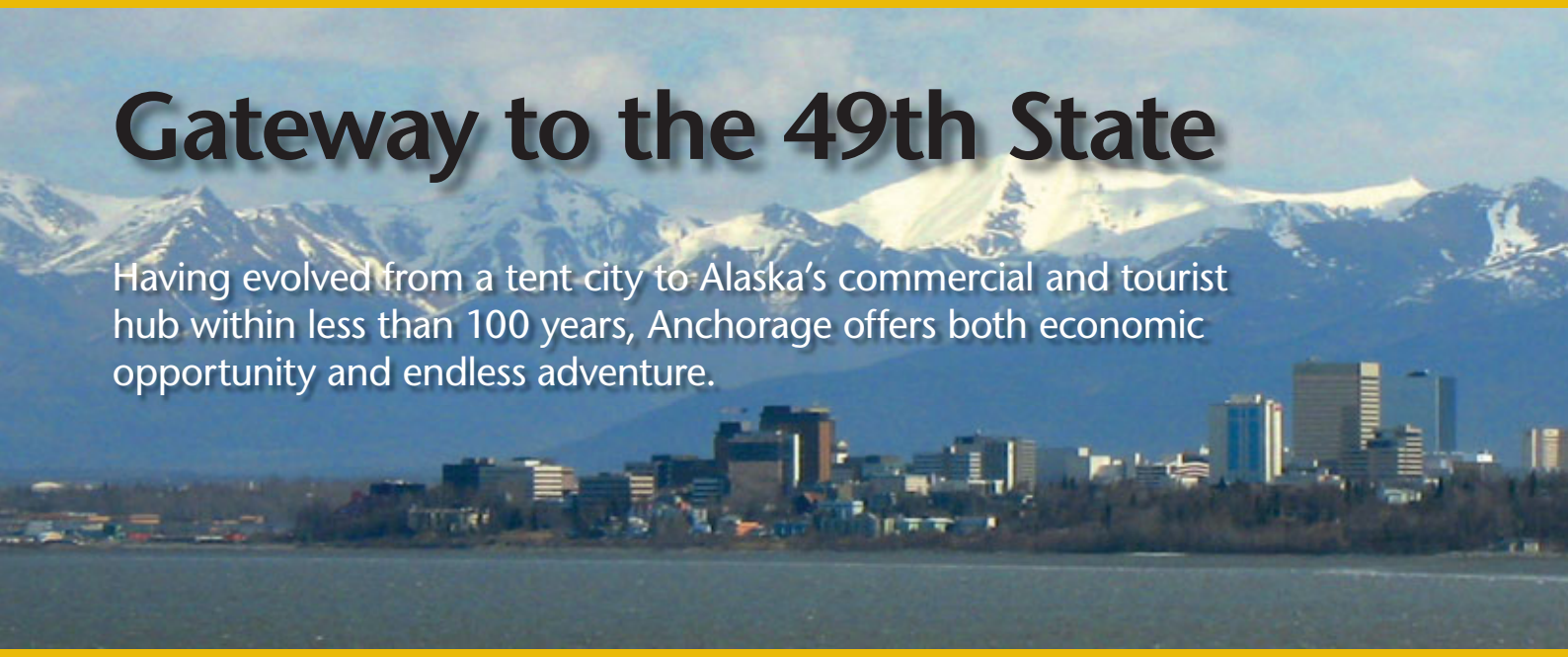
Just recently DNV (Det Norske Veritas, an independent foundation with the purpose of safeguarding life, property and the environment) presented the results of intense and targeted work, coming up with a concept for year-round drilling and exploration offshore north-east Greenland. More than anything their work illustrates a massive need for new technologies, improved standards and increased Arctic research. But that's not all; they predict that drilling in the Arctic could be up to four times as expensive as drilling in the North Sea. This could be an underestimate…

It's inevitable that North American and western European bodies are somewhat advanced in responding to the summer 2010 events in the Gulf. What does the Russian government think? ■

Reference:

Drachev, Malyshev & Nikishin, 2010 : Tectonic history and petroleum geology of the Russian Arctic Shelves: an overview, in Petroleum Geology: From Mature Basins to New Frontiers, published by the Geological Society, London.

Gateway to the 49th State



Having evolved from a tent city to Alaska's commercial and tourist hub within less than 100 years, Anchorage offers both economic opportunity and endless adventure.

THOMAS SMITH

I took my first oil company job in Anchorage in 1975. Leaving Seattle on a Western Airlines Boeing 707, I was so excited I could not sit still. On descent, all I could see were snow covered mountains. Where could this city be? Finally, after breaking through thick clouds, a flat coastal area came into view. Between the dark, churning waters of Turnagain and Knik Arms of Cook Inlet and the beautiful Chugach Mountains, sat a fascinating city that would be my home and workplace.

Times were exciting in those days. The Trans Alaska Pipeline was being built; a series of Outer Continental Shelf sales offered in the Gulf of Alaska were scheduled over the next several years, and exploration activity was brisk. I knew my journey was just beginning.

Here I found outdoor adventure just minutes from my doorstep. Where else can you walk a short distance from the downtown area and catch huge salmon? Or mountain bike in summer on trails through town and on into uninhabited forest? Or ski in winter on many kilometres of maintained trails only minutes from home?

A Short History

The first explorer to describe the Anchorage area was the English Captain James Cook during his third voyage in 1778. Looking for the Northwest Passage, he discovered Cook Inlet and charted the majority of the North American north-west coastline. Cook named the River Turnagain (now Turnagain Arm) as he could not proceed any further inland and was forced to turn around.

In 1867, the Russians sold their North American holdings, what is now Alaska, to the United States for $7,200,000, but it was not until 1915, when President Wilson authorised funds for the Alaska Railroad, that Anchorage got its early start. The Ship Creek Landing was chosen as headquarters and a tent city sprouted up in the area with more than 2,000 inhabitants.

Entrepreneurs flocked to this exciting frontier bringing with them everything needed to build the new town. The first hardware and clothing store, called "The Anchorage", was an old dry-docked steamship. Still the town was not named until the US Post Office Department formalised the use of Anchorage.

Anchorage remained a small frontier town until the beginning of World War II, when the population exploded from 8,000 to over 43,000 with the construction of airfields, roads, and other infrastructure related to the war effort, and water, sewer, and utility systems were greatly improved. The state benefited directly from the construction of new airfields and the development of electronics and devices for safe flying, making life easier for bush pilots that had become a critical part of life in Alaska.

Becoming an Oil City

Oil was discovered on the Kenai Peninsula at Swanson River in 1957 (see GEO ExPro Vol. 8, No. 2). Less than a year later, 17 oil companies set up offices in Anchorage and spent tens of millions of dollars on exploration. Alaska became a state on January 3, 1959, opening the doors to new oil and gas exploration opportunities through state land selections.

What could have been a major set back for Anchorage came on Good Friday, March 27, 1964, when the city was shaken by the strongest earthquake ever to hit North America. The 9.2 Richter scale jolt lasted 4 seconds, ripped through the region (damage covered 130,000 km²) leaving roads impassible, buildings toppled, and 131 people dead. However, with its frontier spirit, the city was rebuilt at lightning speed with improvements to its entire infrastructure.

The huge oil discovery in 1968 on the North Slope at Prudhoe Bay would soon bring major changes to the state and to Anchorage, although it took a monumental effort to gain access to these large reserves. After much opposition, the US Congress authorised the construction of the Trans Alaska Pipeline System (TAPS) in 1972. Construction began in 1974 and oil started flowing to the port of Valdez in 1977.

This was boom time in Anchorage. House prices quadrupled. Construction was everywhere, with new homes, offices, cultural and arts centres, hospitals, roads, and a network of trails and parks throughout the city. Today, Anchorage is

Thomas Smith

Anchorage is framed by the Cook Inlet and Chugach Mountains. It is known as the "City of Lights" in the winter and the "City of Flowers" in the summer.

home to about 41% of Alaska's residents with a population of 292,000.

Anchorage remains the northland's oil capital with most oil, service and drilling companies located there, as well as the government agencies overseeing oil and gas activity.

Year Round Recreation

Anchorage is blessed by a maritime climate that is rarely too hot or too cold and there are new adventures at every turn. Wilderness and outdoor activities are a way of life, and wildlife roam the city's greenbelts. In only a few minutes you can fly to a remote lake or river, or take a train to Denali National Park right from downtown.

Thomas Smith

Ship Creek, where the city started, is just steps from downtown and has prolific king and silver salmon runs. Hiking into the Chugach Range from one of the many trail heads that border the city, one can be rewarded with views of the downtown area, Cook Inlet, surrounding volcanoes, and of course Denali, North America's highest peak. Moose, white Dahl mountain sheep, and bears, both brown and black, can be spotted along many of the trails.

Adventure is just beginning for some as the snow falls. Anchorage has its own ski area and Mt. Alyeska Resort is only a short drive up Turnagain Arm. The city also boasts world class cross-country ski trails and maintains over 175 km of groomed ski trails throughout the city. Other winter activities include trails for dog mushing, ski-joring, and snow shoeing.

Tired yet? Try hoisting a pint at one of Anchorage's brew pubs or dinner at one of the city's excellent ethnic or Alaskan style restaurants, followed by a symphony or a play at the Anchorage Performing Arts Centre. Anchorage has always hosted a great deal of cultural diversity. Learn about the many distinct cultures across the state at the Alaska Native Heritage Centre. Here, Alaska's first people share their rich heritage, the wisdom of their elders and the traditions that endure. And there are events and festivals in nearly every month of the year if you have time left over.

Anchorage is one city where working really does get in the way of adventure. ■

French Guiana: Jubilee Play Crosses Atlantic

The widely held belief of many in the industry that the major discoveries in the West African Transform Margin in Ghana and Sierra Leone should be mirrored on the South American side of the Atlantic has been confirmed. Well GM-ES-1, drilled in 2,000m of water in the Foz do Amazonas Basin and the first ever deep water well offshore French Guiana, was reported on 9 September to have found 72m of good quality oil-bearing sandstone reservoirs in three intervals in two turbidite fans.

The exploration well, known as **Zaedyus**, found the reservoir at a depth of about 5,000m and is continuing to drill, expecting to reach over 6,000m. It lies in the 32,500 km^2 Guyane Maritime permit, about 150 km offshore French Guiana. Initial, very rough estimates of recoverable oil are in the region of 300 MMbo.

The operator on the block is Tullow Oil, with a 27.5% interest, partnered by Shell with 45%, Total with 25% and Northpet, a company jointly owned by Northern Petroleum and Wessex Exploration, with 2.5%. Tullow plan to drill the **Bradypus** prospect in the same block during the third quarter of 2012, and the company hope to continue its outstanding success rate: to date 18 out of 25 wells drilled in 2011 have found hydrocarbons, a success rate of 72%, while in 2010 the rate was an amazing 83%.

French Guiana is an overseas department of France, politically an integral part of that country.

This important discovery opens up a new hydrocarbon play for this remarkably underexplored area. It is expected that a number of further prospects off Suriname and Guyana, as well as French Guiana, have been de-risked by this find and will also soon be investigated with the drill bit. ■

Azerbaijan: Caspian Sea Discovery

In September Total announced a major find in the Caspian Sea, about 100 km south-east of the Azerbaijan capital of Baku. First results from the **Absheron** discovery well suggest that it may hold at least 3.5 Tcfg, as well as associated condensates, in reservoirs that are expected to extend throughout the 270 km^2 structure. The discovery well, Absheron X-2, encountered over 160m of cumulated net gas pays within high quality sands on the northern flank of the structure.

The discovery is located in 500m of water and lies about 25 km north-east of Azerbaijan's giant Shah Deniz gas and condensate field.

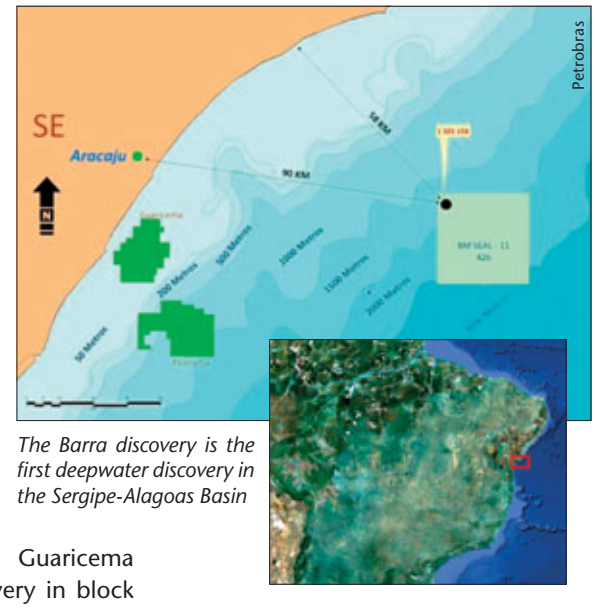
Total, operators of the block, are known to have been targeting deeply buried, high pressure reservoirs, and the well has already reached 6,550m. Drilling will continue to explore further deeper objectives that look attractive. The well will then be tested to better confirm the reservoir potential.

Total have a 40% share of the Absheron licence, with SOCAR holding another 40% and GDF SUEZ 20%. ■

Brazil: New Oil Province

Deepwater exploration is being vigorously pursued throughout Brazil, and not only in the prolific pre-salt areas of the Santos and Campos Basins.

Petrobras recently announced a new discovery in the offshore Sergipe-Alagoas Basin, in north-east Brazil, about 1,500 km north-east of Rio. The basin was the location of the first commercial oil discovery in the Brazilian continental margin, the Guaricema Field in 1968. This discovery in block SEAL-M-426, 58 km off the Sergipe coastline and 90 km from the city of Aracaju, is the first ultra deep discovery in the basin, located at a water depth of 2,341m and opening up a new frontier for Brazilian explorers.



The Barra discovery is the first deepwater discovery in the Sergipe-Alagoas Basin

The discovery, known as **Barra**, was initially made in late 2010, and the West Polaris drill ship re-entered the wildcat in early May 11 for deepening and testing operations and drilled to a depth of over 5,500m. Good quality oil was encountered in two reservoirs at depths of between 5,050m and 5,400m, the upper one containing gas and 43° API condensate and the lower one containing 32° API oil. Both reservoirs are reported to show excellent permeability and porosity characteristics.

Petrobras are operators of the block with 40%, the remaining 49% being held by IBV-Brasil. ■

Mozambique: 10 Tcfg Potential

For long an exploration backwater, Mozambique is rapidly moving nearer to becoming a gas-producing nation. The results from wells drilled in Offshore Area 1 of the deepwater Rovuma Basin in the last two years have continually exceeded expectations since Windjammer, the first discovery off Mozambique, was announced early in 2010.

In early October Anadarko, operator of the 10,500 km^2 block, said its most recent exploration well at the Camarao prospect had encountered approximately 73m of natural gas in an excellent quality reservoir and confirmed that it was in static pressure communication with the Windjammer and Lagosta discoveries, 25 km to the north and 15 km to the south respectively. The new well also opened up a new shallower play with the discovery of a 43m gas column in Miocene and Oligocene sand packages, not found in the earlier wells. The Camarao discovery well is in 1,442m of water, about 80 kilometres off the coast of northern Mozambique.

Anadarko have therefore announced that it believes that the complex of Windjammer, Barquentine, Lagosta and Camarao cumulatively hold at least 10 Tcfg recoverable. And with a number of additional prospects identified and the mobilisation of a second drillship to the Rovuma Basin in the near future, the company is confident that this current resource estimate will increase. ■

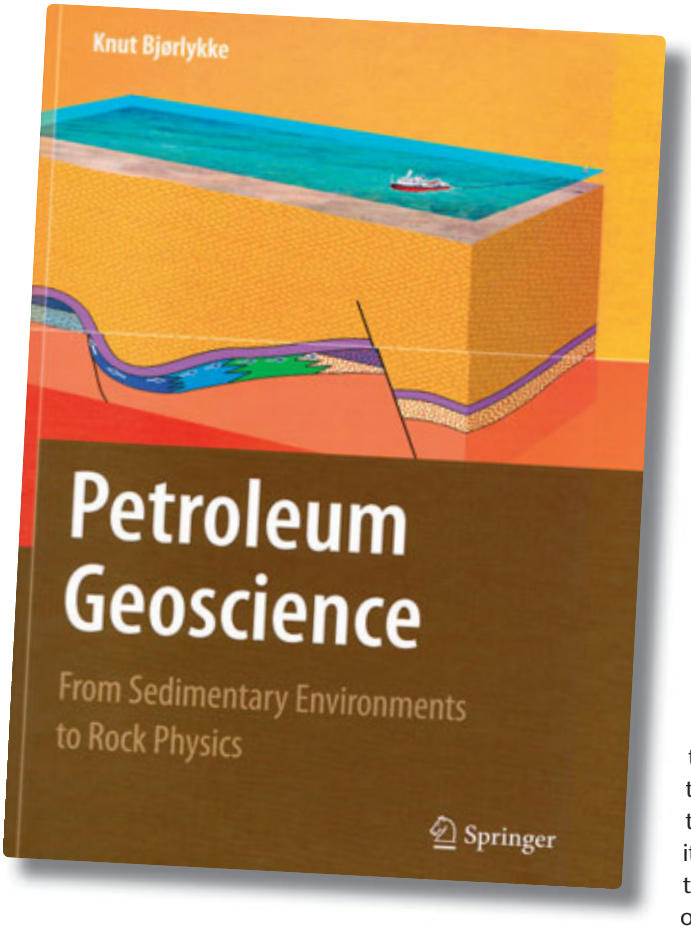
A Comprehensive Introduction

This textbook has lots of information of great value to petroleum geoscientists, both students and professionals. It would have been even better with more examples from modern oil and gas fields.

Petroleum Geoscience: From Sedimentary Environments to Rock Physics
Knut Bjørlykke (ed.) Springer, 2010

It is massive! It has 500 condensed pages with numerous illustrations, most of them reflecting the advanced technology that is the basis for modern petroleum geoscience.

'It' is a textbook – a "basic introduction to disciplines relevant to petroleum exploration" – with lots of knowledge for the curious petroleum geoscience specialist. Regrettably, the book only includes "some aspects of petroleum production", as the editor says in the Preface. Knowing that more and more emphasis will be put on producing what is left in the ground, and keeping the book's title in mind, it would have been interesting to know more about how geoscientists can be involved in production, and what kind of knowledge is required.



Knut Bjørlykke, Professor Emeritus at the University of Oslo, has updated his previous textbook and now presents a version with several new chapters reflecting the incredibly rapid advancements in petroleum geoscience. Many of the new chapters are written by professionals with an outstanding reputation in the Norwegian petroleum community.

Taking into account that there are few other alternatives, it is assumed that this book will be used by both students and by professionals who need to update themselves with the latest knowledge about petroleum exploration and petroleum production.

Writing a textbook about petroleum geoscience is an ambitious task. The first question is of course what to include: "petroleum geology is not a well-defined academic subject", as the editor and main author admits himself. With 22 chapters, each covering separate topics, he has been able to demonstrate the complexity of petroleum geoscience. The subjects discussed include sedimentology, geochemistry, stratigraphy, fluid flow, geomechanics, rock physics, structural geology, petroleum generation and migration. In addition, technologies used in finding and exploiting hydrocarbons, such as well logging and seismic, are also covered. Bearing in mind the possible importance of electromagnetic surveying (CSEM) in the future, it may have been appropriate to have covered this subject with a separate chapter.

It is noteworthy that this textbook has several chapters that deal with recent advancements and modern technology, in addition to classical subjects like generation, migration and trapping of oil and gas. We are, for example, given an introduction to fluid flow and geomechanics, rock physics and 4D seismic.

This book is written (in English) by a largely Norwegian team, and the final chapter is a 30-page account of the geology of the Norwegian continental shelf, nicely illustrated with a lithostratigraphic summary, maps, cross-sections and seismic. It should be very useful as an introduction for both students and others interested in the Norwegian offshore.

My main criticism is that there is a lack of reference to the "real world". Too much theory is another way to put it. To take just one example: there is a two page discussion of barrier islands, seen from an academic viewpoint, but there is no reference to any fields in which barrier islands constitute the reservoir. I would have liked to have seen more examples from oil and gas fields around the world, the North West European continental shelf included. That would have been a considerable improvement.

However, there should be no doubt that the present book covers the basic needs for all students in petroleum geoscience. Moreover, because of its coverage of basic principles it should also be a valid reference for professionals who want to update themselves on subjects in which they do not have special expertise. ■

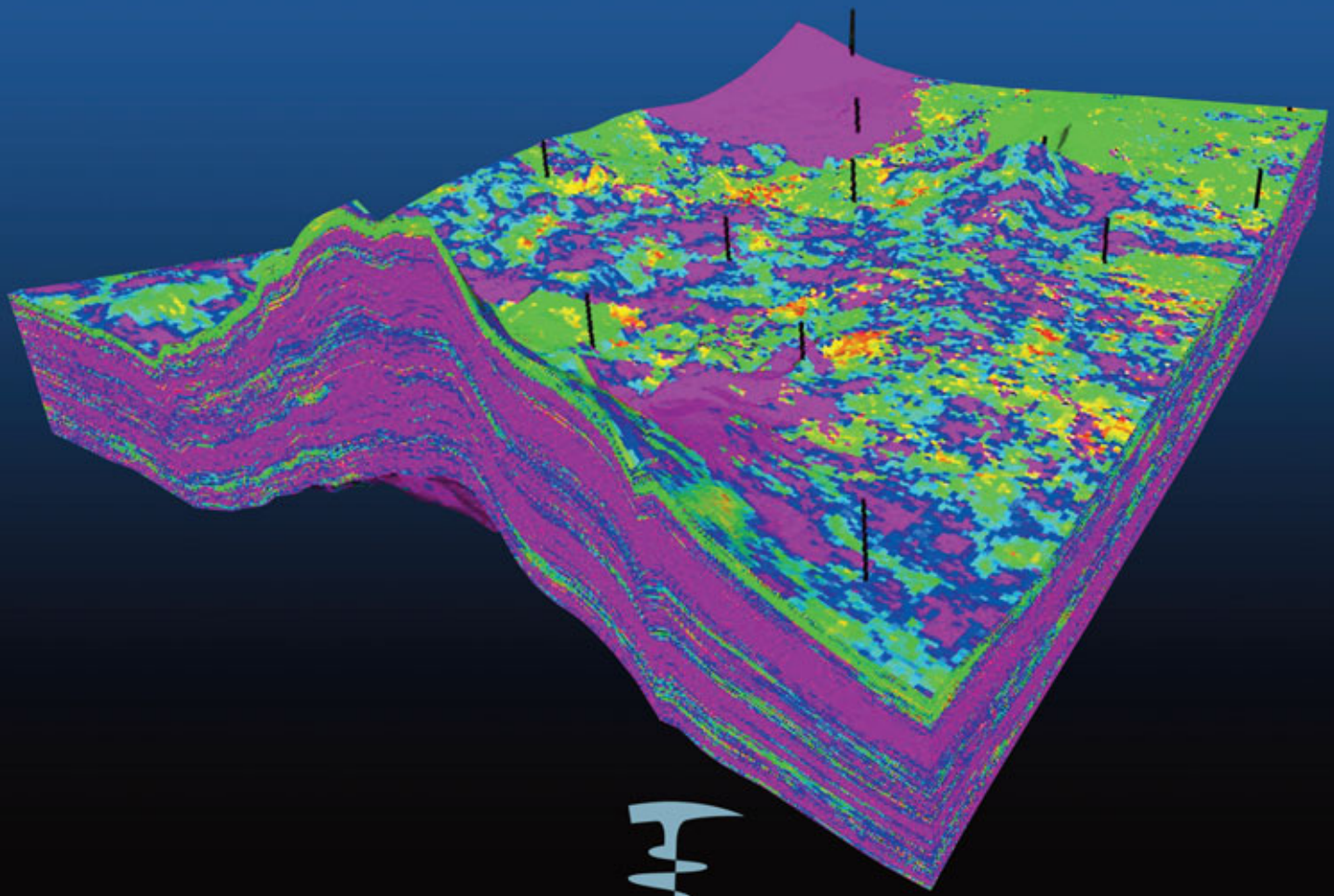
HALFDAN CARSTENS

Production Geoscience 2011

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

Stavanger, November 1-2, 2011

www.geologi.no/pg2011



GEOLOGICAL SOCIETY
OF NORWAY

PROSPEX: It's All About Deals & Networking

Mike Bowman, Head of Geoscience for BP until 2010, and now Professor of Development and Production Geology at Manchester University, is President-Elect of the UK-based PESGB (Petroleum Society of Great Britain) and Chairman of PROSPEX, which will be held in London in December. We talk to him about this prospects fair – and whether there are too many events to attend in the industry now.

What is PROSPEX and how long has it been going?

PROSPEX was launched by the PESGB in 2003 to promote licence opportunities, initially only within the UKCS; it offered a combination of exhibits and presentations enabling people to promote and assess opportunities, and to discuss topical issues. It also provides a vehicle for the Government and other groups such as DECC (UK Department of Energy and Climate Change) and UK Oil & Gas (formerly UKOOA) to get information across to the attendees and beyond. Working for BP for many years, I had heard of PROSPEX, but I had never been involved – it was perceived by the majors as being of interest primarily to the independents – but the more I hear about it, the more I can see that it should appeal to a broad range of exploration companies irrespective of size. It's all about deal-making and understanding the commercial framework surrounding these, together with the regulatory framework in the UK and surrounding areas.

Guy Elliott/PESGB

What is your involvement?

The President-Elect of the PESGB chairs and co-ordinates PROSPEX as part of the role and, in conjunction with the organising committee, puts together the programme, although much of the leg work is done, in outstanding fashion, by the PESGB office team; I am really impressed by the enthusiasm of people to participate in, sponsor and sign up to attend PROSPEX – it already looks as though 2011 will be one of the most successful ever.

How many people do you expect to attend and where do they come from?

The highest number of attendees we have ever had was 730 in 2008 and we could easily equal that number this year, coming from places as far apart as the United States and Poland. We already have 65 confirmed exhibitors, so it looks as though all of the available space will be sold out. I think it reflects the vibrancy of the industry, with many people looking for opportunities to do deals.

What differentiates PROSPEX from events like NAPE and APPEX?

Appex is similar in its intent, but with the backing of the AAPG it has a different, more international focus. Since PROSPEX is promoted by a UK-based organisation, it is more UK focused. Having said that, PROSPEX has now extended its boundaries and not only covers the UKCS but also surrounding areas of North West Europe, from Norway to the Faroes. It's a great vehicle for smaller and larger companies to talk deals together.

Do you think we are in danger of having too many shows, seminars and conferences?

While there is demand, I can see no problem in having them all BUT I also feel that there has been a proliferation of conferences and events in recent years – we must not overload the system. It is important that the heads of the various organisations like PESGB, the Geological Society of London, AAPG, EAGE and SPE all work together to make sure that the balance is correct; competition will not help any of us – collaboration will be the key to on-going and future success.

What are you looking forward to in your year as PESGB President?

My predecessors, Steve Garrett (2011) and Henry Allen (2010) together with Guy Elliott (the new PESGB Executive Director), have worked hard to get more structure and business focus into the organisation; I believe that this will allow me to concentrate on some of the bigger issues of relevance to our community and members. I am keen to promote collaboration with other organisations, such as the Geological Society and EAGE, for our mutual benefit, ensuring that we are all aligned and catering to the needs of our members and the broader business community. I am also keen on outreach and education, being particularly anxious to continue our work to help promote the earth sciences in schools. We will continue to respond positively to the recent cut in central government funding of UK MSc grants by helping establish sponsorships. The PESGB already sponsors a number of Masters students, as do several large companies, but I want to find ways for smaller UK-based organisations, which could not afford to sponsor an MSc student alone, to be able to contribute towards a central 'pot' for funding future students.

One of the best things about holding office in an organisation like this is that you meet great new people, both on the Committee and the office team, as well as in the organisation itself. It is also fascinating to be able to take part in things like House of Commons advisory committees, being able to really find out and participate in the important issues confronting our members and the business we work in. ■

Norway Bjarmeland Platform

New Multi-Client 3D Data

Polarcus has acquired a ~1,300 sq. km high density multi-client 3D project over the Bjarmeland Platform in the Barents Sea, offshore Norway. Data processing is currently underway at GX Technology, with delivery of the final migrated data volume expected in Q1 2012 ahead of the 22nd Concession Round in Norway.

For further information please contact:

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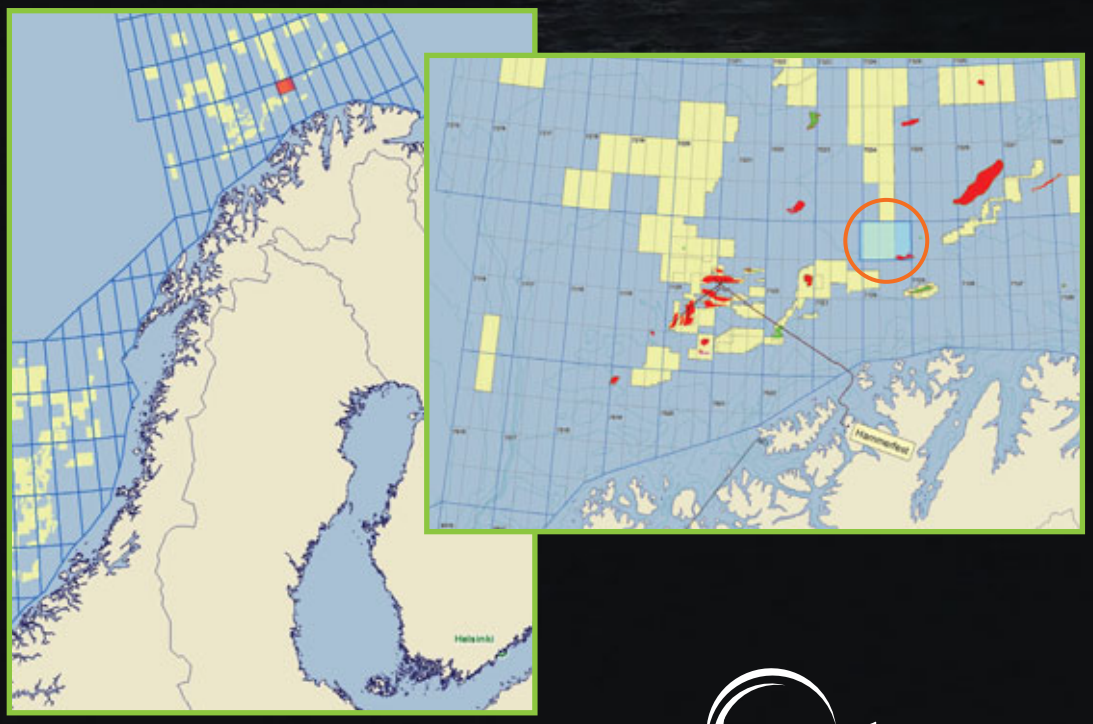
To view data sheet for the Bjarmeland Platform survey please scan.



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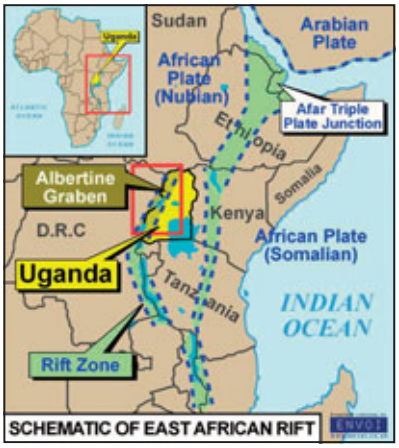
Uganda: Key to Future Hotspots in Landlocked Africa?



Mention East Africa to the world's general public and it will probably bring to mind a colourful mosaic of images, from spectacular landscapes through to abundant wildlife and notorious geo-political instability. Large oil fields, with over one billion barrels recoverable discovered in the last decade, would not typically be one of them. But the East African Rift System is now one of the world's 'exploration hotspots', potentially just as significant for landlocked Africa and its underexplored rift systems as the Barnett Shale in Texas was to the birth of unconventional shale gas in North America.

MARTIN RIDDLE, Envoi Ltd

The large scale features of the region's topography are clear evidence of the regional plate movements and faulting responsible for the geological evolution of the East African Rift system (EAR), defined by a roughly north-south arcuate series of discontinuous fault-bounded depressions (*GEO Expro Vol. 8, No. 4*).

The recent exploration successes are located in the Albertine Graben, along the western edge of Uganda north of Lake Albert, where the rift segment, covering an area approximately 50 km across and 400 km long, is bounded on both sides by Palaeozoic metamorphic basement. The main phase of Albertine Graben development occurred during the Middle Miocene, with north–south trending, asymmetrical crustal rifting filled by thick fluvial, lacustrine and deltaic syn-rift sediments and now on-laps basement at its margins.

Rapid exploration

Although active oil seeps had been recognised in the Albertine Graben as far back as the 1930s, sporadic early exploration only found oil shows. The subsequent 60-year exploration hiatus lasted until renewed stability in Uganda enabled new international participation and active, modern exploration in the late 1990s, pioneered by Hardman (before its acquisition by Tullow), albeit in the face of some industry scepticism.

The first new exploration was south of Lake Albert, where the Turaco wells, drilled by Heritage in 2001/02, encountered oil in a 300m Tertiary clastic section, although the subsequent flow tests produced some 90% CO_2, which has since been associated with carbonates locally 'cooked' by high heat flows associated with deeper volcanics to the south. These wells proved the presence of an active hydrocarbon system containing good quality reservoir sands.

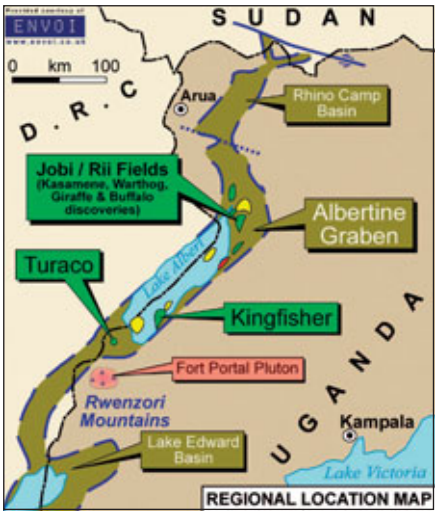
Heritage's follow-on exploration well, Kingfisher-1 drilled in 2006/7, was drilled south of the Lake away from the influence of high heat flow. It found Miocene and Pliocene sands which flowed at almost 14,000 bopd from four reservoir zones, and little or no CO_2. The appraisal well exceeded these flow rates and led to a rapid acceleration of exploration progressively further north along the eastern margin of the Graben by the Heritage/Tullow joint venture. This has led to an unprecedented 96% success rate: 26 new discoveries from only 27 wells, partly due to new technology and the very effective use of high resolution aerial gravity gradiometry surveys to map the basement structure and indicate probable reservoir distribution.

Billion Barrel Potential

The most recent discoveries include the Jobii/Rii cluster of large fields in the Butiaba region, at the north end of Lake Albert, in which oil columns up to 140m are understood to have been found. These fields, in a large deltaic play, are estimated to contain around half of the reserves found to date in the Graben and are responsible for triggering the major international interest in the East African Rift. Exploration is also now progressing in other sub-basins on trend within the Albertine Graben, including the Rhino Camp Sub-Basin to the north by Tower and the Edward Sub-Basin by Dominion to the south of Lake Albert.

In the proven central part of the Albertine Graben hydrocarbons are believed to have been generated in the western, deeper axial part of the rift, possibly migrating up dip along the hanging wall faults of the rift, resulting in the accumulations found to date, mostly situated on the eastern flank of the Graben. To the north of the Butiaba region, and beyond the east-west trending sinistral accommodation zone which offsets the northerly Rhino Camp segment of the Graben, the polarity is reversed. A recent gravity gradiometry survey and subsequent new seismic has confirmed the deeper axis is on the eastern inside of the Rhino Camp Basin.

The discovery of a potential billion barrels recoverable so far has comfortably surpassed the commercial thresholds of the Albertine Basin and catapulted the region to its current 'hotspot' status. It begs the question: "How many other landlocked rift systems might have the same untested potential?" ■



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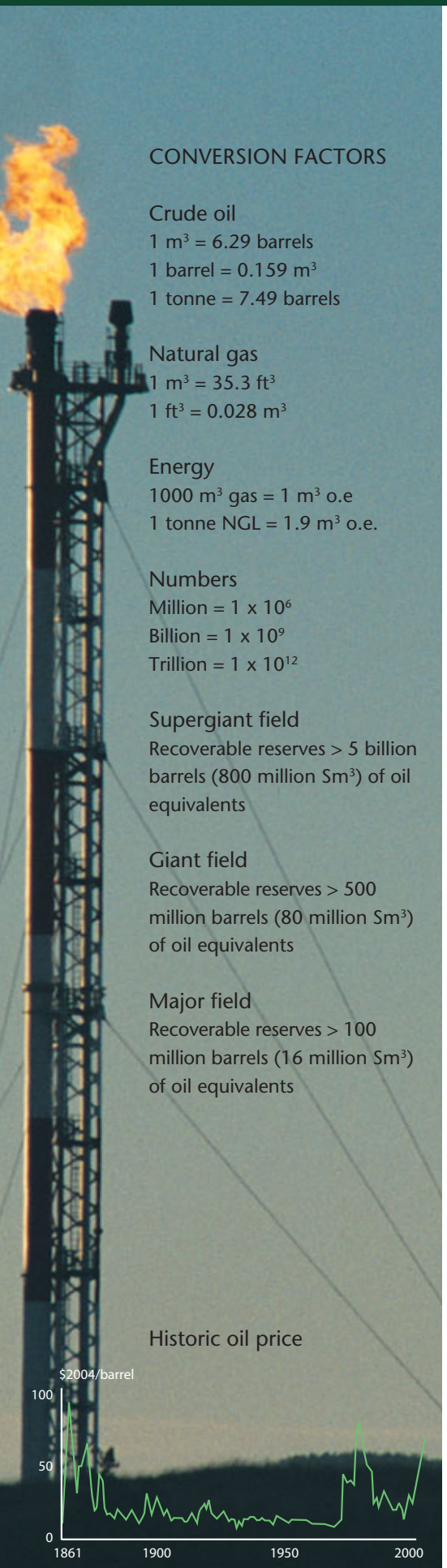


CONVERSION FACTORS

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

Probably the Largest in the World


Halfdan Carstens

We were all aware that giant discoveries on the Norwegian continental shelf belonged to the past. The last giant (a field with >500 MMboe recoverable) Orman Lange, was found in 1997 and put on stream in 2007.

Since then a number of very small (uncommercial), small (possibly commercial) and medium discoveries have been made. Several major discoveries with more than 100 MMboe have also been proven. But no giants – until now.

The surprising find on the Utsira High was made last year with oil reservoired in Upper Jurassic sandstones. This is a basement block due east of the prolific Viking Graben. In September this year (see page 32), following the drilling of several appraisal wells, Lundin Norway announced that the Avaldsnes discovery might actually contain 1.8 Bbo – a fourfold increase from their previous estimate one year ago. Combined with the neighbouring structure Aldous, which is part of the same accumulation, it is possible that the combined structure has more than 2.6 Bb of recoverable oil.

The high estimate makes Aldous/Avaldsnes the third largest oil field on the Norwegian continental shelf. If the low estimate proves to be correct, it is still the seventh largest oil field. It may also prove to be the largest discovery in the world this year.

This discovery is all the more surprising because it is made in a mature petroleum province. The Utsira High is now in the third generation of exploration. It started in the mid-1960s with the very first licensing round on the Norwegian continental shelf. While one significant discovery was made in the early days (Balder), a number of dry wells made the oil companies look elsewhere.

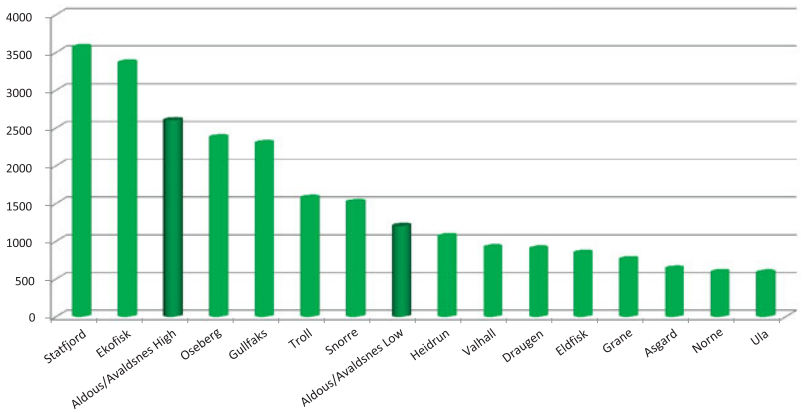
The second generation culminated with the discovery of Grane in 1991, up to now the largest field on the Utsira High. Again, a number of dry wells turned off many oil companies. Oil shows encountered in several wells during the second generation were, however, crucial to understanding the petroleum system and were used successfully during the third generation.

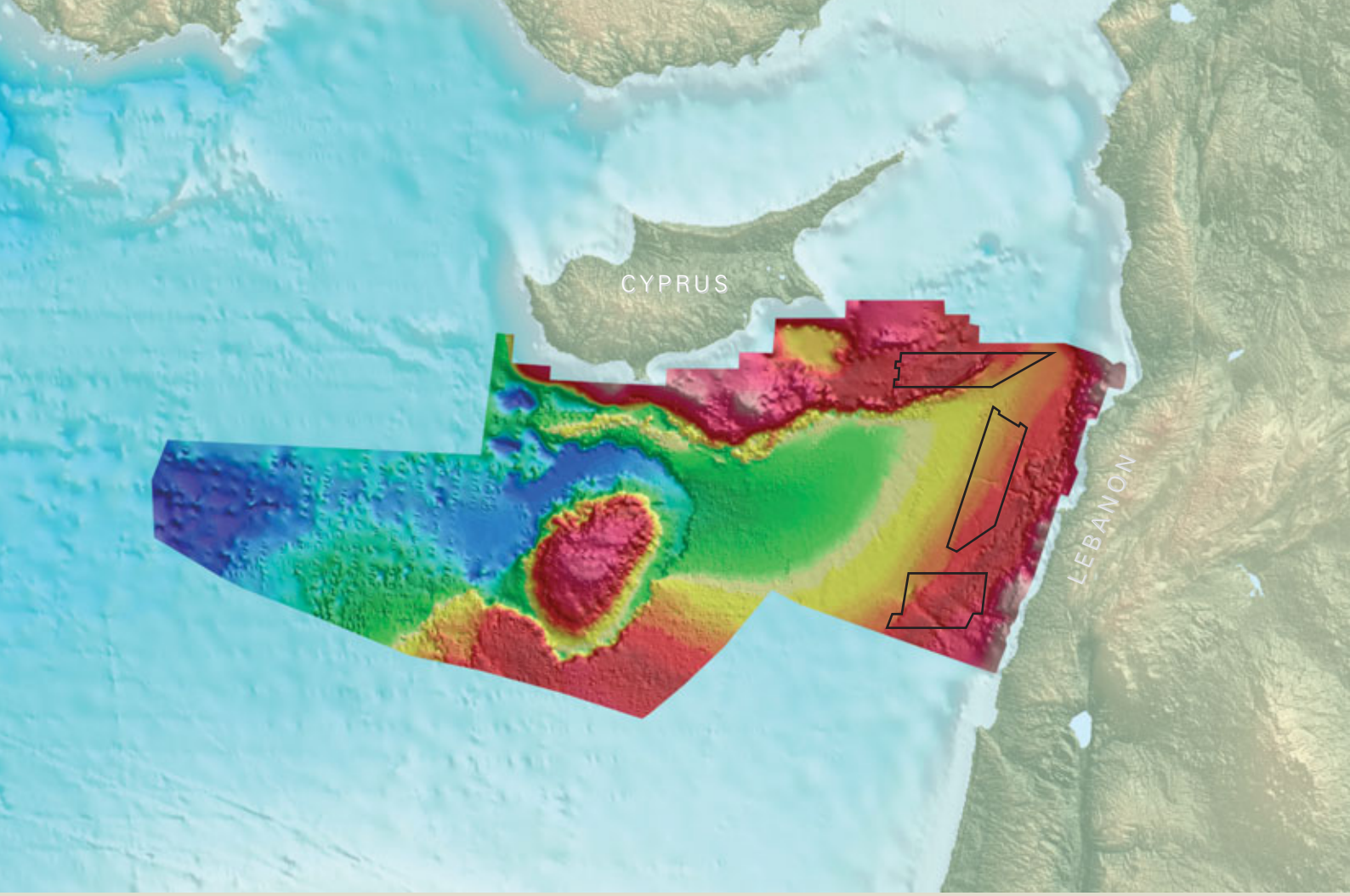
Annual licensing rounds and a new tax regime that allowed small and medium companies without producing assets to take part in the race triggered the third generation and the number of exploration companies offshore Norway tripled.

Making acreage available on a regular basis in mature areas made a huge difference. Areas previously discarded were now taken up by small independents. One of them, Lundin Norway, was particularly interested in the Utsira High. In 2004, it applied for acreage that no other company wanted to touch, and, to cut a long story short, three years later a surprising discovery was made (Luno) that has expanded both laterally and stratigraphically, all the way down to basement.

Lundin used their geological knowledge to secure more acreage on the Utsira High. Four years after their initial discovery we know that good exploration involves taking risks and being persistent. Above all, these finds show that you have to look for oil where the oil is. ■

Fifteen oil fields on the Norwegian continental shell are classified as giants (>500 MMbo)





MegaSurveys

Eastern Mediterranean MegaProject

Regional interpretation

GeoStreamer data

Subsalt horizons

Upcoming license rounds

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

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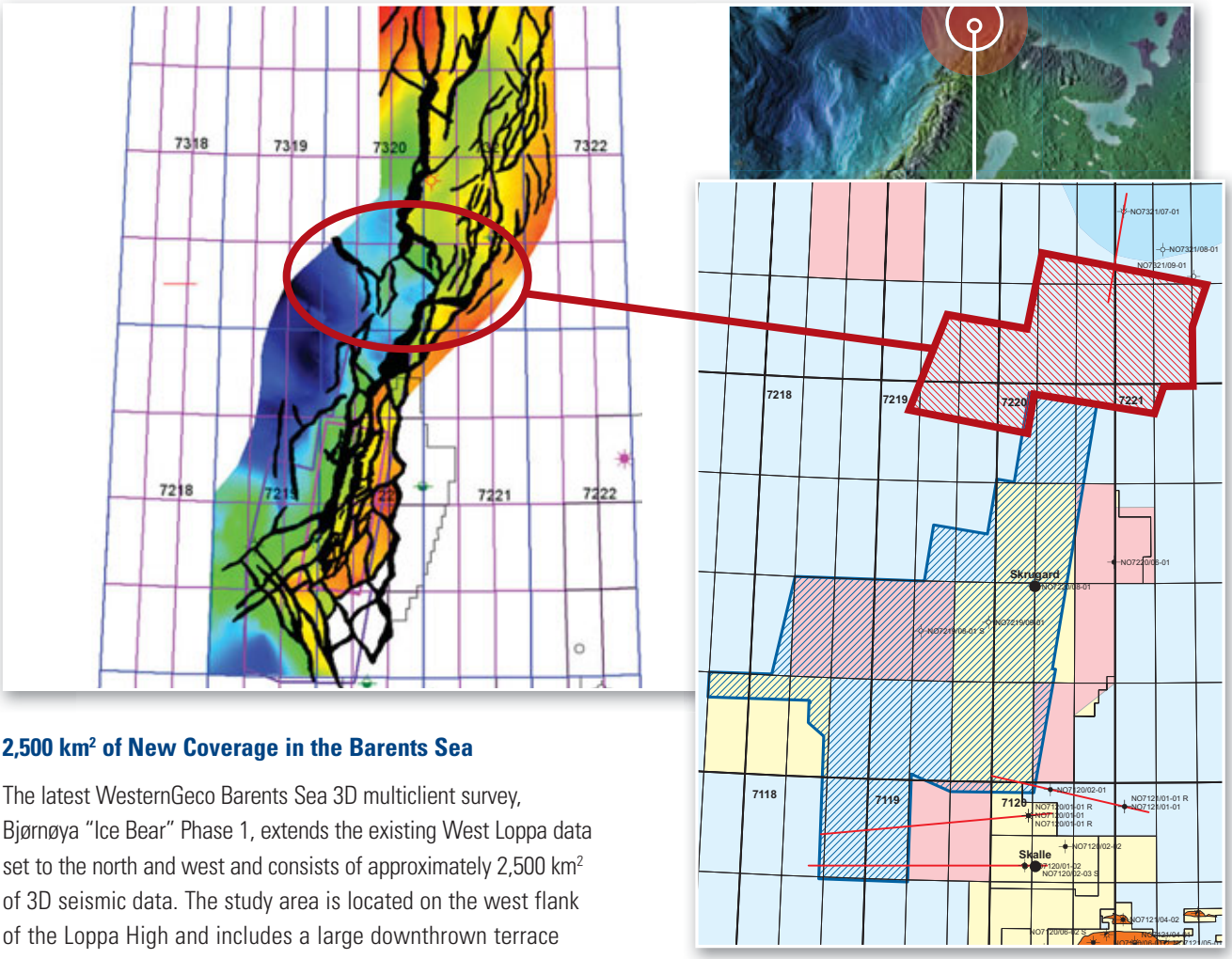

2,500 km² of New Coverage in the Barents Sea

The latest WesternGeco Barents Sea 3D multiclient survey, Bjørnøya "Ice Bear" Phase 1, extends the existing West Loppa data set to the north and west and consists of approximately 2,500 km² of 3D seismic data. The study area is located on the west flank of the Loppa High and includes a large downthrown terrace in the north together with other Jurassic horst structures and some interesting Cretaceous features. Other promising features are seen in the southwestern part of the survey area.

- Acquired by *Geco Eagle* using 10 x 7 km streamers
- Fast-track cube available in November 2011 in time for 22nd Norwegian Licensing Round nominations
- Final data volume expected March 2012 in time for 22nd Norwegian Licensing Round applications
- Late commitment rates with delivery of the fast track data in November available on request

For more information, please contact us on +44 (0) 1293 556533.

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