VOL. 10, NO. 5 – 2013

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

EXPLORATION
East Africa: Riding High

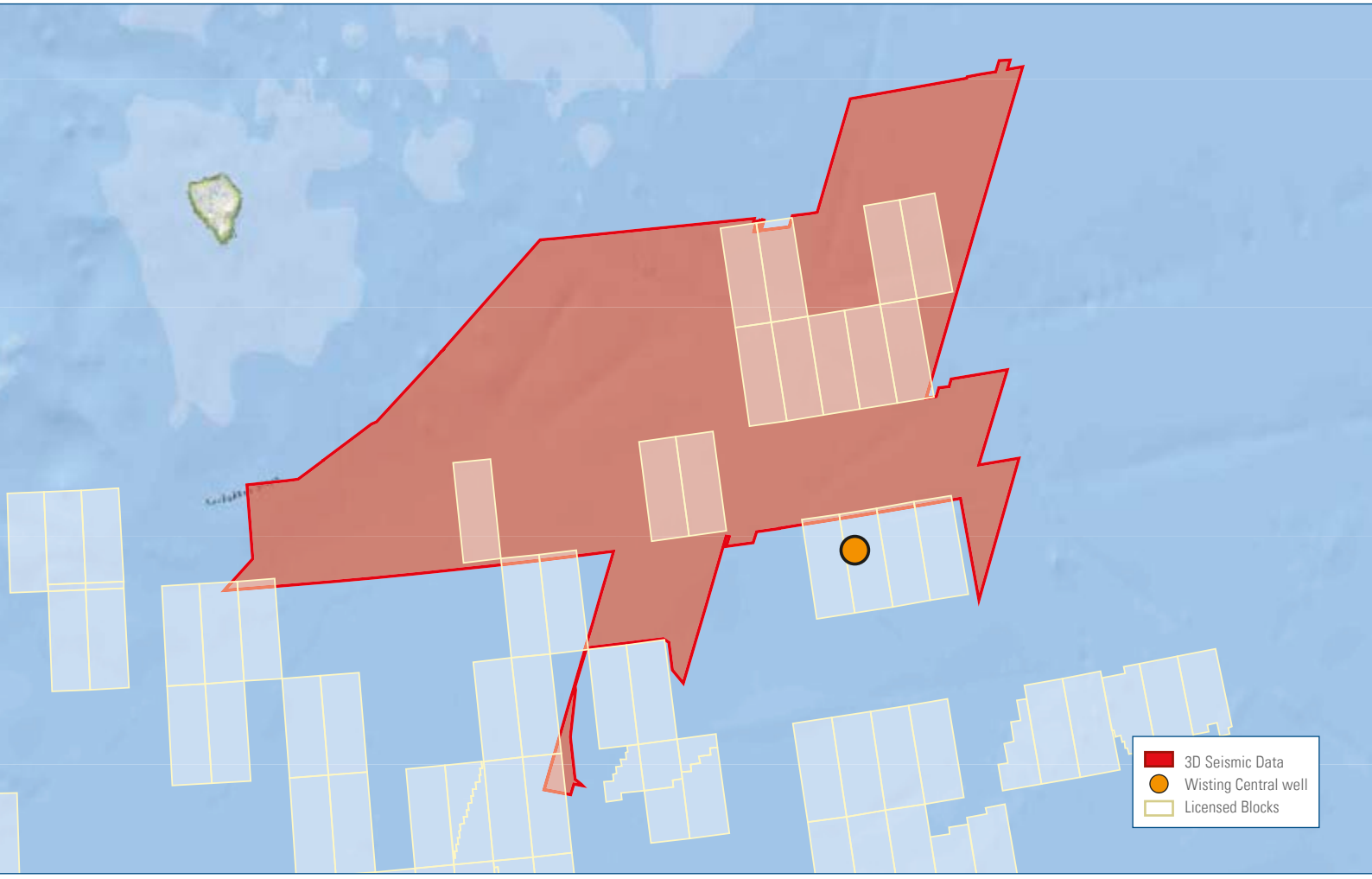
geoexpro.com

EXPLORATION
Central Caspian Jurassic Reservoirs

GEOTOURISM
Green Pearl of the Canary Islands

GIANT FIELDS
Kashagan: Precaspian Supergiant

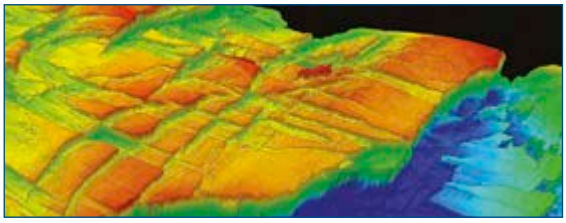
GEOLOGY GEOPHYSICS RESERVOIR MANAGEMENT



THE HOOP ADVENTURE CONTINUES

The Wisting Central discovery marks the start of a new era of petroleum exploration in the Hoop area, and many prospects similar to Wisting Central as well as several other very promising play models, which remain untested.

TGS can provide the data you need for this next exploration phase.



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GEO ExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED

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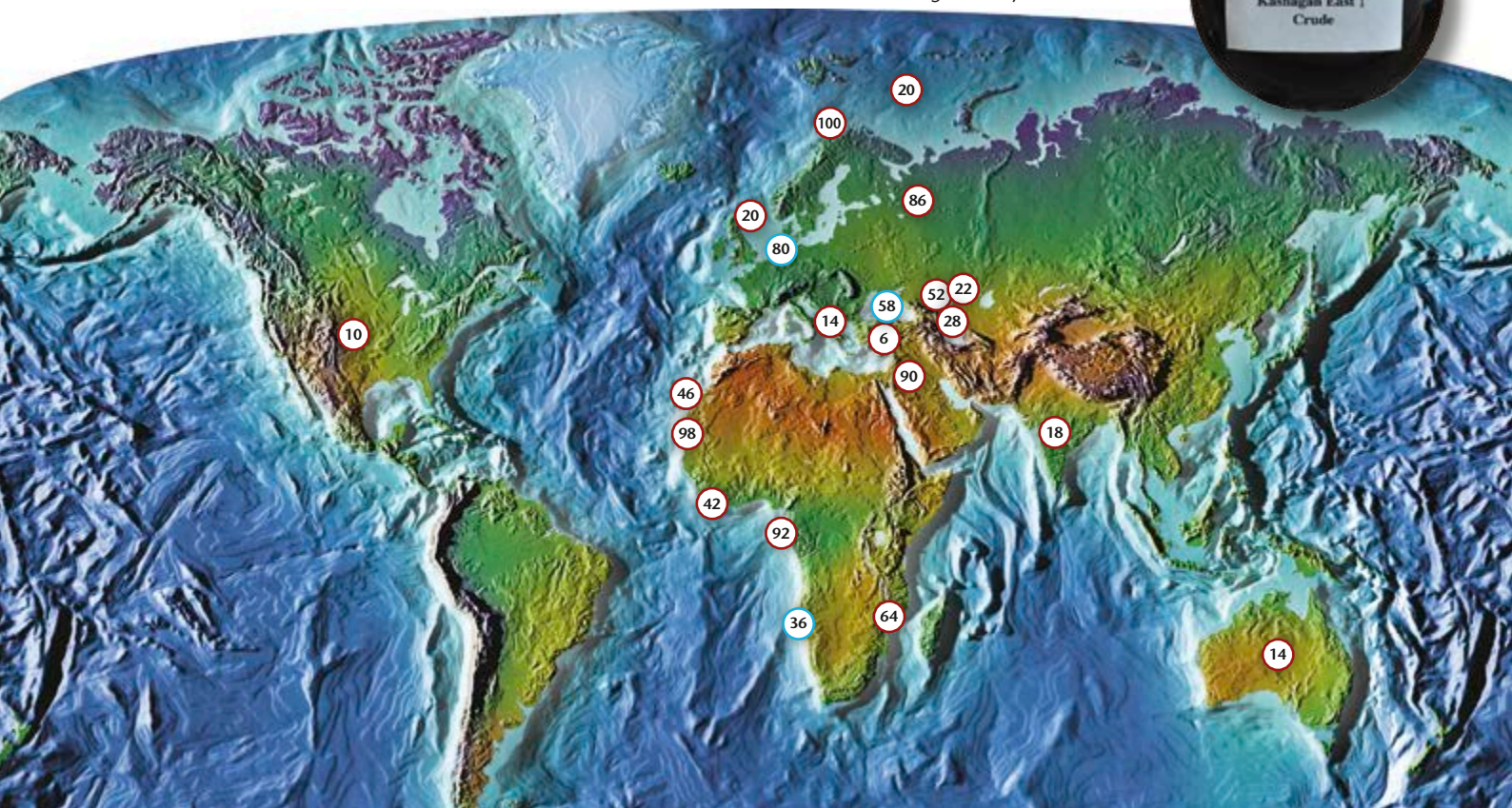

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Working Together

This copy of *GEO ExPro* focuses on Africa and the Former Soviet Union countries, but there is another theme running through it – that of collaboration. It is becoming more and more apparent that to find and exploit the ever more elusive hydrocarbon resources of the Earth in the most efficient way, we need to combine our efforts and brain power and work together.

For a number of years now E&P companies have been organising their exploration effort into multi-skilled teams, with geologists, seismic interpreters, processing experts, reservoir engineers and drilling specialists all being involved in the discussions on where, how and when to drill, and on the best way to exploit any reserves discovered. But the articles in this magazine illustrate the importance of teamwork in a number of other ways.

Take, for example, the way in which the three largest and most influential professional and technical bodies in the upstream industry – the Society of Exploration Geophysicists, the Society of Petroleum Engineers and the American Association of Petroleum Geologists – have combined forces to sponsor and organise an important new conference on unconventional resources, URTeC, where all the disciplines involved in this rapidly developing side of the industry were able to share cutting-edge ideas and techniques. Similarly the SEG and the AAPG together recently launched a new technical journal, *Interpretation*, with the intention of promoting the exchange of the ideas, skills and practices that an interpreter needs, from both the geological and the geophysical viewpoint.

Organisations and governments are also encouraged to work together for the greater good of the combined region. After the collapse of the USSR, for example, the countries surrounding the Caspian Sea only looked at their own territory and prospects, making a regional perspective difficult because, as we all know, geology does not follow arbitrary political boundaries. A consortium of scientific institutions and organisations 'Geology Without Limits' here discusses the issues involved in exploring in the Caspian Sea region and the necessity of collaboration for a successful outcome for all. And we also report on an interesting partnership between two seismic service companies and five governments in North West Africa aimed at promoting available acreage and exploration in the region.

Without a doubt, the future is collaboration.

JANE WHALEY
Editor in Chief

THE CASPIAN

Callovian (Middle Jurassic) marine sandstones and shales near Doshan on the north of the East Karatau ridge, Mangystau oblast, Western Kazakhstan. Pale-coloured Lower Jurassic in the background sits unconformably on darker Upper Triassic. The near-continuous Mesozoic outcrop here exposes deposits which accommodate major petroleum systems across the Central Caspian and the southern part of the Precaspian Basin.

Inset: Flow testing on Anadarko's Barquentine discovery in Mozambique, the country which has led the recent surge of interest in East Africa.

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Turkey Moves Forward

Turkey revises 60-year-old law in a bid to attract investment for exploration

Despite a lack of domestic production, Turkey remains pivotal for the international gas market as the country is the meeting point for Russian and Middle Eastern resources. It is a hub for key pipelines, notably the Blue Stream gas pipeline from Russia, the Baku-Tbilisi-Ceyhan oil pipeline from Azerbaijan and the Kirkuk-Ceyhan oil pipeline from Iraq.

Largely in response to recent large gas discoveries in nearby Cyprus and Israel, the Turkish government plans to increase exploration in its territorial waters with a view to increasing domestic production and reducing the country's dependence on imports of oil and gas. It also has plans to exploit any potential shale gas opportunities. To this end, in June 2013 Turkey's parliament passed a new petroleum code that replaces the 1954 law, understandably criticised as being out of date and failing to encourage investment. The new law embraces virtually all aspects of upstream from applications to production, including gas storage, and marks the end of the Turkish Petroleum Corporation (TPAO) hegemony, through which the state company had right of first refusal on any acreage award and compulsory partnership with any foreign operator. The Turkish Chamber of Petroleum Engineers issued a critical statement regarding this law prior to its acceptance in parliament.

The new legislation has removed the old system that separated the country into 18 different geographical regions and has replaced it with a much simpler onshore and offshore regime, with the latter sub-divided into territorial and non-territorial waters. The preferential rights of TPAO have been removed; it will now compete in future licensing rounds on the same terms as other companies, thereby levelling the playing field for foreign investors. Analysts believe the change also paves the way for TPAO to be privatised.

The Turkish government has also made the permit and licensing regime more attractive. Companies can now be issued with a 'search permit' to collect geological and geophysical data, and organisations holding these permits will be allowed to sell the data collected under the permit to interested parties for a period of eight years. Exploration licences can be granted for up to 560 km^2 for onshore and territorial waters and 10,000 km^2 for non-territorial waters. The Turkish government has also increased the duration of a licence. Onshore licences are now granted for five years (rather than four) and eight years (rather than six) for territorial waters. These licences can be extended by two and three years respectively.

The new Petroleum Law requires an applicant for an exploration licence to provide a bond equal to 2% of the financial commitment in the work plan in the licence application. A reduced rate of 1% applies to offshore exploration where the financial investment is expected to be higher. The requirement to post a bond is intended to ensure that only investors with the requisite financial and technical capability apply for exploration licences. There are also fiscal incentives for investors as the new law lowers the ceiling for income tax from 55% to 40%. In addition, companies are exempt from customs duty, levies and stamp tax for equipment imported and supplied locally. The government's share in oil and gas payable as a royalty (in cash or in kind) remains unchanged at 12.5%. No new applications for exploration licence shall be accepted by the General Directorate within the first year commencing on the date the Law came into force. In other words, new exploration licence applications will need to be filed starting from 11 June 2014.

The new Petroleum Law is intended to bring Turkey's petroleum regulation in line with European Union laws in order to help facilitate Turkey's accession as the country is a candidate for full membership, although discussions have been stalled for three years over numerous concerns about democracy and human rights. ■

ABBREVIATIONS

Numbers
(US and scientific community)

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

Liquids

barrel = bbl = 159 litre	
boe:	barrels of oil equivalent
bopd:	barrels (bbls) of oil per day
bcpd:	bbls of condensate per day
bwpd:	bbls of water per day

Gas

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

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

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

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

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

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

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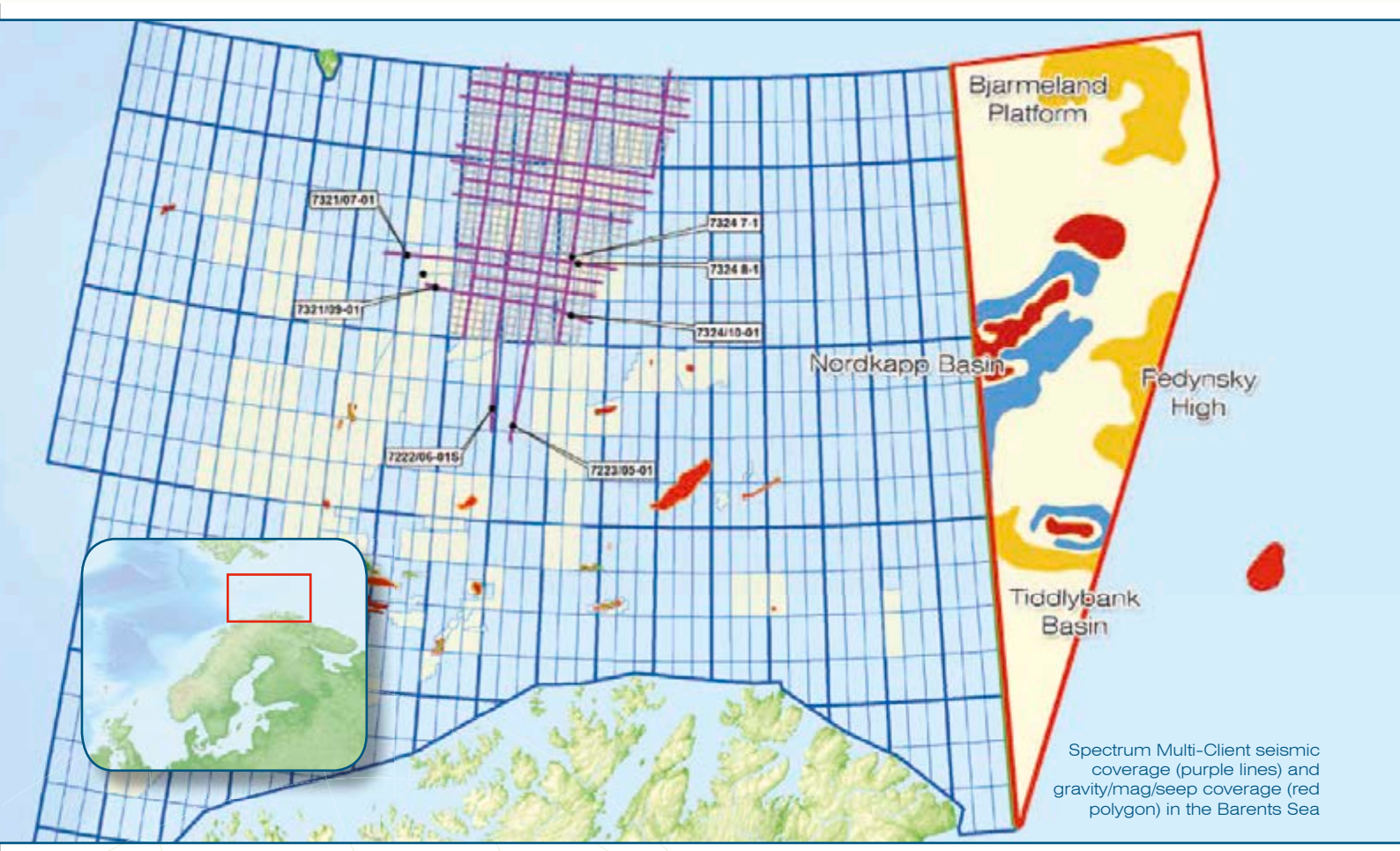
www.glossary.oilfield.slb.com

Barents Sea

New 2D Multi-Client Seismic and Airbourne Grav/Mag/Seep Survey



Spectrum Multi-Client seismic coverage (purple lines) and gravity/mag/seep coverage (red polygon) in the Barents Sea

Seismic Imaging

Phase 1 (2,226 km) of a regional 2D Multi-Client survey in the Barents Sea has been acquired between the Fingerdjupet Sub-basin and the Hoop Fault Complex.

A comprehensive and advanced data package of AVO ready gathers, bandwidth extended seismic, well tie panels and seismic inversion results has been developed. This will enable a fast and efficient seismic interpretation and help evaluate prospectivity.

Gravity / Magnetics / Seep Data

A new airborne geophysical survey in the South East Barents Sea has been acquired using gravity, magnetic and SEEPFINDER data. Measurements will include the revolutionary GRAVEX high-sensitivity gravity sensing system.

The survey spans an area of 48,700 sq km in a 2 km x 10 km grid. This area was opened for exploration in June 2013.

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It's Our Ocean to Save…

Coral reefs have survived ocean warming, acidification, coastal development, tectonic and weather events – but can they survive these events if combined with an oil spill?

Somewhere in the world this 'worst case scenario' already exists.

Hydrocarbon spills need to be addressed. Many island nations around the world lack formal (or informal) response programmes for such disasters. Imagine waking up to find your pristine beach and the coral reef right off the coast coated in an oil slick. Tourism dries up. Animals coated in oil are dying on the beach. Your livelihood is ruined. There is an urgency to raise awareness for the need for coastal first response programmes that can be used by developing and under-served island nations around the globe.

In many developing nations, if the offending parties do not take the initiative to clean up after an ecosystem-destroying event, the burden and responsibility to save delicate coastal ecosystems often falls on people who may not have the resources to adequately mount a defensive posture for such a devastating marine event.

We live in the real world. We all know that nothing is perfect, accidents happen and leaks occur. Hydrocarbon spills are one event where we can have an immediate impact by sharing information. And for those of us who believe in evidence-based science, we have a responsibility to share what we know.

Stewardship and Development

The World Federation for Coral Reef Conservation (WFCRC) is a philanthropic effort whose mission is to advance the understanding and conservation of coral reefs through integrated programmes including data gathering and sharing, education, and outreach. WFCRC strives to build active, long-term partnerships with divers, conservationists, the scientific community and local island governments. It aims to minimise the effects of a spill by providing information and training to coastal communities.

WFCRC works with developing island nations and coastal communities to train local authorities and the community and to build formal first response plans, which are the most effective avenue to minimise damage from hydrocarbon spills. It puts critical first response clean-up information, case histories and examples not only in the hands of the managers of Marine Protected Areas, but also of affected individuals. This ensures that local fishermen and coastal constituents around the globe know how to respond when a spill occurs. When these preventive measures are shared on a broad basis, the result will have a positive effect on coastal eco-systems around the world. The best results will come from focusing on events that will have an impact whose effect is measured in years, not lifetimes.

In additional to local training seminars, WFCRC (www.wfcrc.org) shares first response information via its live GIS dashboard and geoportal, which is useful for identifying large-scale threats to reefs, and allows researchers to identify those that are in the most trouble. Drone technology with on-board spectral sensors makes visualisation, coral inventory, change management, and beach erosion a more informed decision process.

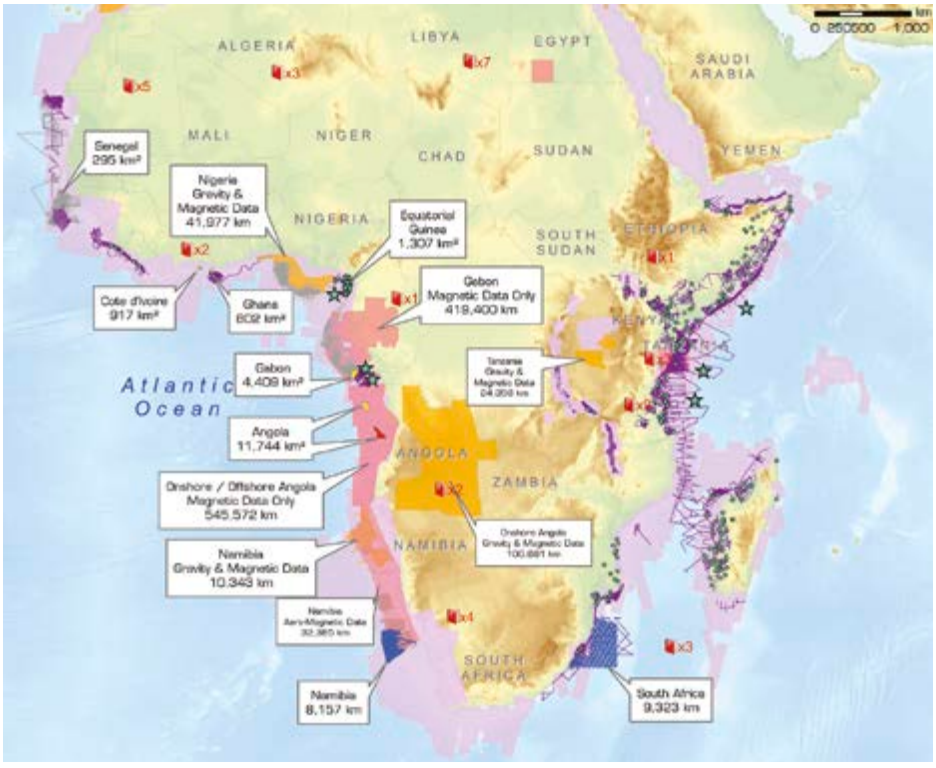
It is unlikely that coral reefs will be able to survive a marine disaster like an oil spill when combined with current issues like global warming, acidification, coral bleaching and habitat loss if we do not enact first response action and preparedness plans now.

WFCRC has developed several programmes focused on coral reef conservation that use current technology and create a worldwide coastal network of like-minded people. This grassroots, philanthropic organisation was developed with the goal of increased awareness for the health, safety, and sustainability of coral reefs on a global scale. As an organisation we feel that preserving our sub-aquatic environment is extremely important and something that we, as a global society, should take seriously for the benefit of future generations. We seek a balance between stewardship and development and feel that by helping to preserve marine ecosystems we are doing a service to everyone in our global community, specifically those who rely on the ocean for their livelihood. We are also preserving these delicate ecosystems for future generations to experience and enjoy. ■

VIC FERGUSON, WFCRC

Covering Africa

Unrivalled exploration insight



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Unconventional Conference Breaks the Mould

The Merriam-Webster Dictionary defines **unconventional** as: 'not conventional: not bound by or in accordance with convention: being out of the ordinary.'

Just as unconventional resources have rewritten the exploration and production play book in the last few years, the Unconventional Resources Technology Conference (URTeC), held in Denver, Colorado this last August, just may rewrite the play book on how conferences are to be held in the future. Being out of the ordinary, URTeC featured the three largest upstream oil and gas societies, namely Society of Petroleum Engineers (SPE), American Association of Petroleum Geologists (AAPG), and Society of Exploration Geophysicists (SEG) as the sponsoring organisations and Technical Program Committee. The result of this collaboration was a unique blend of disciplines that kept attendees buzzing through all three days of the conference.

It was at one of the several evening socials in downtown Denver that I realised just how unique and important this conference is to those developing unconventional resources. While relaxing after an information-packed day of meetings and lectures with C. R. 'Dicky' Hall, P.E., a third generation driller for Southwestern Energy, and Tim Holian, the company's Geologic Discipline Lead for the Fayetteville Shale Division, Tim started off the casual conversation by saying, "I am actually sitting in on various engineering topics, a must now that we are using integrated teams to explore and exploit unconventional resources." Dicky Hall, the drilling engineer, seconded that after some deliberation. He said, "We [geologists, engineers, and geophysicists] have to work together just to get the hole in the right place."

The conference did not break from the central theme of 'the Team Approach' and the integration of geoscience and engineering in unlocking unconventional resources for all three days. The Opening Plenary Session was moderated by Dr. Scott W. Tinker, Director of the Bureau of Economic Geology and State Geologist of Texas. It featured Scott D. Sheffield, CEO for Pioneer Natural Resources, M. W. Scoggins, President of Colorado School of Mines, Vello Kuushraa, President and Chairman of the Board for Advanced Resources International, and Dave Hager, COO for Devon Energy Corporation. These panel members gave very candid and open views on how unconventional methodologies have changed their companies, changed the global supply, and changed academia. Again, the central theme of this panel, setting the table for the entire conference, was the team approach that companies have to take to tap the unconventional resources. Scott Sheffield and Dave Hager gave very factual accounts of how their successes in exploiting unconventionals have led to the amazing growth of their organisations. However, what might be even more astonishing is the huge outlay of capital and manpower that will be required to fully develop these resources. For companies with good positions in these plays, the future is certainly bright and according to Dr. Scoggins, this is a very exciting time for both the institutions with integrated geoscience/engineering programmes and their graduates.

Interspersed with the excellent presentations that featured geology mixed with geophysics and engineering, were interactive panels where the audience had the chance to ask questions or comment. The panels covered everything from new technologies and converting those technologies to money makers, to regulations dealing with the impacts of development and the public image. Discussions were frank and often featured new and cutting edge ideas.

Finally, this conference left me with a much better idea of the true impact this resource has had on the oil and gas industry and the enormous possibilities it has unleashed. Many there referred to it as the biggest oil and gas story ever to hit the US. We now have enough gas for 300 years. You can see the Eagleford development lighting up the night sky from space. The Marcellus has the potential to become one of the largest gas fields ever discovered and the Wolfcamp and Cline shales of West Texas could be one of the world's largest oil fields. These gas discoveries have led to the US becoming the only country to reduce CO_2 emissions enough to meet the Kyoto Protocol.

The second thing to amaze me at this conference was the willingness of companies to share new and cutting edge ideas. Industry leaders, such as Pioneer Natural Resources, had employees presenting 22 technical papers illustrating their current knowledge of unconventional plays, as did many other oil and gas companies as well as service companies participating in this play. All in all, I cannot wait until next year's conference.

THOMAS SMITH

The headline at the entrance to the Exhibition Hall gives attendees the 'flavour' the Unconventional Resources Technology Conference will offer over the next three days.

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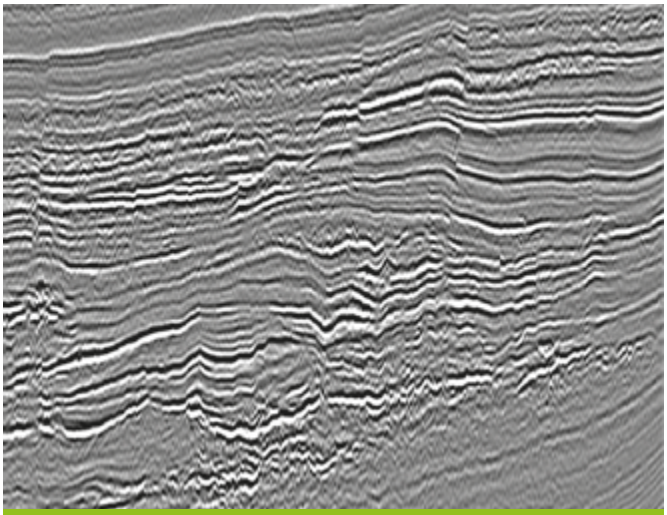
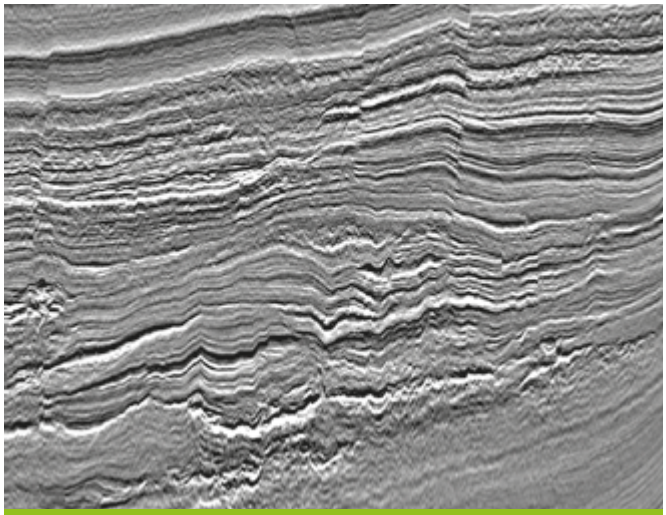


Conventional seismic data



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Competency Management becomes an essential tool

International oil and gas companies are challenged to realise strong returns on their assets while maintaining the highest standards of safety and operating performance. To achieve these goals a leader must build and maintain a competent and skilled workforce throughout the organisation. That task is becoming ever more difficult because of the impact of an ageing workforce, competition for new hires and the need to meet expanding compliance regulations just when everyone is busy with the challenges of daily operations. To solve this dilemma many petroleum companies are turning to competency management to help them implement and manage a competent workforce solution.

A competent workforce can be described as one that has demonstrated, through an audited assessment, that all employees have the skills at the appropriate level of competency necessary for effective performance in their respective jobs.

The International Human Resources Development Corporation (IHRDC) helps its clients to achieve a competent workforce through a deliberate Competency Management Process. IHRDC specialists review job descriptions and, in association with client personnel, prepare competency models for each job, relying on its inhouse database of generic competency models as a guide. Typically the requirements are specified at one of four increasing levels of competency, ranging from Awareness and Basic Application to Skilled Application and the highest level, Mastery.

IHRDC learning specialists can then link appropriate learning resources, such as classroom teaching, e-learning, on-job assignments or mentoring, to each competency model entry. These models serve as the foundation of employee competency assessment, with self-assessment being performed by the employee and a confirming assessment completed by his/her supervisor. If there is a deviation between these two on any competency, an audit is performed to confirm the proper level to record. New employees usually complete an intensive and organised orientation programme and at least one year of service before being asked to undertake a competency assessment. Experienced employees complete their assessments as soon as possible as part of their 'skills enhancement' process.

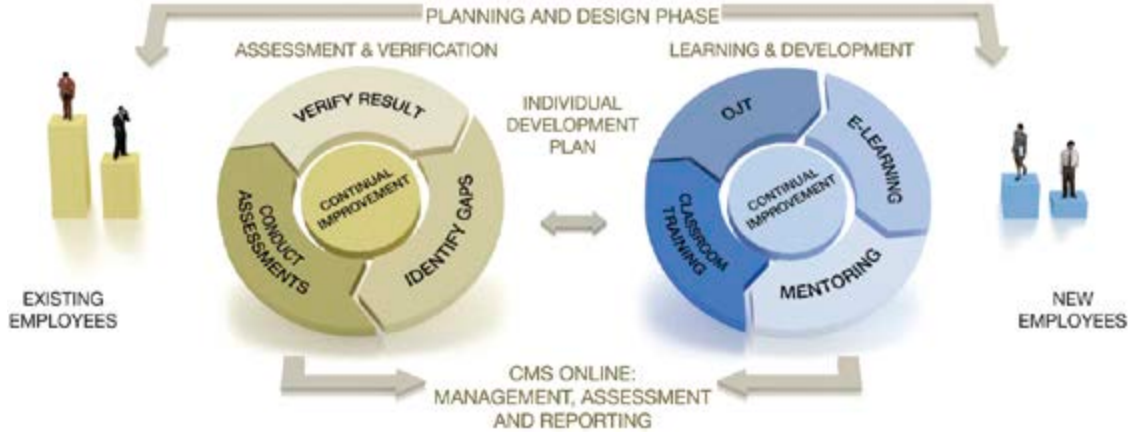
The recorded competency profile of an individual is then compared to the job competency requirements to identify any competency gaps, and training organised for the employee to achieve the required competence levels. This becomes part of each employee's Individual Development Plan (IDP) which represents a priority list of the learning that he/she must complete before the next assessment. In this way each employee, relying on his/her own IDP, moves expeditiously to become fully competent, which, in time, means that the whole workforce will achieve this goal.

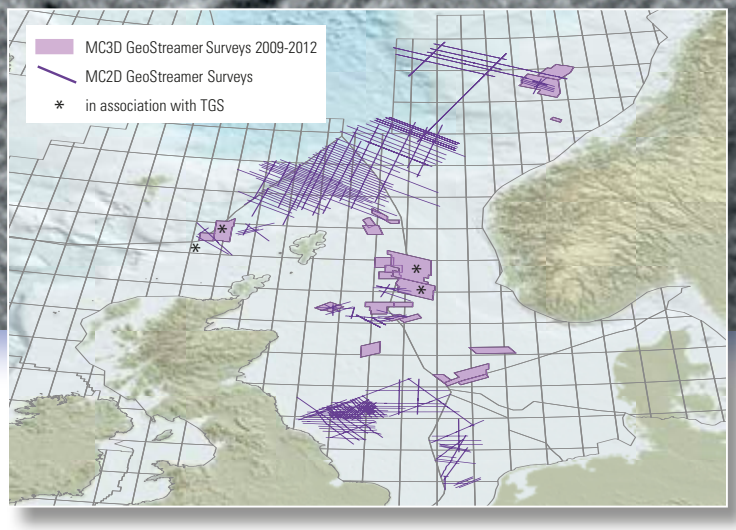
CMS Online

The foundation of the IHRDC Competency Management Process is CMS Online, a widely used and respected competency management and reporting system. It captures competency models, records the assessment process, prepares the IDPs and tracks the progress of employees as they make efforts to become fully competent. Its reporting and recording system allows management, at a glance, to monitor results on an individual or organisation-wide basis and accelerate the development of its workforce.

The efficiency of the competency management process is demonstrated by a project undertaken by IHRDC to implement a full-scale competency management system for a national oil company, using CMS Online to manage the entire process. It built competency models, managed employee and supervisor assessments, and created individual development plans for 500 employees. CMS Online housed the competency models, was used to administer assessments, store the results, and track the progress of each employee. Two years after the initial assessment, IHRDC and the company reassessed the workforce to determine the current workforce competency levels, measure its progress in eliminating competency gaps, identify the competencies that needed further development, and refine Individual Development Plans. Progress was impressive and the competencies level had increased significantly throughout the workforce.

Dr. DAVID A.T. DONOHUE, PhD, JD.





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Eastern Europe Competes with Down Under

Hungary

Hungary has invited bids from both foreign and domestic companies for seven new exploration licences, four for hydrocarbons in south-eastern Hungary near existing fields and three for geothermal exploration in the eastern and south-eastern parts of the country. The ministry said it would announce the winners within 90 days following the 15 November deadline to submit bids. The four oil and gas concessions cover a total area of 1,488 km^2 and will be valid for 20 years, while the geothermal ones last for 35 years with extensions possible. The blocks in the Szegedi Medence and Battonya areas are located in the Szeged and Bekes Sub-basins, tectonic units of the Pannonian Basin. A few other open areas already pre-selected for hydrocarbon exploration are slated for tendering at a later time, possibly by the end of 2013. The legal, financial, technical and other conditions and information relating to the tendering procedure can be found in the tender document, which may be collected at the Customer Service Office of the Hungarian Office for Mining and Geology.

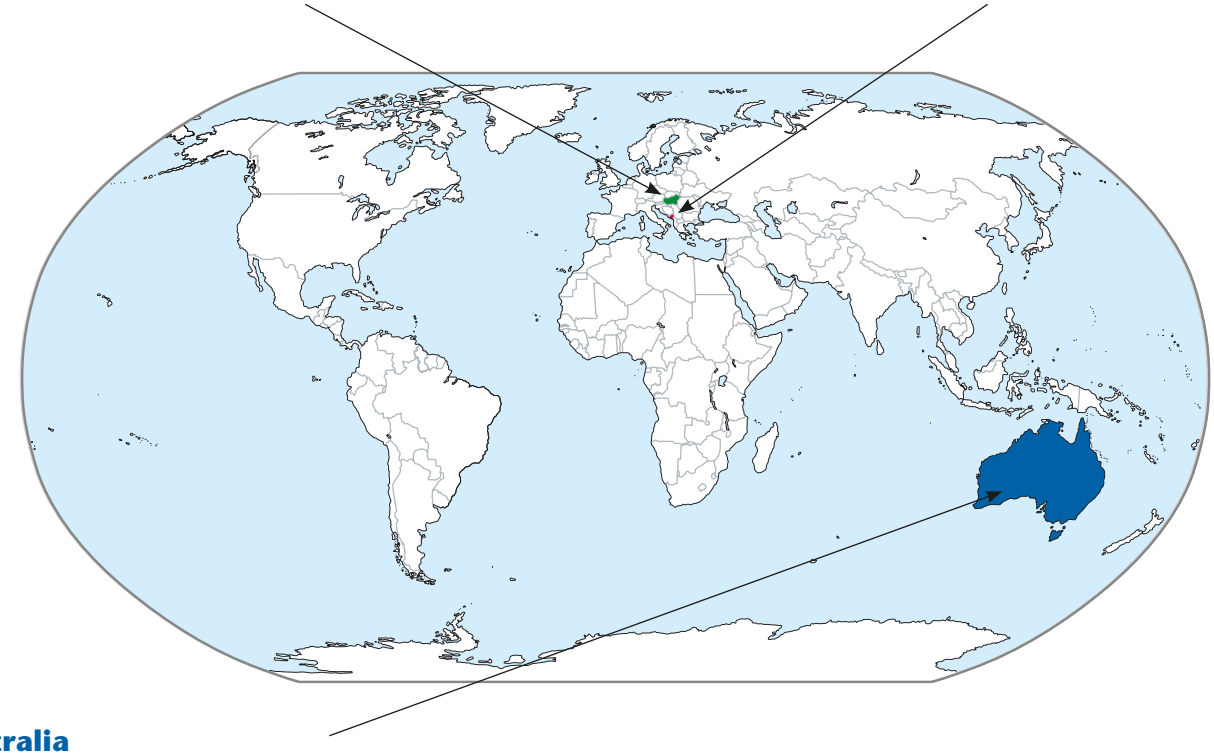
Conventional reserves of oil and gas in Hungary are negligible and have been in decline for several years and remain a major source of concern for the government, which has put considerable effort into diversifying supply options and increasing storage capabilities. The government is keen to talk up its shale gas potential as a bargaining chip in negotiations with upstream suppliers, especially Russia, although there remains the possibility that the anti-fracking movement may spread to Hungary.

Montenegro

The Ministry of Economy is inviting oil and gas companies to participate in the country's first licensing round, which will remain open for tenders from 7 August 2013 until 28 February 2014. This first bidding round inventory includes 13 offshore blocks totalling 3,191 km^2 in southern Montenegro, a completely unexplored area adjacent to the maritime border with Albania. This seems to be an opportunity with great potential, with 18 companies reported to have expressed an interest. The new petroleum law, which is a pre-requisite for launching a tender call, was prepared by the government in late 2009 and adopted by Parliament on 11 March 2010.

In the offshore area of Montenegro prospects have been identified both within the Dinarides Thrust Belt and in the adjacent Adriatic-Ionian foreland basin. Offshore Montenegro is considered an attractive exploration area and identified prospects span a wide range of stratigraphic units (see *GEO ExPro* Vol. 9, No. 5). Several Pliocene prospects, for example, have been identified at depths ranging between 700m and 1,300m in waters up to 120m. The area of these prospects is covered by 3D seismic data and the gas indicative nature allows the exploration risk to be considered as medium to low.

The tiny Balkan country, which became independent in 2006, has no oil production, but based on unprocessed and fragmented data it could cover its oil and gas needs from its own resources, according to the ministry. The need for new energy sources is acute across the Balkans, a region that has lacked investment in capacity for nearly two decades due to wars and political turmoil.



Australia

In addition to the regular acreage releases by the Federal government, the various states of Australia offer several blocks independently and often running concurrently. At this time the Federal government is offering a total of 31 blocks located offshore Western Australia, Northern Territory and Victoria. The blocks available cover a combined total area of nearly 110,000 km^2 over six basins. The bidding is closing in two tranches, as is standard with the annual Federal Acreage Release. Twenty blocks are closing in the first tranche on 21 November 2013, with the remaining eleven blocks closing on 22 May 2014. The closing dates depend on data availability over each block. A total of 29 blocks were chosen for the round based on industry nomination, with the remaining two blocks, located in the Perth Basin, nominated by Geoscience Australia.

The Victoria State Government has opened four areas as part of its 2013 acreage offer. Two onshore blocks located in the Netherby Trough have been released and a further two blocks, in the offshore Gippsland Basin within the three nautical mile limit, are also available for bidding. The government reports that a range of geoscience data is available over these blocks, which can be acquired from the Victoria Department of Primary Industries. Applications must be submitted by 21 November 2013.

The Western Australian State Government is offering seven blocks comprising six new areas as well as one re-released area, which was part of the Discreet Area Release in 2012. The seven blocks cover around 21,000 km^2 and are located in the North Carnarvon, Perth and Officer-Gunbarrel Basins. Applicants must submit a proposed work programme with any applications in the round, which closes on 14 November 2013.

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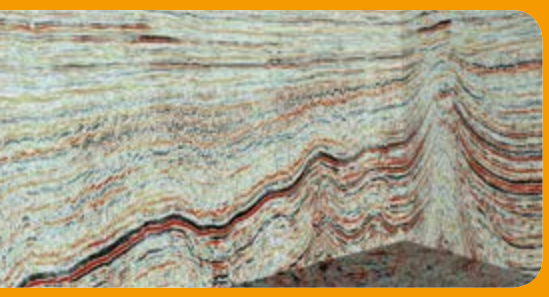
Marine Seismic



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Triple-Digit Barrel is Here to Stay

THINA MARGRETHE SALTVEDT, PH.D

Oil prices have remained stubbornly high in 2013 as growth in global supply disruptions, mainly in the MENA region, has outpaced growth in US tight oil production. Over the next year we expect the global supply/demand balance to soften and reduce upward pressure on oil prices, mainly due to growth in North American oil production and a slowdown in the Chinese economy. The risk of supply losses remains high after the resumption of unrest in the MENA region. Further supply outages may push oil prices above our forecast while a hard landing in China could cause a sharp fall.

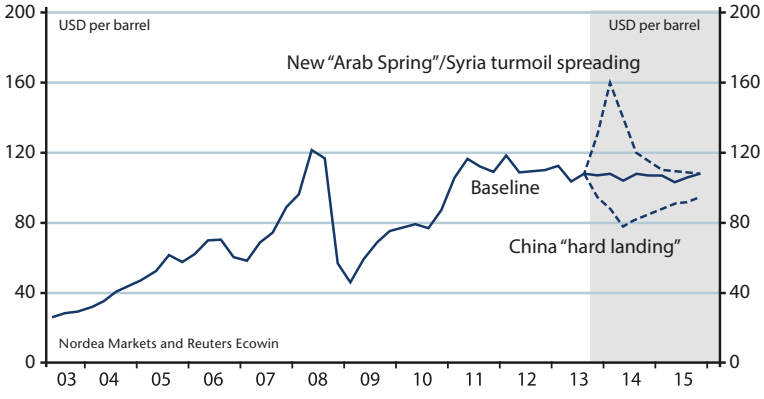
Remarkable Changes

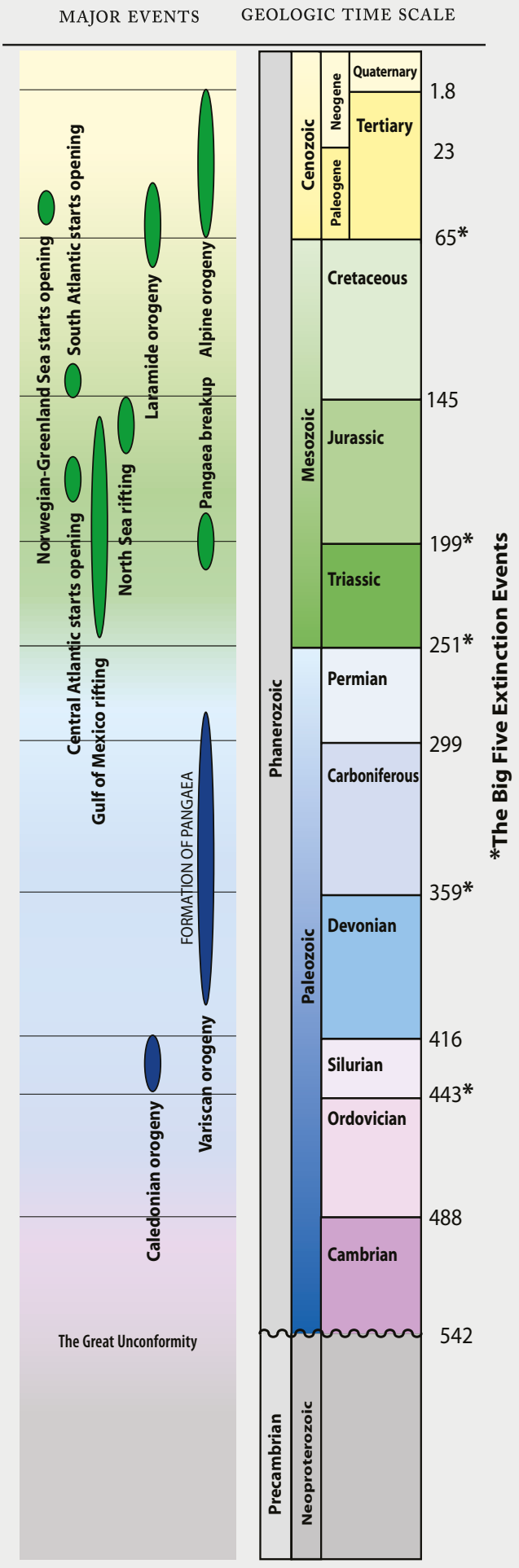
The global oil market has undergone remarkable changes in the past few years. While sustained high oil prices have triggered a surge in tight oil and oil sand production in North America, political turbulence in the Middle East has blurred the production capacity of countries such as Libya, Egypt, Syria and Iraq. The natural decline in oil production from the world's mature oil fields such as the North Sea has been replaced by oil from more expensive production areas such as Canadian oil sands and US shale oil and to a lesser extent by oil from less expensive areas like the Middle East, pushing up the replacement cost of oil over the past few years. Going forward, escalating costs are expected to be a huge challenge for capacity expansions, which in a worst case scenario can cause new projects to be put on hold if margins come under pressure or profitability is squeezed.

We expect the long-term trend for OECD oil demand to be in structural decline. Oil intensity is expected to continue to fall as high oil prices gradually make an impact on consumer choices and fuel efficiency requirements. Non-OECD oil demand is expected to surpass OECD demand before the end of 2015, driven by income growth, economic activity and population increase, especially in Asia and the Middle East. The transportation sector accounts for around 60% of total oil demand and this share is expected to rise due to increasing vehicle ownership and subsidised fuel prices in many countries. A new sulphur cap regulation within the SECA region effective from 2015 may push prices on gasoil and diesel higher as ship operators will start competing with car owners and airlines for better fuel grades.

Climate issues will move high on the agenda again before the important 2015 global climate talks. Although we do not expect major changes in investment or consumption before this meeting, the outcome could clearly change the outlook for the oil market in the longer term. ■

Oil price forecast, high- and low-price scenario.





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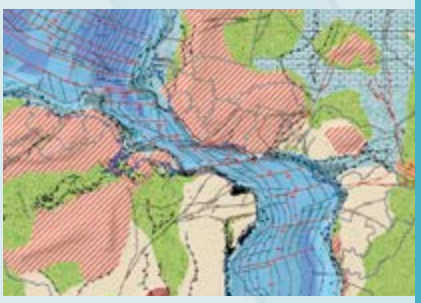

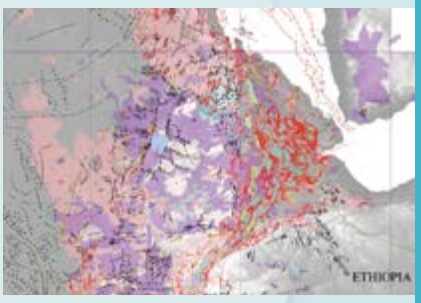

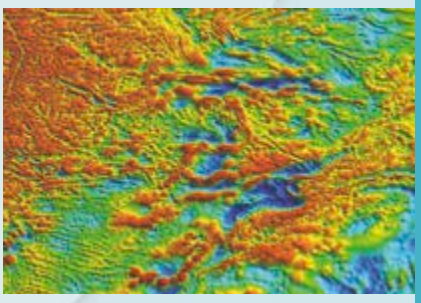

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New Levels of Collaboration

Wembley has played host to many nations – but they usually come to this famous corner of north-west London to grace the hallowed turf of the English national football stadium. On 10 September this year, however, representatives of five nations came here for a very different reason. Dolphin Geophysical, led by Ian Edwards, VP Global MC Surveys and New Ventures, and partners TGS (represented in London by Phil Slater, VP AME), came to celebrate the successful completion of their recently acquired **2D multi-client survey** of the **North West Africa Atlantic Margins (NWAAM)**. The London roadshow, mirrored by one in Houston a few days before, brought key personnel from Dolphin Geophysical and TGS together with their partners from Mauritania, Senegal, The Gambia, Guinea Bissau and Guinea Conakry to review almost 30,000 km of long-offset seismic data, with associated gravity and magnetics datasets, and to showcase the G&G study that complements the survey.

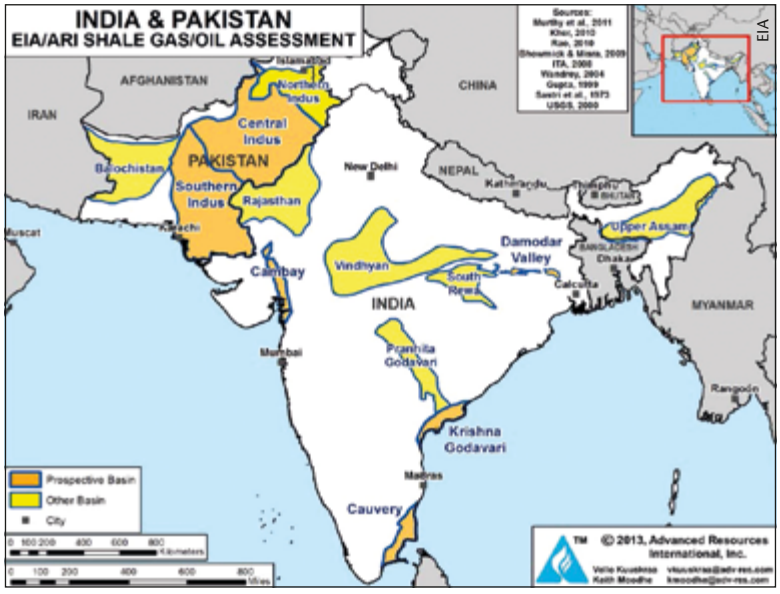
Dolphin Geophysical and TGS staff with ministerial representatives from Mauritania, Senegal, Guinea Bissau, Guinea Conakry and The Gambia.

Interpretation reports created by TGS are available, based on individual countries or the entire region. Deliverables include PSTM seismic, gravity and magnetic data, and an interpretation and prospectivity report which provides the industry with a consistent regional understanding of the area. Originally designed to help promote available acreage, these deliverables will provide an insight to potential farm-in opportunities, in a region where numerous exploration wells are scheduled over the next 18 months (*see page 98*). ■

India's Shale Resources

India's shale gas resources are primarily expected in the Cambay, Krishna-Godavari, Cauvery and Damodar Valley Basins

Despite being the world's fourth-biggest energy consumer, **India** has so far shown little interest in developing its shale gas resources, estimated by the US Energy Information Administration to be in the region of **96 Tcf**, or 26 years of demand. However, by approving a policy to allow state-owned companies ONGC and Oil India Ltd to start exploration for shale oil and gas on acreage already awarded to them, the government has begun to open the door on this resource. Between them, these companies hold 356 blocks, about half of which are thought to possibly hold shale resources. Contracts with these companies gave a broad remit to look for petroleum, which was interpreted to include unconventional resources, but the wording of contracts for blocks awarded later to non-state-owned companies specifically discuss natural gas and oil, assumed not to include shale gas. The government is looking into this discrepancy. ■



A New Era

Leading designer and manufacturer of seismic equipment, **Sercel**, has launched what it believes will lead to 'a new era in land seismic acquisition'. A large and applauding crowd gathered in front of the Sercel booth when they launched the **million channel system** at the SEG in Houston in September.

In the market today there are either real-time systems (recording the data centrally in real-time) or autonomous systems (recording remotely before transferring data to the central system). The new system has complete flexibility to be 100% real-time or 100% autonomous or any combination in between, still with real-time QC of all data. This means that it can be used in an optimal way in all environments, with zero downtime recording because of the built-in redundancy, automatic data rerouting, local data storage and testing and troubleshooting during production. The new system, 508^{XT}, is powered by cross-technology (X-Tech™), as it combines the best of cabled and wireless technologies. It includes the new lowest noise sensor, QuietSeis™, and features a scalable central unit, significantly fewer batteries, low weight and low power usage, thereby reducing crew numbers required. ■

508 XT is Sercel's new cross-technology powered land seismic acquisition system, driving productivity, data quality and adaptability to a new level. With its new architecture, X-Tech™, 508 XT offers the most productive balance between real-time data and autonomous modes.

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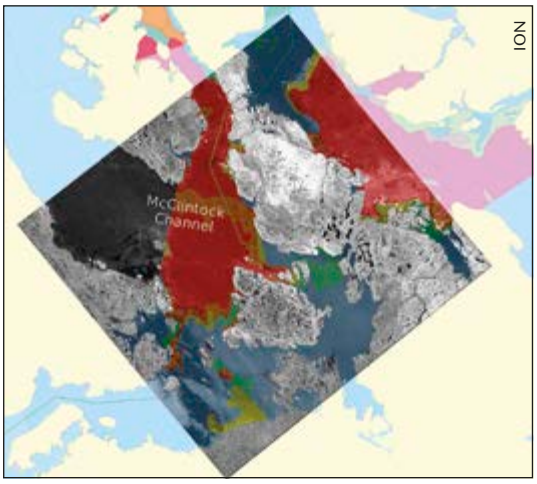
Exploring the Arctic

The Arctic could contain up to 25% of the world's undiscovered hydrocarbon resources – but in some of the harshest and most inhospitable conditions known to man. One of the greatest hazards to companies prospecting for and producing hydrocarbons is the formation and unpredictability of ice.

With this in mind, **ION Geophysical Corporation** has launched the first fully integrated ice management system designed to reduce risk and improve efficiency in seismic data acquisition and drilling operations in or near ice. Known as **Narwhal**, the system gathers, monitors, and analyses data from various sources, including satellite imagery, ice charts, radar, manual observations, wind, and ocean currents. From this information, operators can forecast, track, monitor and predict ice movements and make informed decisions to improve efficiency and minimise risk for a range of operations, from vessel routes and optimising seismic acquisition to maximising the operating window for drilling. ION began working in the Arctic in 2006, and since then it has obtained about 65,000 km of seismic data, including over 30,000 acquired under the ice, giving the company a unique understanding of this challenging environment. ■



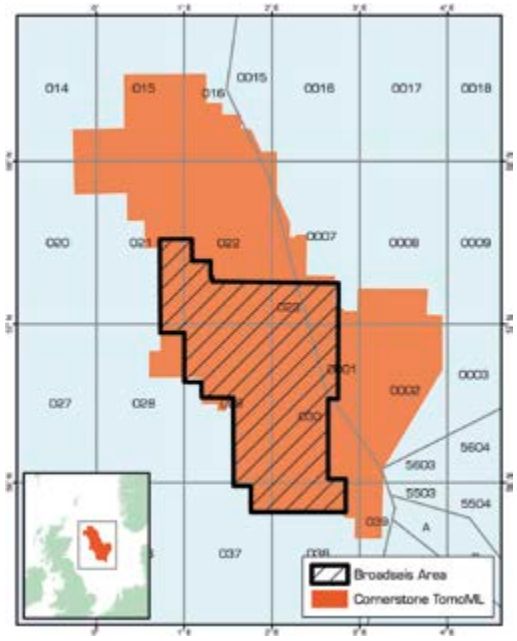
Narwhal is currently in commercial use in the Canadian Northwest Passage

Record Investment

Investment in the offshore oil and gas industry in the **UK Continental Shelf** reached an all-time high this year, according to **Oil & Gas UK's 2013 Economic Report**, with £13.5 billion being invested. Renewed commitment by the government has been in part responsible for this, in particular new tax allowances which have boosted investment in production by £6 billion since the beginning of 2012, while confirmation of tax relief on decommissioning has also been welcome, and as a result, exploration activity has increased. However, the report comments on the decline in production efficiency of existing assets. Annual production declined by 14.5% to 1.54 MMboepd in 2012, and only nine new fields, with total reserves of 146 MMboe, began producing, although 15 fields, with combined reserves of 470 MMboe, should come onstream in 2013. If the current rate of investment is sustained, the UKCS should be able to satisfy up to 50% of the UK's total demand for oil and gas in 2020. ■

CGG Re-Imaging North Sea Data

Leading geoscience company CGG has recently started re-imaging its Central North Sea '**Cornerstone**' dataset to create a 35,000-km^2 contiguous broadband PSDM volume. The existing conventional north-south long-offset data will be reprocessed with a deghosting technique to produce an extended-bandwidth dataset which will complement the company's BroadSeis™ true broadband east-west coverage. CGG's next-generation multi-layer tomography, Tomo^{ML}, which will incorporate the latest 3D tomographic shallow channel inversion techniques, will be used to deliver a high-quality PSDM product. The Cornerstone project will provide oil companies with access to a huge volume of state-of-the-art broadband data, of which approximately 8,500 km^2 will be dual-azimuth, focused on the High-Pressure/High-Temperature area of the Central Graben of the North Sea. ■



Bigger Than Ever!

PESGB and DECC bring you **PROSPEX 2013**, the 11th show in their highly successful series of Prospect Fairs – the UK's leading networking event for exploration and development. The show has gone from strength to strength; in 2012 there were over 70 exhibitors and 798 attendees, in addition to a full two-day programme of 'prospects to go', overviews from government and presentations by explorers and consultants. This year the show is looking to be even bigger. Here are what some attendees and exhibitors said last year:

"PROSPEX is the industry benchmark conference, where you meet all the right people;" "This show always has a buoyant and optimistic mood;" "The exhibition was a constant hum of activity!"; "A yardstick for activity within a region."

If you want to see what all the talk is about, registration is now open and includes admission to the exhibition and conference, all-day refreshments, luncheon and a networking wine reception – head to www.pesgb.org.uk for more details. PROSPEX 2013 runs 11–12 December 2013 at Business Design Centre, Islington, London. ■

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Jurassic Reservoir Systems of the Central Caspian

GRAHAM BLACKBOURN
Blackbourn Geoconsulting

The Mesozoic Central Caspian province lies between the great hydrocarbon provinces of the South Caspian Basin and the Precaspian Basin. We take a look at the petroleum systems of this underexplored area.

Figure 1: *Limestones of the Middle Triassic Khozbulak Suite near Doshan, outcropping on the north side of the East Karatau ridge, western Kazakhstan. These limestones, deposited on a restricted marine shelf, comprise the main oil source rock across a wide area of the Central Caspian province. The inset is a close-up view of one of the individual limestone beds. Where fractured or dolomitised, these limestones (together with Triassic sandstones) also form reservoirs, although the Triassic reservoirs tend to be compartmentalised, and the most productive fields occur where hydrocarbons have migrated into the overlying Jurassic and Cretaceous.*

The Caspian Sea accommodates three major petroleum systems. The North Caspian Basin lies on the southern flank of the Precaspian Basin, where giant oil and gas fields such as Kashagan (up to 13 Bbo recoverable, *see page 52*) and Astrakhan (<100 Tcfg) occur within Devonian and Carboniferous carbonate build-ups overlain by Lower Permian salts. The main source rocks here are Late Devonian 'Domanik' shales. In the South Caspian, Lower Pliocene clastic reservoirs sealed by intraformational and Late Pliocene mudrocks host numerous large fields such as ACG (the Azeri-Chyrag-Guneshli group; 5-6 Bbo) and Shah Deniz (40 Tcfg).

Between these two hydrocarbon provinces, both in terms of geography and the age of the petroleum systems, lies the Central Caspian province. Blackbourn Geoconsulting has worked on the petroleum systems of the Greater Caspian region for over 20 years. Here, we outline the large-scale depositional systems responsible for the Mesozoic Central Caspian hydrocarbon province, from the Caucasus and Precaucasus in the west to western Kazakhstan and Turkmenistan in the east, concentrating on the Jurassic. Our work in the Central Caspian province has been greatly enhanced by numerous field studies undertaken in the Karatau hills of western Kazakhstan, and in Mesozoic (and other) outcrops of the Caucasus in Russia, Azerbaijan and Georgia and the Kopetdag Basin of western Turkmenistan. Examples are provided of how fieldwork, combined with information from the extensive, but often hard-to-obtain, Russian-language geoscience literature, has assisted in developing these models.

Sub-Mesozoic Basement

The basement comprises a mosaic of microcontinental blocks which consolidated during the late Palaeozoic and now extends westwards as the Scythian Platform, and eastwards as the Turan Platform. This Palaeozoic basement is blanketed by younger

Graham Blackbourn

sediments, and its formation, including successive periods of accretion, rifting and strike-slip tectonism, is poorly understood. Figure 2 presents a conceptual model for the development of the Scythian and Turan platforms (and the Precaspian Basin) during the late Palaeozoic which is broadly consistent with most of the available evidence, although considerable uncertainty remains.

The Caspian Sea itself is a relatively recent accident of geomorphology which has little geological significance, apart from in the south. In referring here to the Central Caspian region, we mean those parts of the Scythian and Turan platforms beneath, and to either side of, the present Caspian Sea.

Permo-Triassic Rifting

Northward subduction of Palaeo-Tethys beneath the Central Caspian region during the Permo-Triassic (Figure 2D) created crustal tension, with the formation of linear rifts such as the Manych Trough in the Precaucasus and the Karatau rift in western Kazakhstan. Throughout the Triassic these rifts lay within a wider area of gradual subsidence centred on the present Northern and Central Caspian, and this sedimentary basin was at times isolated from Tethys by the volcanic arc which separated them. Mid-Triassic organic-rich limestones which accumulated within this basin comprise the most important oil source within the Central Caspian region (Figure 1).

Palaeo-Tethys closed at the end of the Triassic when the Cimmerian continent (actually a collage of separate terranes) collided with the south Eurasian margin. The resulting Early Cimmerian orogen was short-lived but intense in the Caspian region. Uplift was particularly marked within the Karatau rift, where sinistral transpression resulted in inversion and intense deformation of the rift fill. A near-complete succession of Late Permian to Late Triassic sediments is now exposed within the former rift zone, unconformably onlapped by a similarly complete and beautifully exposed Early Jurassic to Miocene succession. The entire stratigraphy has been studied in some detail by Blackbourn Geoconsulting during many field excursions since 1994.

Major River Systems

Sometime after Palaeo-Tethys closed, the Neo-Tethys Ocean to the south of Cimmeria began to subduct northwards beneath Eurasia, leading to the collapse of the Early Cimmerian orogen. The present Great Caucasus mountain range became the site of a deep rift during the Early Jurassic, the Great Caucasus Basin (GCB). At this time the Central Caspian area comprised a gently undulating subaerial plain. Fluvio-lacustrine and coal-swamp deposits accumulated within small isolated basins.

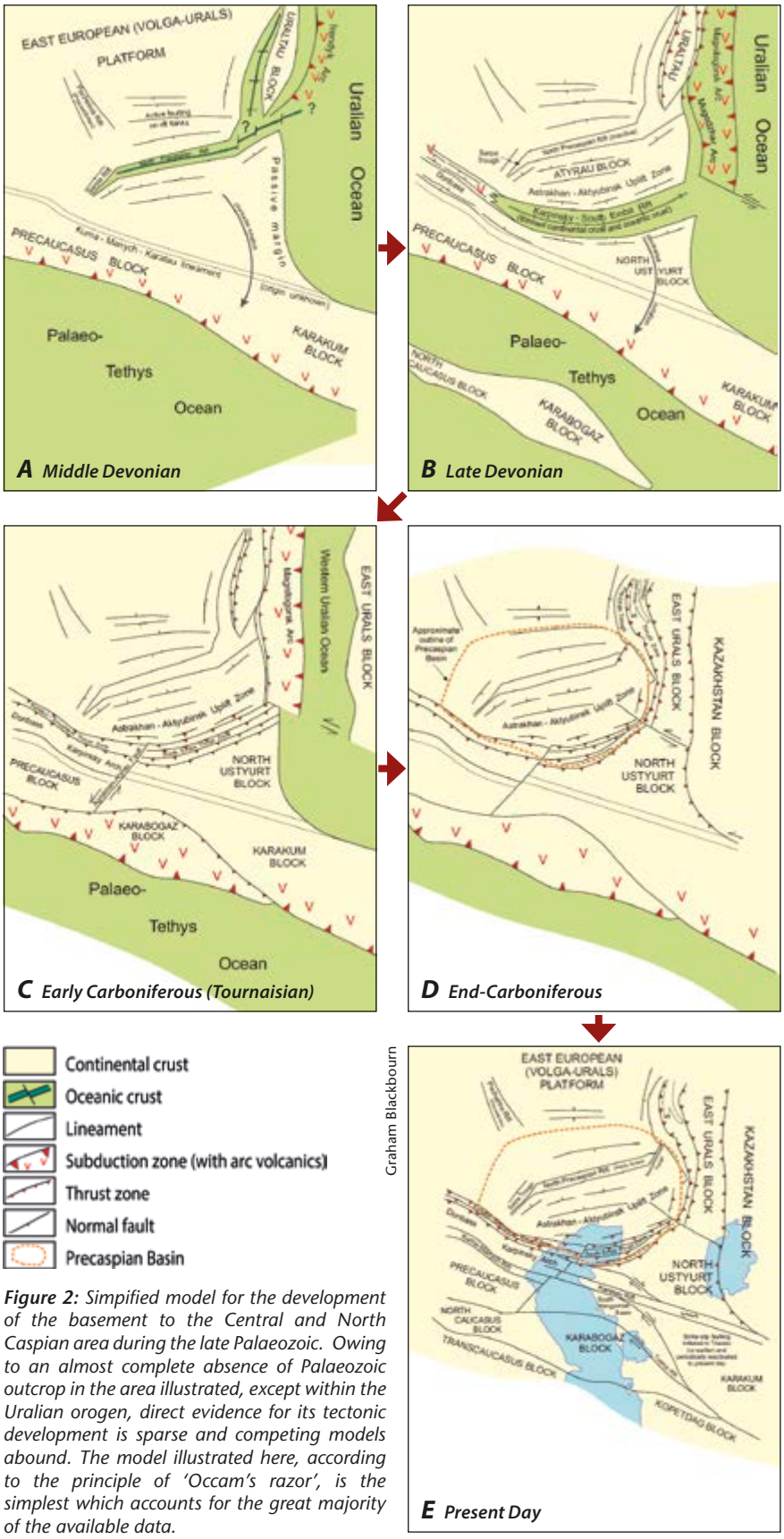

Figure 2: Simpified model for the development of the basement to the Central and North Caspian area during the late Palaeozoic. Owing to an almost complete absence of Palaeozoic outcrop in the area illustrated, except within the Uralian orogen, direct evidence for its tectonic development is sparse and competing models abound. The model illustrated here, according to the principle of 'Occam's razor', is the simplest which accounts for the great majority of the available data.

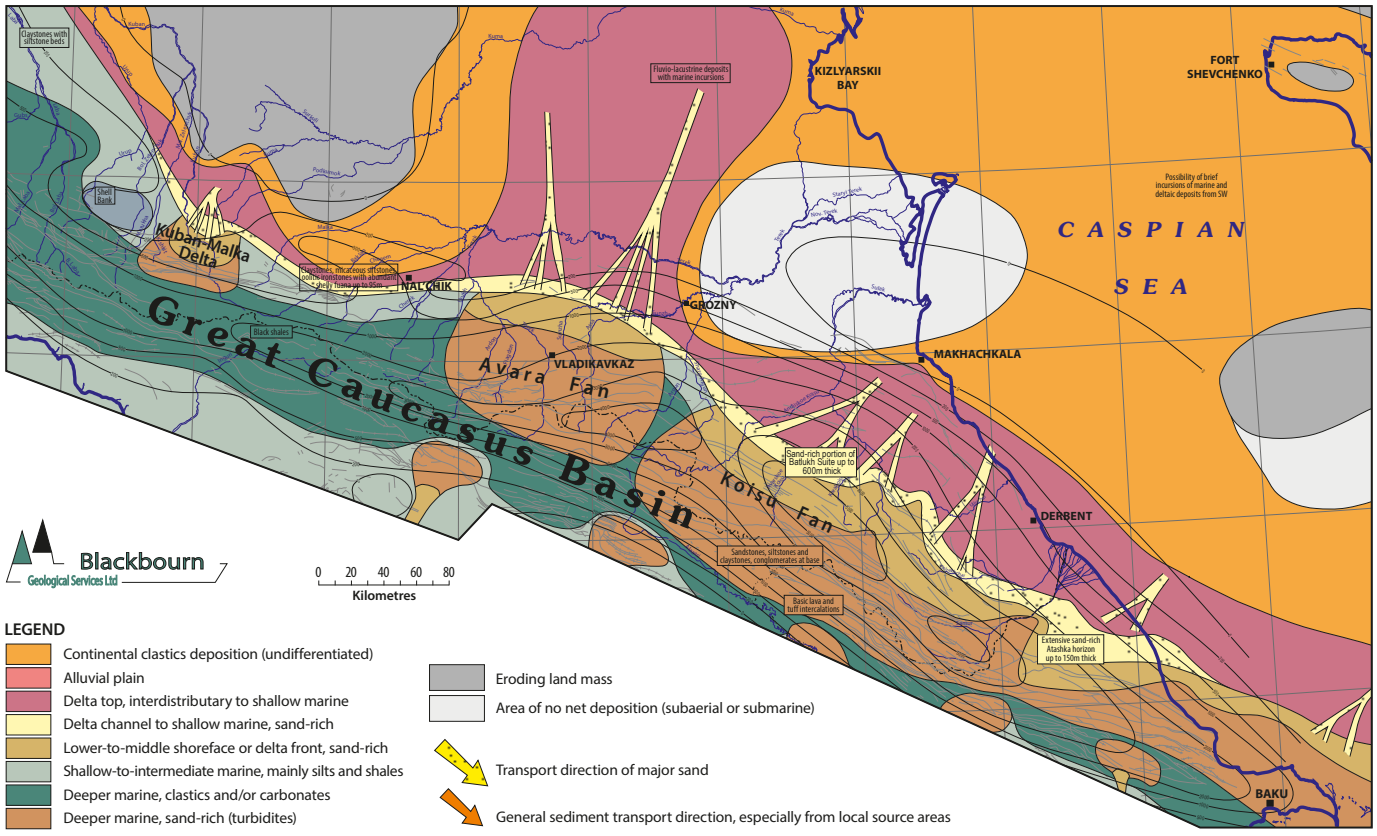

Figure 3: *Palaeogeographic map of the Great Caucasus Basin and west-central Caspian during the Early Aalenian (earliest Middle Jurassic). (Map has not been palinspastically restored, and prior to the considerable Cenozoic shortening, the GCB would have been almost twice as wide.) A massive deltaic to deepwater fan system accumulated along the north-eastern margin of the basin during the Early Jurassic, with up to 9 km of sediment, fed by major rivers from the north-east. By the Middle Jurassic the delta system began to be abandoned, as rising sea levels led to most of the sediment being deposited farther to the north-east closer to the source areas (Figure 4). A period of sea-level fall during the Early Aalenian, however, led to short-lived reactivation of the system, with high-energy reworking of sands along a narrow coastal strip, shown here in pale yellow. This corresponds with the Atashka horizon, the oldest known hydrocarbon-bearing unit in Azerbaijan.*

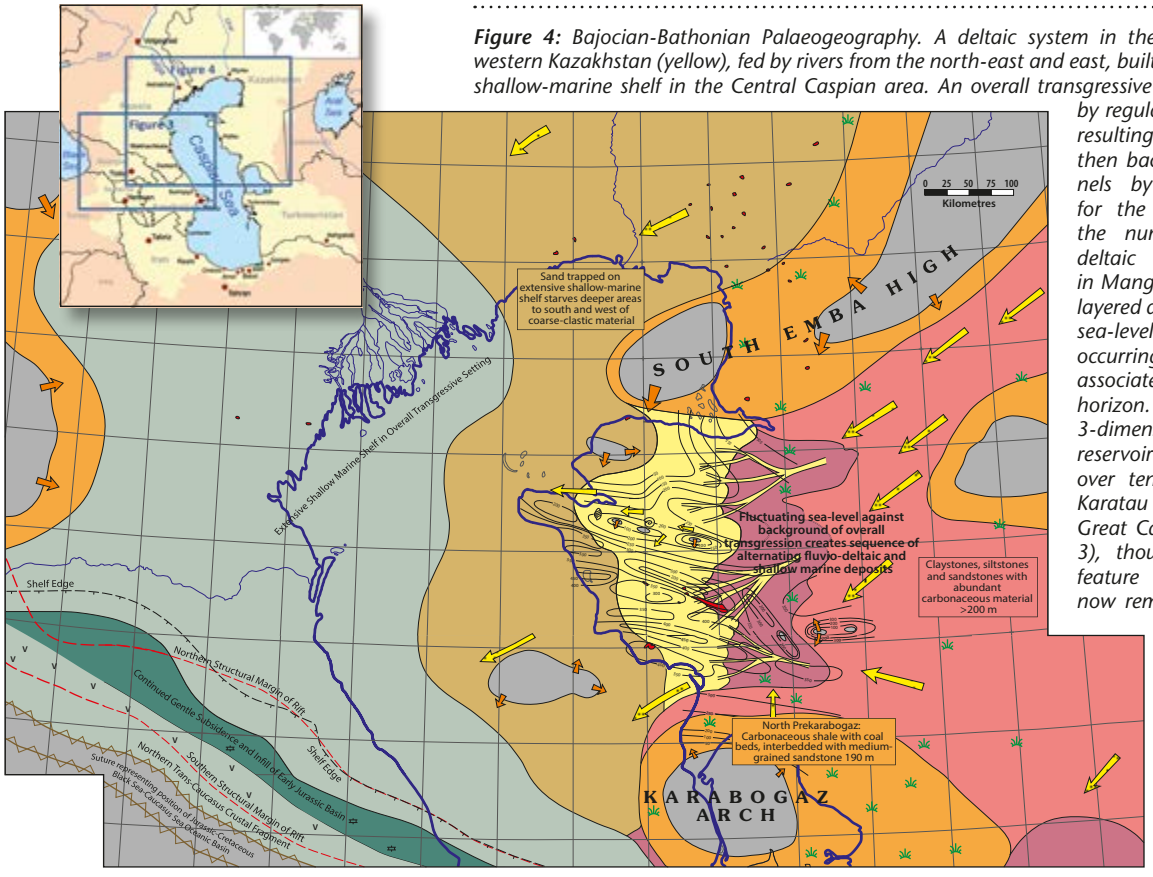

Figure 4: *Bajocian-Bathonian Palaeogeography. A deltaic system in the Mangyshlak region of western Kazakhstan (yellow), fed by rivers from the north-east and east, built out onto a low-gradient shallow-marine shelf in the Central Caspian area. An overall transgressive regime was punctuated by regular cycles of sea-level fall, resulting in repeated ravinement, then backfilling of incised channels by sand. This accounts for the observed geometry of the numerous Jurassic fluvio-deltaic hydrocarbon reservoirs in Mangyshlak, which are multi-layered as a result of the repeated sea-level cycles, the best reservoirs occurring within incised channels associated with each reservoir horizon. Beautifully exposed 3-dimensional examples of this reservoir geometry can be traced over tens of kilometres in the Karatau hills of Mangyshlak. The Great Caucasus Basin (cf. Figure 3), though still a topographic feature on the sea bed, was now remote from any source of coarse sediment. It underwent an episode of partial inversion and erosion during the Bajocian before returning to slow subsidence.*

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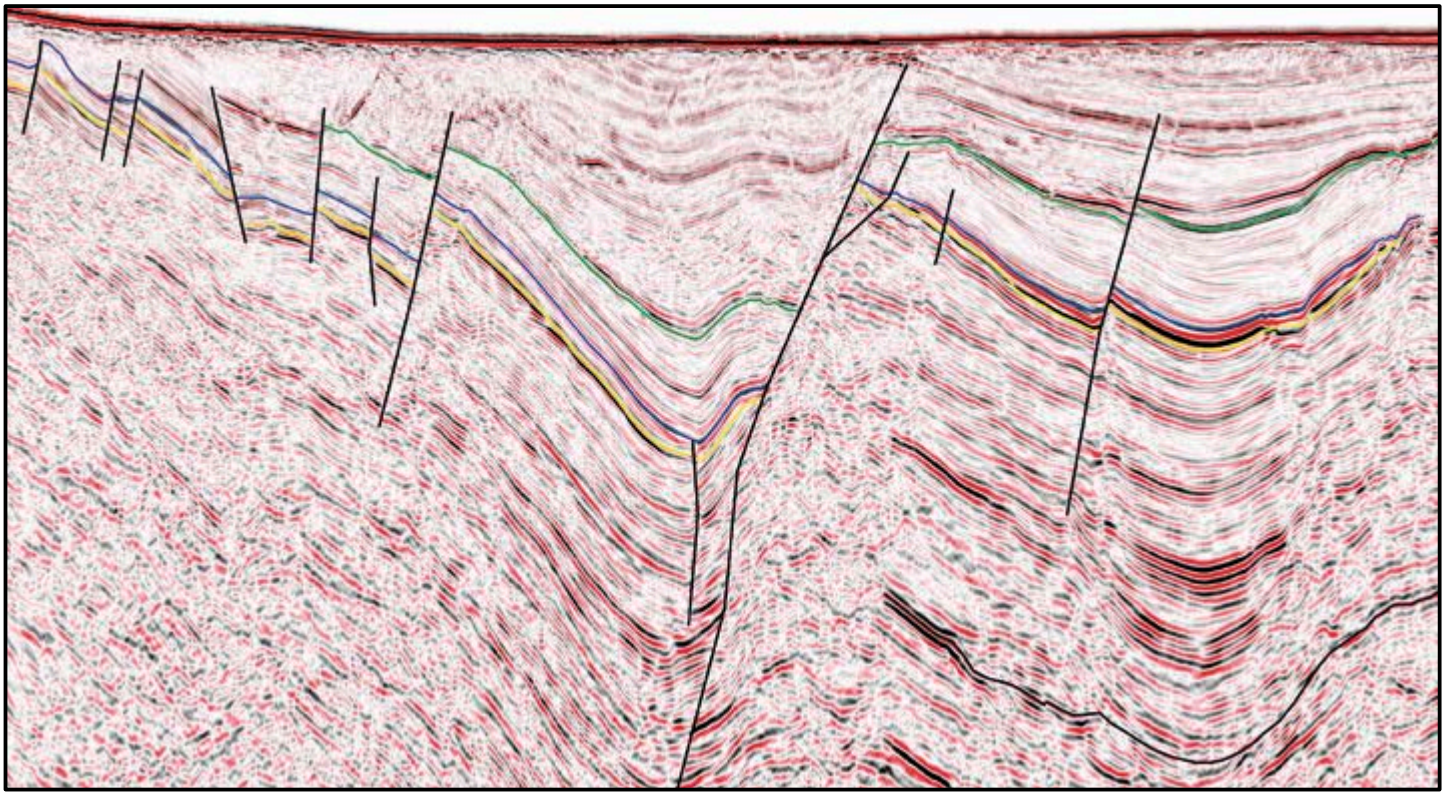

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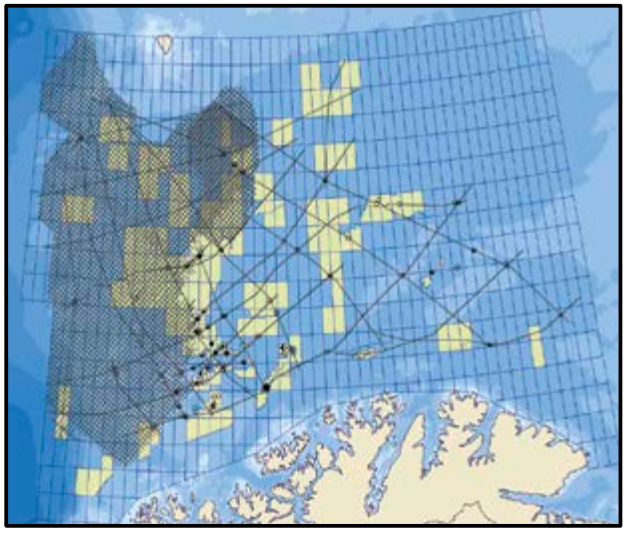

For more information please contact per.dahl@mcg.no

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In time a major river system developed, transporting sands from the Southern Urals 1,500 km to the north-east, across western Kazakhstan and towards the GCB, where they passed through a series of deltas culminating in deepwater fans along the north-eastern margin of the basin (Figure 3). The rivers also transported sediment from more localised sources, such as the South Emba High and Karabogaz Arch, as they flowed across western Kazakhstan. Tributaries drained the southern part of the Precaspian Basin in the north.

Initial rifting within the GCB ended with a brief compressional episode during the Bajocian, although the basin experienced later phases of reactivation and long-term thermal and load-related subsidence. Active extension shifted to a newly-developing rift immediately to the south. Unlike in the GCB, oceanic crust formed within this southern basin during the Middle Jurassic, some of which survives at considerable depth as the basement of the present South Caspian Basin.

Rising Jurassic sea levels led to a gradual marine transgression. The shoreline shifted across the Central Caspian from south-west to north-east, reaching Mangyshlak in western Kazakhstan during the Bajocian and Bathonian. The fluvio-deltaic to shallow-marine sandstones form major reservoirs in the area, such as in the Uzen field on the northern flank of the South Mangyshlak Basin, with an estimated 8.4 Bbo initially in-place. Such reservoirs are characteristically multi-layered, with the best qualities seen within channelised deposits. Typical reservoir geometries are clearly observed within outcrops in the Karatau hills (Figures 4 and 5).

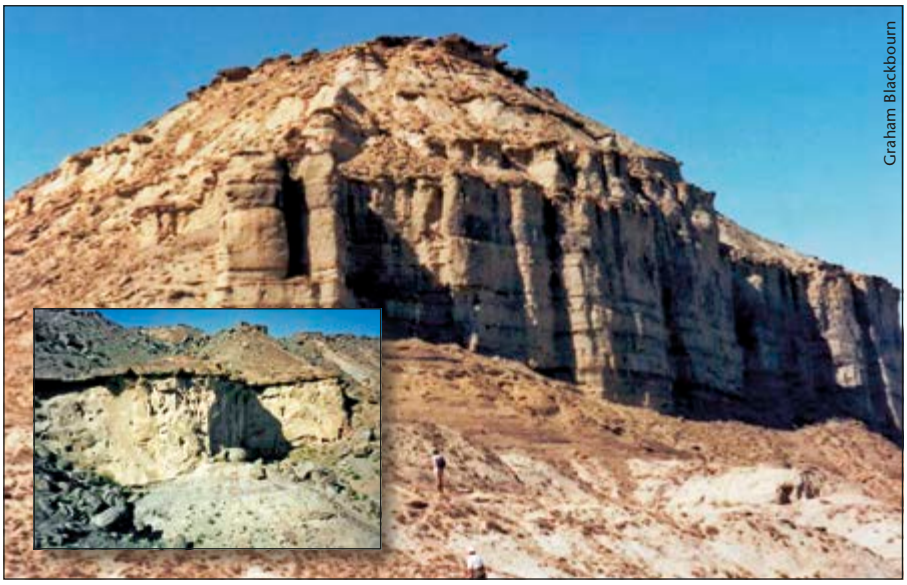


Figure 5: *Middle Jurassic of the Karatau hills. The main picture shows Mount Karadiirmen, the type section of the Bajocian-Bathonian Karadiirmen Suite, which is the reservoir for many of the major oil fields of western Kazakhstan. Cemented 'caps' (such as that at the summit of the hill, with several more visible in the slopes) represent short-lived periods of sea-level fall during accumulation of this fluvio-deltaic succession (Figure 4). Associated channel incision and later backfilling gave rise to thick channelised sands, such as the 13m thick body illustrated in the inset. Three-dimensional exposures of these Jurassic rocks (and the overlying Cretaceous) can be followed for tens of kilometres, providing excellent examples of reservoir geometry.*

Jurassic Shelf Carbonates

Further sea-level rise during the Late Jurassic led to a shallow-marine shelf extending over much of the Central Caspian region, on which both clastics and carbonates accumulated. Renewed tectonic activity was probably associated with the collision of continental blocks against the Eurasian margin far to the south-east. Relative uplift of the western part of the Karatau rift zone recommenced, with erosion of parts of the Middle Jurassic, although moderately deep-marine Late Jurassic mudrocks are preserved locally in the east beneath the base-Cretaceous unconformity.

Late Jurassic shelf carbonates form an important oil and gas reservoir in Mangyshlak and the Central Caspian. They are not well-developed in the Karatau hills, where the Upper Jurassic is clastic-dominated and affected by numerous unconformities and disconformities, although well-exposed Early Cretaceous limestones provide a fair analogue. Superb exposures of Late Jurassic carbonate-shelf deposits do however occur in the North Caucasus, such as the Skalistyi Ridge in the Baksan valley of the Central North Caucasus, where Oxfordian shelf carbonates are overlain by cliffs of Early Cretaceous (Valanginian) limestone. These exposures were visited by Blackbourn during the early 1990s, although extended visits to the area are now difficult owing to security concerns.

Elsewhere, such as in the Terek-Caspian Basin of the eastern Precaucasus and in the GCB, renewed basin subsidence in a carbonate setting led to the development of basin-fringing reefs. Thick evaporites developed in several of the basins, including Terek-Caspian, and localised evaporites are known in the South Mangyshlak Basin, while the GCB remained a reef-fringed open-marine basin.

Geological research during the Soviet era tended to be compartmentalised within narrow geographical limits. As an example, geologists working in the Caucasus asserted that the huge Jurassic delta-fan system on the north-eastern margin of the GCB was sourced from a (notional) Central Caspian Arch, while Kazakh geologists envisaged the contemporary fluvial system of Mangyshlak as flowing south-westwards into the Caspian Sea. The institutional set-up was not capable of linking these two sets of observations. The wealth of Soviet and more recent geological literature from the local area, with added context and detail from field studies, has enabled the sedimentological and tectonic background to the various petroleum systems of the Greater Caspian region and other parts of the former Soviet Union to be more clearly understood.

Acknowledgements

This article is a brief summary of some of the work carried out by Blackbourn Geoconsulting over more than 20 years. In addition to the fieldwork undertaken, it draws heavily on contributions from Russian-language authors, far too numerous to acknowledge here. Conversations with very many clients and co-workers have also been of considerable assistance, though care has been taken to exclude any proprietary information from this account (which would have required some slight adjustments to the maps provided, but not of regional significance). For all of this the author is enormously grateful. ■

THE UNITED REPUBLIC OF TANZANIA

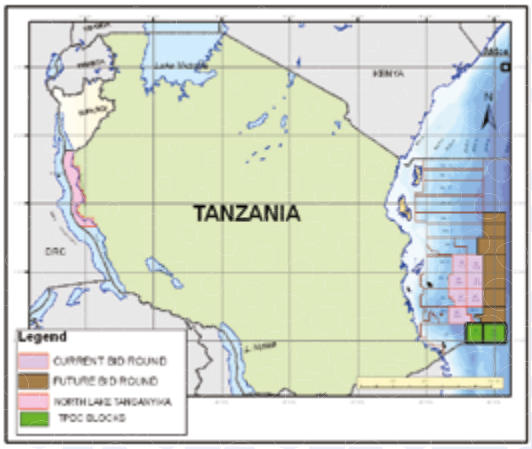
Announcing the 4th Tanzania 2013 Licensing Round

Deep Offshore | North Lake Tanganyika

The Government of the United Republic of Tanzania through Tanzania Petroleum Development Corporation (TPDC) is pleased to announce the 4th Tanzania Deep Offshore and North Lake Tanganyika Licensing Round. The delayed 2012 round will now be launched during the 2nd Tanzania Oil and Gas Conference and Exhibition.

When:	**Friday, 25 October 2013**
Where:	**Mwalimu Nyerere International Conference Centre** **Dar es Salaam, Tanzania**
Round Close:	**Thursday, 15 May 2014, Dar es Salaam**

4TH TANZANIA OFFSHORE AND NORTH LAKE TANGANYIKA LICENSING ROUND



The round includes the deep offshore sedimentary basins comprising of seven blocks (averaging 3000 sq km: Blk4/2A, Blk4/3A, Blk4/3B, Blk4/4A, Blk4/4B, Blk4/5A, Blk4/5B) and is located between 2000 m to 3000 m of water depths from 40°30'E to 41°40'E and 7°30'S to 9°00'S. Blocks 4/1B and 4/1C are reserved for the TPDC to execute exploration using a strategic partner. The blocks have excellent coverage of modern regional 2D seismic data available from ION Geophysical and WesternGeco.

The North Lake Tanganyika block is located offshore in the western arm of the east African rift system. Lake Tanganyika is the world's longest (650 km) and second-deepest (1500 m) and is covered by sparse 2D seismic data collected in the 1980s during the African Lakes Drilling Project. The data and copy of report will be made available.

Tanzania Petroleum Development Corporation

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Gaining a Regional Perspective

Graham Blackbourn

What has happened in recent years in the Caspian region, how has it changed – and what is preventing companies from operating here?

EUGENE PETROV, NIKOLAY AMELIN
Geology Without Limits

Looking out through a hollow in the hill-capping basal-Cretaceous sandstones of Kulmambiot, on the northern side of the West Karatau ridge in the Mangystau oblast of western Kazakhstan. The Triassic hills on the skyline form the uplifted core of the ridge.

In 2010, the international scientific consortium Geology Without Limits was established to study the development of new geodynamic models of sedimentary basins (see *GEO ExPro* Vol. 9, No. 3). One of its founding principles is that geology knows no political boundaries – and a new study of the Caspian region found some interesting obstacles to overcome.

Relying upon the experience of many years in conducting international programmes in offshore areas of various states, the organisation has identified several factors restricting regional geoprospecting operations in marine offshore areas which are especially relevant in the Caspian Sea. These include political, geographical and geological limits, as well as economic and financing issues and the gap in technological know-how between countries. These challenges are compounded by the complex and lengthy process of coordinating the work scope and obtaining permissions from various governmental and supervisory agencies, which often leads to derangement of time schedules and work performance.

Many world giants of the petroleum industry, such as Schlumberger and BP (Anglo-Persian Oil Company), started out in the Caspian region, and by the beginning of the 20th century it was the centre of petroleum geology, with the world's best geologists and the latest technologies involved. Hydrocarbon resources were a powerful catalyst in the development of this region, yet now these same hydrocarbon resources are the main obstacle to progress. The region of the Caspian Sea always was a complex and inextricable tangle of contradictions between participants in activities in this region; after discovering mineral resources, especially hydrocarbons, relations became yet more strained.

Let's look at these issues in more detail and work out what is preventing companies from operating in the Caspian.

Territorial Disputes

The territory of the Caspian region is under the jurisdiction of the five Caspian States: Russia, Kazakhstan, Turkmenistan, Azerbaijan, and Iran. The state borders between the countries are not consistent with the natural limitations which determine petroleum geological and landscape-climatic zonation, like geological features, geodynamic and morphological structures or fluid systems. This dramatically complicates efficient use of natural riches in the region and the solution of environmental problems.

Since the breakup of the USSR, the main barrier for conducting regional operations has been the partition of the Caspian Sea, which, as an inland water body, is not automatically subject to the international law of the sea. Territorial disputes and different approaches to the principles of delimiting the water and air space remain the main impediment to solving the status of the Caspian Sea. The issue is vital as not only use of its bioresources depends on it, but also its hydrocarbon riches and their protection and exploitation. Only three coastal states – Russia, Kazakhstan and Azerbaijan – have signed an agreement on delimitation of the seabed, partitioning 64% of the Caspian, so Kazakhstan obtained 27%, Russia 19%, and Azerbaijan 18%. For Iran, a share of 14% is suggested, but Tehran, supported by Turkmenistan, lays claim to 20%, transferring the boundary 80 km north of the line along which the Iran-Soviet maritime boundary was drawn.

Depending on how the Caspian Sea is divided, the amount of hydrocarbon resources falling to the share of individual countries changes significantly. The value in dispute is high, especially for Iran, with estimates of oil and gas resources differing by 150% for the country, depending on the division used. As a result of these disputes over territorial limits, there have been displays of military force and military exercises by the states in the Caspian Sea, giving rise to concerns about the destiny of the region.

The unsolved legal status makes it impossible for companies to conduct regional investigations or to invest in geoexploration operations on known fields. A solution is only possible with the involvement of the five Caspian states and through the development of mutually profitable scientific regional programmes in the Caspian Region.

Geology Without Limits has the support of all the Caspian states for the new regional programme. All the geological services of the countries in question are extremely interested in new regional data which will make it possible not only to reconsider the structures of the existing fields but also to reveal new prospects.

Extending the Boundaries

The issues affecting geographic limits are a lack of scientific cooperation, plus outdated geological information, not compliant with contemporary technical standards and often contradictory.

Most regional geoprospecting operations were conducted during the time of the USSR, when the foundations for the key concepts of the regional structure of the Caspian region were identified. After the breakup of the USSR, for economic and political reasons, the newly formed independent states did not give due consideration to regional investigations, leaving subsurface users to rely either on new data obtained within a particular field, or on old regional data. The exchange of new data among state geological institutions and the reconciliation of models practically ceased, resulting in the

Caspian State	Length of Coastline km	Bboe 'International Lake' Rules	Bboe 'Enclosed Sea' Rules
Russia	695	14.67	17.16
Azerbaijan	850	29.33	20.83
Kazakhstan	2,320	33.00	20.83
Turkmenistan	1,200	11.00	15.69
Iran	900	3.67	14.23

Distribution of hydrocarbon reserves depending on legal status of the Caspian Sea.

The seat of the trouble – territorial disputes

emergence of a multitude of unilateral geological models discordant with each other. This fragmentation gave rise to uncertainty over the prospectivity of the Caspian region.

All geologists now admit that a region should not be limited by political and geographic boundaries and any basin should be investigated as an organic entity. In the last decade, many leading geologists have come to understand that the Caspian region has been subject to recent sedimentation inside the Caspian catchment basin, which comprises the Caspian Sea offshore area, the Precaspian Lowland, the Ustyurt Plateau, and the lowland plains of western Turkmenistan and Azerbaijan.

However, taking into consideration that this region could be a main source of hydrocarbons for Western and Eastern Europe, the boundaries could be considerably extended. They should be drawn along the perimeter of the petroliferous sedimentary basins of Palaeozoic and Meso-Cenozoic age that are situated inside the major area of downwarping of the basement in the central sector of Northern Peritethys (at the periphery of the East European Palaeozoic continent exposed to the Palaeo-Tethys ocean).

Location of assessment units (AU) in the Caspian Sea area; as can be seen, the basins of the Caspian area do not follow geographical boundaries – nor should research.

A solution to the problem of discordance in the models in the Caspian countries and extension of the limits of investigation is only possible through international cooperation based upon new regional data, relying on all exploratory work undertaken during the latest decades.

Sharing Financial Burden

Any major project is underlain by an economic justification. Conducting a regional investigation will require coverage of the entire basin as a single entity; the countries of the Caspian do not conduct regional surveys within their respective offshore areas, partly because of the cost, but also due to the futility of such surveys over small areas. Fulfillment of a large-scale regional programme will require big financing, especially in view of the wide range in water depth – from 5m in the north to 1,020m in the south.

Conducting regional investigations within the framework of an international scientific consortium makes it possible to solve the problem of covering the entire basin as a single entity.

Operations are undertaken throughout the offshore basin and adjacent onshore areas, using the same technology, looking at exploration maturity, peculiarities of structure, and prospects for the basin. Working within the consortium makes it possible to raise funds from several sources for sharing the financial burden among participants of the programme, thus making it possible for countries to obtain unique information for the entire region under investigation.

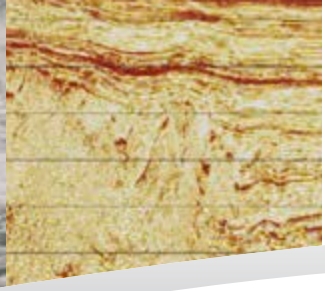
Undoubtedly, regional surveys should also be of interest to oil companies. Quantitative estimates of initial resources of the Caspian region made by different petroleum companies have varied widely, differing by a factor of two and more for some provinces. The reason for discrepancies in estimates of the resource potential are mainly associated with differences in opinions over which part of the section of the sedimentary cover is to be considered as potentially prospective.

High and Low Estimates

Low estimates of resource potential result if only the part of the section of the sedimentary cover that is well studied, with field-proven exploration operations, is taken into account for the analysis. As a rule, these are deposits of the 'platal' complex occurring at depths up to 5 km. High or optimistic estimates take into consideration the resource potential of the entire section of the sedimentary cover, including deep (>6 km) horizons of the 'platal' complex, and also that of deposits of the 'pre-platal' and 'folded' complexes with unclarified prospects, but evaluated by many researchers as potentially prospective. Thickness of such rock masses in the central, most subsided parts of the Precaspian, Terek-South Caspian, Ciscaucasian-Mangyshlak and Aral-Caspian provinces reaches up to 15 km.

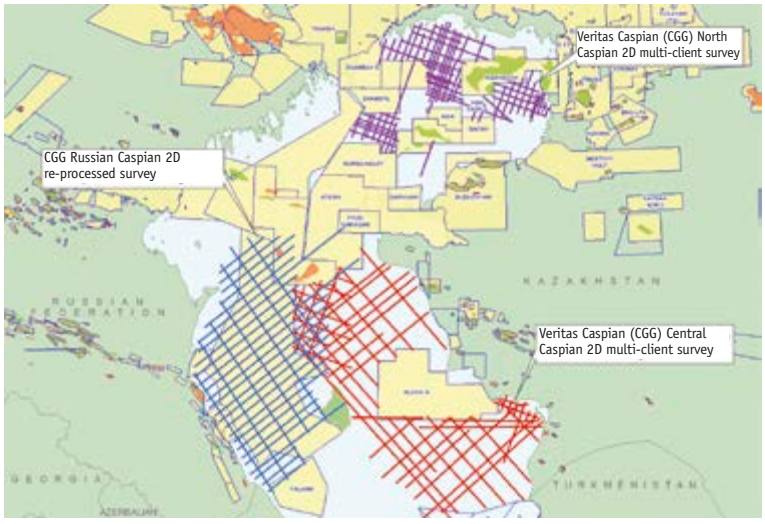
By optimistic estimates, the subsurface of the Precaspian, Ciscaucasian-Mangyshlak and Terek-South Caspian provinces



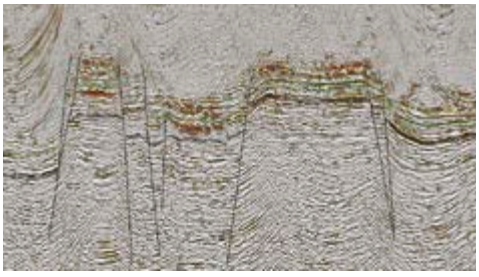



Veritas Caspian: North East & Central Caspian

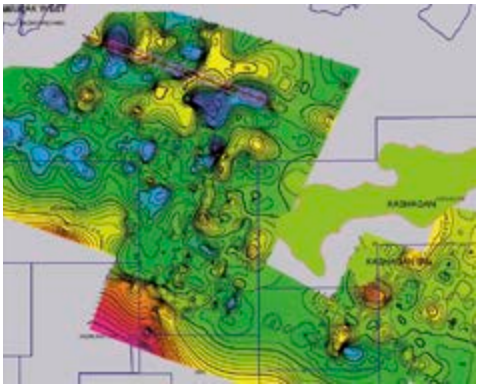
Caspian seismic database



Coverage map showing Veritas Caspian (CGG) data library surveys.



Example of seismic data from Veritas Caspian (CGG) multi-client library.



Example of Time structure map - NE Caspian data.

The unrivalled Veritas Caspian (CGG) data for the Caspian brings a new level of illumination to the unexplored reservoirs in the Kazakh sector of the Caspian Sea. The processed and interpreted data provides invaluable geophysical and geological information that is commercially available and can contribute to cost-effective hydrocarbon exploration within the unlicensed blocks.

We are proud to be granted the opportunity to participate in such a key project that has greatly increased the visibility of the Republic of Kazakhstan in the international oil and gas arena.

For more information, contact Chris Twigg on (+7) 727 258 1101 or Alexander Baki (+44) 1293 683 119 or visit our website cgg.com/multi-client

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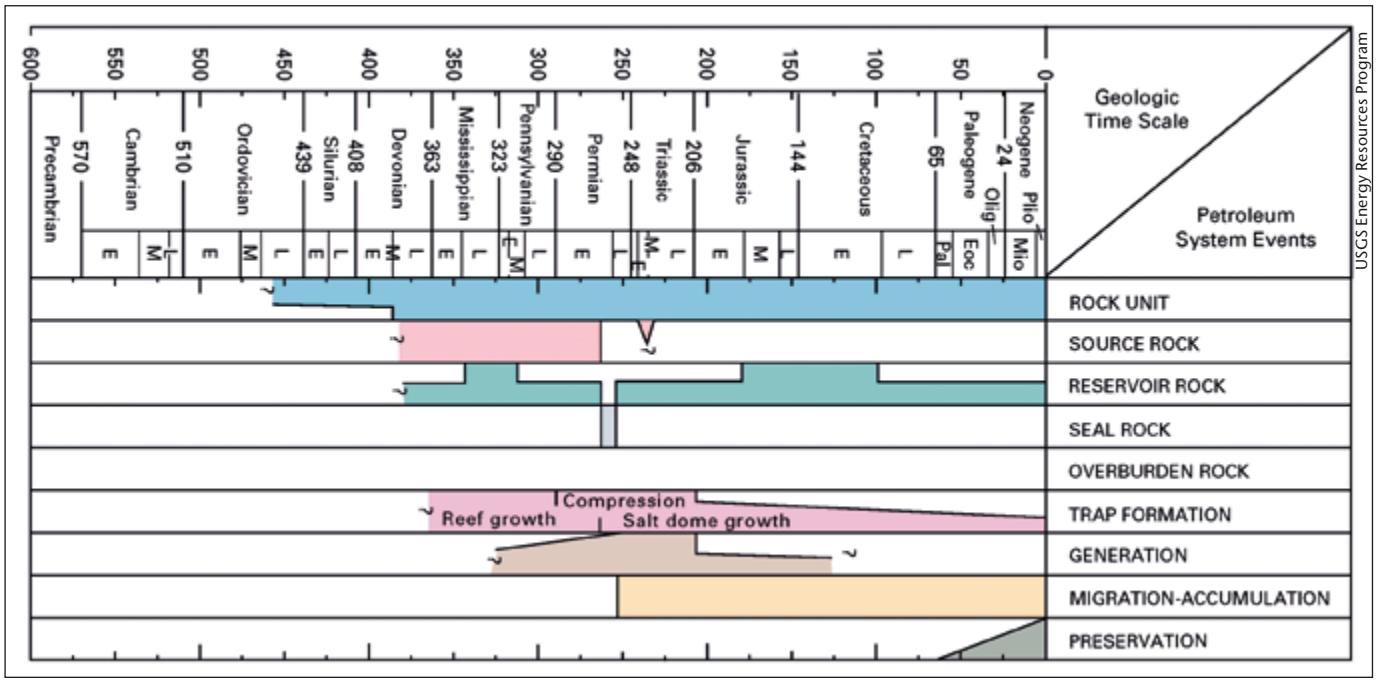


Events chart for the North Caspian Palaeozoic Total Petroleum System. Queries indicate uncertainties in extent or identification. Much of the data referred to in this report dates from the USSR era.

retain a considerable unexplored resource potential, almost two-thirds of the initial resources – about 660 Bboe in place, comparable with the resource potential of the eastern and northern regions of Russia currently under development. The highest resources are owned by the Precaspian province and, importantly, unexplored resources are confined to strata where hydrocarbons have already been proven by drilling.

Looking at more pessimistic estimates, the forecast is not so rosy. Firstly, in this view, significant unexplored potential resources are found in only one province – the Terek-South Caspian. Secondly, this forecast shows that in the Caspian region the traditional directions of petroleum exploration, based on regional investigations in the last century, have practically sputtered out by now and cannot lead to significant new discoveries.

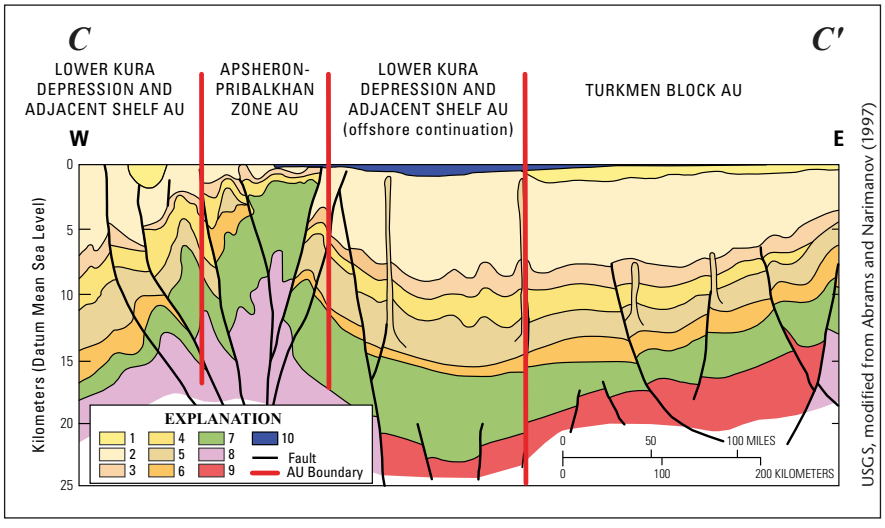
In both estimates, companies agree that build-up of resource potential for the Caspian region is only possible through development of the lower horizons of sedimentary cover (5– 8 km). For such deep accumulations to be economic, they need to be giant and supergiant fields. Such requirements are met by non-conventional sedimentary traps, such as major intra-basinal carbonate platforms or giant submarine fans. The search for such traps requires the study of sedimentary basins as holistic geological features. The same approach is needed in the search for non-conventional, non-structural traps, in the previously explored upper intervals of the section. Thus, a new cycle of regional investigations will yield the expected result only if sedimentary basins and major geological structures are studied as holistic objects, without reference to interstate boundaries.

Technological Limits

A significant gap exists between technologies used for regional research by oil and gas companies and those used by research institutes. The former utilise state-of-the-art technologies to obtain maximum information about the subsurface, but the high costs of new equipment and technologies compel the institutes to use older technologies, which impacts on the quality of regional models, as they may not coincide with structures based on information obtained by more modern equipment.

Performance of regional surveys within the framework of the

South Caspian Basin Province, 1. Quaternary; 2. M–U. Pliocene; 3. L. Pliocene; 4. Miocene; 5. Oligocene –Miocene; 6. Paleocene–Eocene; 7. Mesozoic; 8. Continental crust; 9. Oceanic crust; 10. Caspian Sea. See map on page 30 for line of section.



Geology Without Limits consortium makes it possible to solve these problems, as operations are performed all over the basin and adjacent onshore areas, with utilisation of uniform technologies.

Geoprospecting Together

As already noted, few countries, on obtaining new geological information, share their results with neighbouring institutes, resulting in differences in geological models. Such inconsistency is often caused by 'overestimation' of prospectivity of the region, attempting to raise investments. In addition, limited circulation and integration of new geological information means it is difficult to gain a clear understanding of the existing geological model in order to further develop it in an effort to reveal 'blind spots' in the understanding of the evolution of geological structures.

So, what geological problems can be solved by all of the countries of the Caspian merging their efforts in order to activate geoprospecting operations in the region?

Within the framework of international cooperation, we need answers to the following issues in the fields of tectonics, stratigraphy and petroleum geology, on which the prospectivity of the structural-tectonic complex depends:

- Age and composition of the consolidated crust of the south-eastern margin of the Precaspian Depression, Scythian and Turanian Plates;
- Tectonic nature, evolution and structure of the Jurassic-Paleogene of the South Caspian Depression; of the Early Palaeozoic Tugarakchan Trough and the Donbass-Tuarkyr folded system; and of the South Emba Palaeozoic uplift;
- Regional structure of the Upper Permian-Triassic and Pliocene-Quaternary structural stages of the post-salt complex of the Precaspian Depression;
- Structure of Palaeozoic deposits of the 'folded complex' sediments of the Scythian and Turanian Plates;
- Boundaries of the Early Permian halogenic basin of the Precaspian, and its interrelationship with the Devonian-Carboniferous and Mesozoic-Cenozoic basins;
- Interrelationships of the folded systems of the Ural and Tien Shan Mountains;
- Post-collision transregional shift faults and their role in the formation of the structure of the 'pre-platal complex';
- Unified regional schemes of seismostratigraphic partitioning of the section for each petroleum province and an inter-regional scheme of the Caspian region as the whole;
- Evaluation of the resource potential of deep horizons, including the formation of hydrocarbon deposits in over-pressure conditions and the prediction of high-capacity traps at depths of over 6 km.
- Scientifically grounded estimates of the potential of Palaeozoic deposits of the 'folded complex' in the sedimentary and basement rocks of the Scythian and Turanian Plates with non-conventional types of traps, suggesting possible areas for development;
- Scientifically grounded estimates of the potential of the Upper Permian-Triassic complex of the Precaspian Depression and the Upper Jurassic-Paleogene complex of the South Caspian Depression;
- Construction of low/medium-frequency oscillation curves of the Caspian's sea level in the Pliocene-Holocene, caused by geological factors;
- A geomechanical model of spatial distribution of overburden and formation pressures, tectonic stresses, disjunctive faults and dilatancy fracturing of the Earth's crust in the Caspian region, as caused by local and regional tectonic processes;
- An evaluation of the effectiveness of hydrocarbon exploration in crystalline and igneous basement complexes.

Solving Problems

Regional surveys performed with state-of-the-art technology will enable a detailed scientific interpretation of new information on the geological structures of the Caspian region. This will provide a more reliable estimate of potential resources of the area, uncover the history of geological evolution, making it possible to single out new areas where potential giant and supergiant fields can be found, and will help solve environmental problems associated with oscillations of the Caspian sea level. ■

Oil derricks on the shore near Baku, Azerbaijan

Elnur/Dreamstime.com

Production Geoscience 2013

● November 6th, 2013. Radisson Blu Atlantic, Stavanger ● www.geologi.no

Can experiences from mature fields help "New Field development"?

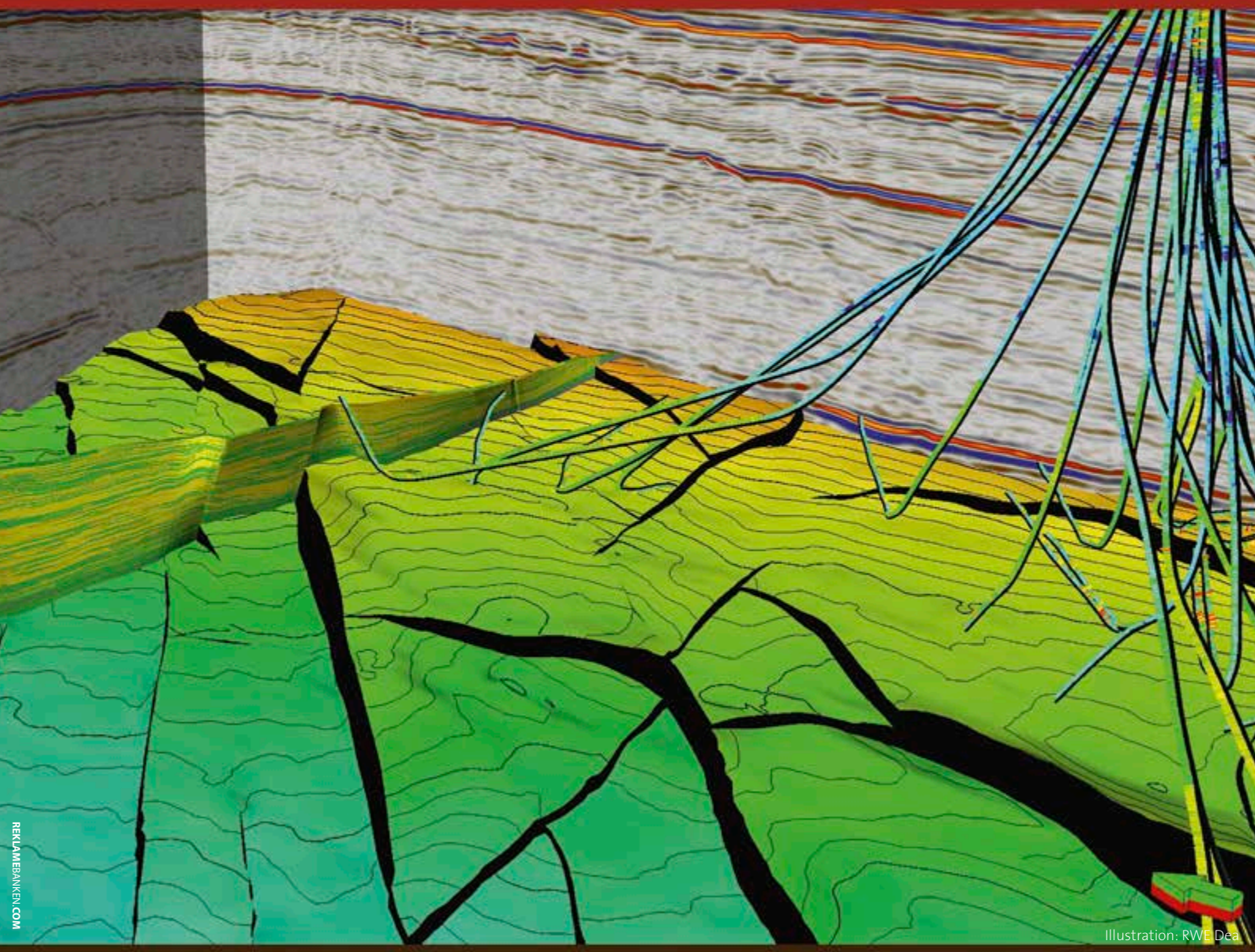


Illustration: RWE Dea

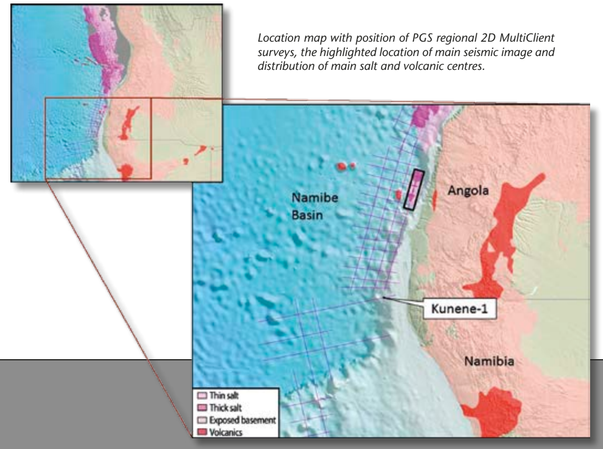
Geological Society of Norway

Petroleum Potential of the Offshore Namibe Basin

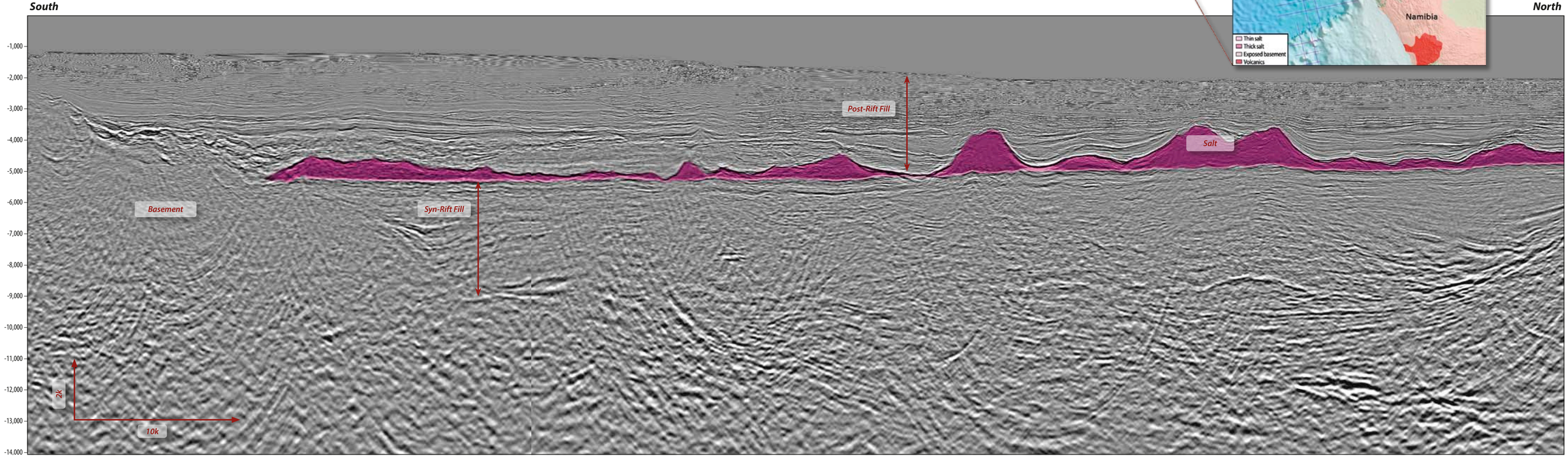
The frontier Namibe Basin holds tremendous potential for hydrocarbons. The offshore West African basins have proven similarities with the equivalent sediments of the Brazilian margin, both part of the Aptian Salt Basin geological province, which formed as the Atlantic Ocean opened.

A GeoStreamer® dual-sensor regional 2D seismic survey, acquired in 2011 in association with Sonangol, covers the Angolan sector of the Namibe Basin and has been used to improve regional understanding of the tectonic evolution, geology and prospectivity of the Namibe Basin.

Section of a regional MultiClient GeoStreamer strike line, showing a salt-filled, perched basin in the Angolan sector of the Namibe Basin



Location map with position of PGS regional 2D MultiClient surveys, the highlighted location of main seismic image and distribution of main salt and volcanic centres.



Evolution, Geology and Prospectivity of the Namibe Basin

JENNIFER GREENHALGH
Petroleum Geo-Services, Weybridge UK

The similarities between Atlantic conjugate margins of West Africa and Brazil are brought to the fore through a new regional 2D survey

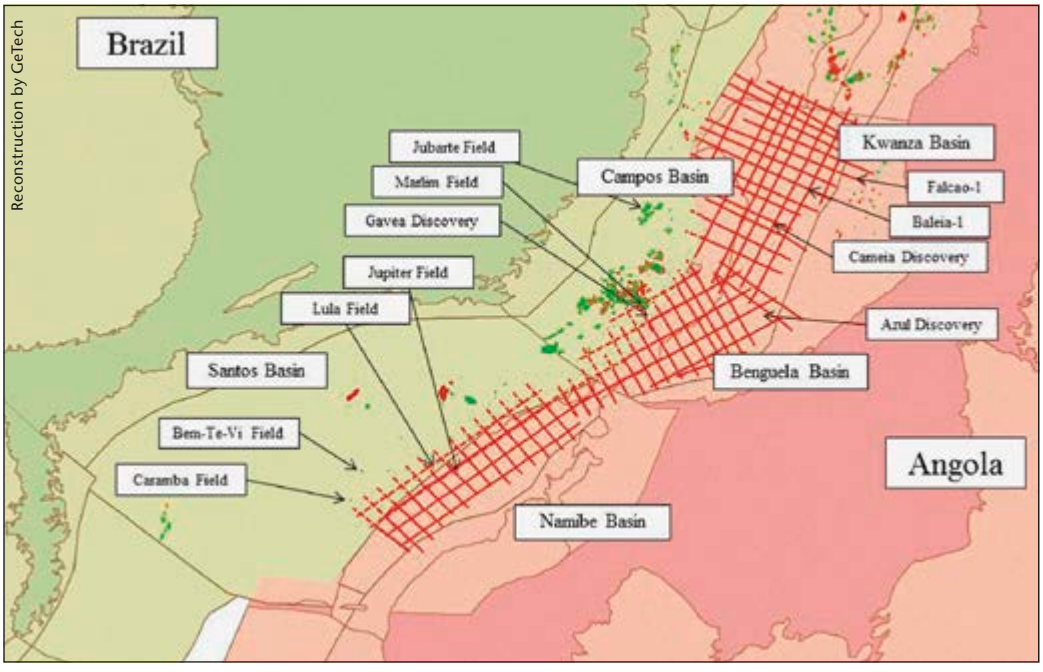
The sedimentary basins offshore West Africa and the equivalent sediments of the Brazilian margin are both part of the Aptian Salt Basin geological province, which formed as the Atlantic Ocean opened. Significant syn-rift discoveries in the adjacent Kwanza-Benguela Basins, such as the Azul and Cameia fields, and analogous discoveries in the conjugate Brazilian Basins, including Lula and Gavea, highlight the petroleum potential of the Namibe Basin.

Regional Geology

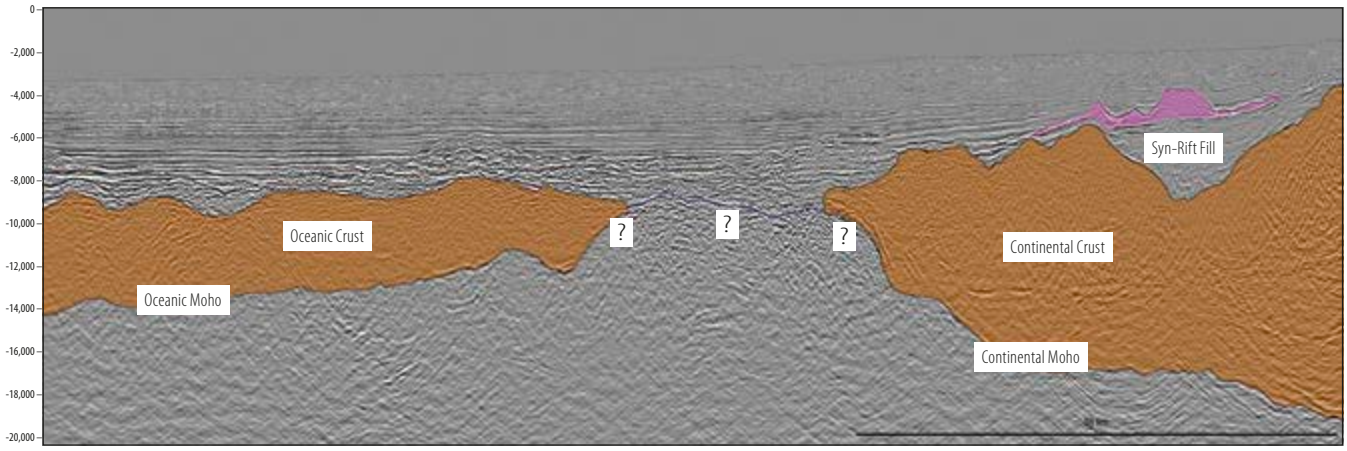
The Angola offshore area is part of the South Atlantic Salt Basin, which extends from the southern margin of the Niger Delta to the Walvis Ridge (Brownfield and Charpentier, 2006). The offshore basins share similar structural and stratigraphic characteristics due to their common origin during rifting of the proto-Atlantic. The tectonic history is shared with Brazil, on the opposing conjugate margin, as seen in the figure below. The history of these basins is divided by basin development stages.

The syn-rift (pre-salt) stage is characterised by extensional faulting, which led to the formation of horst and graben structures. Within the grabens, thick sequences of fluvial-lacustrine sediments were deposited in narrow deep lakes where conditions included a high clastic and terrestrial plant debris input, algal blooms, and anoxic bottom waters. This led to the formation of a world-class source rock lying in close proximity to reservoir facies, ranging from conglomerates and sandstones shed from local horst blocks to lacustrine and fluviatile sandstones. It is likely that several phases of rift block-faulting took place (Karner and Driscoll, 1999).

As extensional faulting ceased, the early post-rift, or sag stage, is characterised by the deposition of continental, fluvial and transgressive lagoonal rocks (Teisserenc and Villemin, 1990; Brownfield and Charpentier, 2006). These contain further source and reservoir units. The sag phase sediments of the Brazilian offshore are of significant interest, due to the 2006 discovery of the Lula Field, where the reservoir is a microbial carbonate developed during the sag phase over a large rifted basement structure. The associated source rocks were deposited in laterally-extensive, shallow hypersaline lakes. Subsequent related discoveries have focused



South Atlantic conjugate plate reconstruction at 120 Ma. (Reconstruction by GeTech). The Angola GeoStreamer 2D survey location and major pre-salt hydrocarbon discoveries have been rotated in position with the plates.



Regional dip line, re-migrated to 30 km, illustrating the nature of the Continent-Ocean Boundary in the Namibe Basin, Angola.

exploration activities on the sag phase sediments on both sides of the South Atlantic. These sediments were overlain by an evaporite sequence, accumulated as a result of cycles of marine incursions and evaporation, and this evaporite layer acts as a regional seal.

Namibe Basin

The Namibe Basin is a frontier basin, extending from the Walvis Ridge in the south to the Benguela Basin in the north. The majority of the Namibe Basin lies in Angolan waters, with just the southernmost part lying in Namibian waters (see map on main foldout page). One discovery has been made in the Namibian sector: Kunene-1, which was drilled in 2008 and is reported to be a gas discovery with oil shows in Aptian-Albian sediments, proving a working petroleum system exists. A regional 2D GeoStreamer GS™ was acquired in 2013 in association with Namcor, which ties to the Kunene-1 discovery as well as into the deepwater areas of Namibia to the south of the Walvis Ridge.

The present distribution of the salt can be seen on the map on the main foldout page. The Kwanza and Benguela Basins have a significant volume of salt present, contrasting with the restricted volume in the Namibe Basin. Well-developed volcanic centres and lava flows are also identified. With a change in geological character in the Namibe Basin, when compared to both the adjacent and conjugate basins, what is the effect on the hydrocarbon prospectivity?

The seismic data shows evidence for syn-rift structures and sediments (see foldout seismic section), analogous to those that have been so prospective elsewhere. A perched basin has been identified containing a well-defined salt body, with a further well-developed sag phase package lying parallel to the base of the salt. The underlying rifted basement rises to north and south, controlling this depocentre. This area of the Namibe Basin not only has potential for hydrocarbons within the pre-salt, syn-rift succession, but the salt itself also provides structure for trapping in post-salt sediments.

Further south, the distribution of the salt becomes less clear, and the frequency of volcanics becomes more pronounced. Gravity and magnetics data, acquired with the seismic, will be analysed to confidently determine the distribution of these units. Significantly, within areas that have no apparent salt deposition, there is clear evidence of syn-rift sediments, and structures can be imaged on the seismic. This petroleum play thus remains a likely source of hydrocarbons along the entire length of the Namibe Basin as well as in the basins south of the Walvis Ridge, to which the Namibe Basin is similar, and where an active exploration programme is ongoing.

The Namibe Basin regional seismic dataset acquired by PGS has been re-migrated to 30 km, from the original 15 km record length. This has allowed imaging of the deepest structures, leading to a better understanding of the position and structure of the Continent-Ocean Boundary, as shown in the figure below. The timing and nature of the continental breakup along this margin can now be better understood.

Clear Evidence

The frontier Namibe Basin has proven source and reservoir units in both the conjugate basin pair (Santos Basin), and the adjacent basins to the north (Kwanza and Benguela Basins).

There is clear evidence of well-developed syn-rift structures and sediments analogous to the prolific pre-salt petroleum play. There is also evidence of a well-developed post-rift succession.

The dual-sensor technology places the entire basin in a regional context, and recent re-migration provides details of the deepest structures, allowing understanding of the relationship between the continental and oceanic crust.

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Unrest Hits West African Oil and Gas

Both political turmoil and oil theft are increasing costs for oil companies and threatening supplies. Can some of the demand-side causes be tackled?

NIKKI JONES

In February this year the International Energy Agency acknowledged that a new wave of political unrest is hitting Africa, and revised downwards its production projections for much of the continent. The January siege at the Algerian In Amenas gasfield, in which 39 civilian lives were lost, was the initial catalyst, an apparent retaliation for French involvement in Mali. However, by February it had become clear that the 'Arab Spring' was far from over and that disruption to supplies is likely to be long-term. In particular Libya, with its light sweet crude, has had its production slashed to less than 200,000 bopd this year by strikes and militias, and post-revolution unrest in Egypt has, throughout 2013, raised the possibility of disruptions to supplies through the Suez Canal.

Further south, tensions between Frelimo and Renamo in Mozambique have resurfaced, which may affect the working environment of companies such as Eni and Anadarko: oil companies will have noted the experience of Rio Tinto, which suffered a US$3bn write-down in June following sabotage to essential railway lines.

In Nigeria, political violence in the Delta has resurfaced this summer as tensions have risen over the choice of candidates for the 2015 election, and the growing Islamist movement in the north continues to seriously threaten the unity of the country. Although neither are a current, direct threat to oil operations, the funding of the Islamist movement and its access to increasingly sophisticated weaponry are causes for

Oil contamination in Nigeria

concern. Rocket propelled grenades and machine guns on pick-up trucks have become a feature of the northern states' conflict and may find their way to other regions. The increased sophistication of Islamist militants and their willingness to strike oil and gas fields was demonstrated by the January attack on In Amenas, a site that had its own army base well equipped with tanks and helicopters, and was providing perimeter patrols and armed convoys for staff. These defences did not prevent the field from being penetrated.

Oil Theft Bigger Problem

However, political violence in Nigeria is *not* the main cause of the country's catastrophic drop in production. Since the implementation three years ago of a cash-for-amnesty deal, which successfully cut the number of politically motivated attacks on pipelines, insurgency has been overtaken by a new wave of banditry on and offshore. The International Maritime Bureau now ranks Nigeria second only to Somalia in terms of piracy, and 'bunkering', the increasingly sophisticated theft of crude, is now estimated to be losing both companies and the country a staggering 250,000 bopd. This equates to between 10 and 20% of production and Shell has, this year, been forced to declare 'force majeure' on some contracts, i.e. that it is not responsible for its inability to deliver. National government is missing approximately US$1bn per month in revenues.

The battle over bunkering has been likened to a war. Shell has had to increase the sophistication of its response and is reported to be considering the use of unmanned drones, infrared cameras, new leak detection systems similar to burglar alarms and also the hiring of locals on surveillance contracts. Private Western security companies circle: their engagement is sanctioned by the one UN code dealing with security in the extractive industries – the Voluntary Principles on Security and Human Rights. Heritage Oil, which bought Delta oilfields from Shell, Total and Eni in January this year, has stated that it aims to improve community relations by distributing a greater proportion of profits in exchange for reductions in vandalism. The amnesty proves that cash payments can be highly effective but given CEO Tony Buckingham's background in providing mercenaries to Africa, it seems likely that private security may also figure high in Heritage's strategy.

The US response, which is motivated by the drive to contain

Islamism and Chinese power on the continent, as well as to secure oil supplies, has been both 'soft', with continued support for development in Africa, and militaristic. In June Obama announced a US$7bn power initiative that aims to double sub-Saharans' access to electricity within five years, but Africom, a special military command established explicitly to counter terrorism, launched by President Bush in 2007, remains in place. Hostility to this combatant force has been such that it is based in Stuttgart.

A second US initiative is the Africa Partnership Station (APS), also launched in 2007. Its first two tours were along the coast of West Africa, providing a mobile university to 'build the skills, expertise and professionalism of African militaries, coast guards and mariners'. One sign of its success may be the April 2013 gaoling of the captains of two Swedish Stena Oil vessels that

Ellen Johnson-Sirleaf, president of Liberia, congratulates graduates of the Armed Forces of Liberia 27 March 2008, in Monrovia, Liberia, who had been participating in Africa Partnership Station (APS) courses in leadership and martial arts aboard the amphibious dock landing ship USS Fort McHenry.

MC2 Elizabeth Merriam

performed a non-authorised transfer of cargo six miles off the Sao Tome coast, apparently to avoid tax.

Tackling Demand for Stolen Oil

The fact that a Swedish company was involved highlights the underlying problem – and the potential solution. Although some fuel is sold cut-price in the domestic market, most is taken to refineries in South Africa, China and Europe. Attempts to maintain security of supply cannot be completely effective without accompanying demand-side measures: any strategy that seriously seeks to tackle the problem of oil theft needs to question where stolen oil ends up and where the money is banked. For this, Nigeria needs Western help – as it did in the tracking down of General Abacha's stashed millions.

However, the possibility of such a similar, embarrassing investigation is hampered by the fact that bunkering now occurs with the widespread collusion of officials in Nigeria. The canoes that transport oil from punctured pipelines, the barges that take it directly from wellheads, and the waiting offshore tankers all operate in full view of the authorities. White collar bunkering flourishes, whereby metres are manipulated to 'minimise' production: there are few penalties for those found guilty of theft.

Costs Escalating

Both political unrest and theft are adding to the costs of oil companies. It is believed that companies were already paying an extra 30% of salary in danger money before the In Amenas attack: this cost has most likely increased. Security measures and court cases are also adding to bills: in January this year Shell was ordered to pay costs for one major Niger Delta spill, and the company is in talks with the Bodo community to settle compensation on two more. The cost of cleaning up Ogoniland alone, which has only a sixtieth of the Delta's population, has been estimated at US $1bn, and it is likely that the oil companies will be expected to contribute.

However, there is little evidence that oil companies are working with governments and international agencies to think long-term and tackle the underlying causes of unrest and theft. Clearly, lack of transparency in oil supplies and in banking has strong defendants. Perhaps the most worrying indication of companies' short-termism is their reported willingness to cut deals with local governments in the recently calmed atmosphere of Somalia, ignoring the protestations of national government and threatening to shatter any unity being established in the country. It appears that, in their rush to reclaim their acreage, they are willing to throw oil on the fire that is Somalia. It seems likely that again they will end up paying much of the costs. ■

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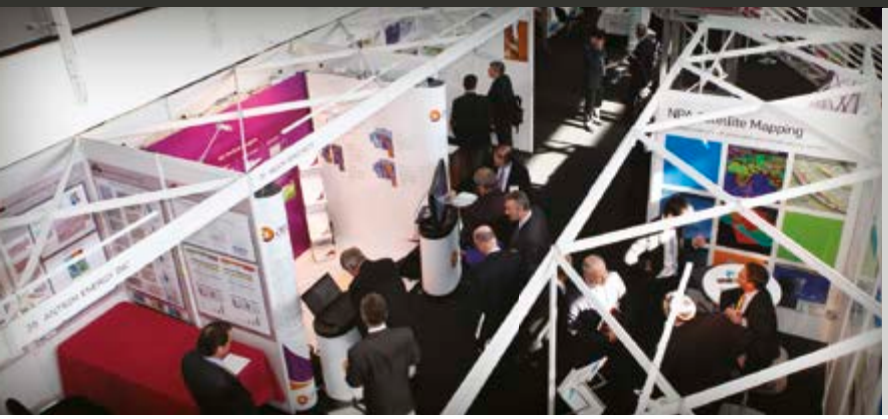

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La Gomera
Green Pearl of the Canaries

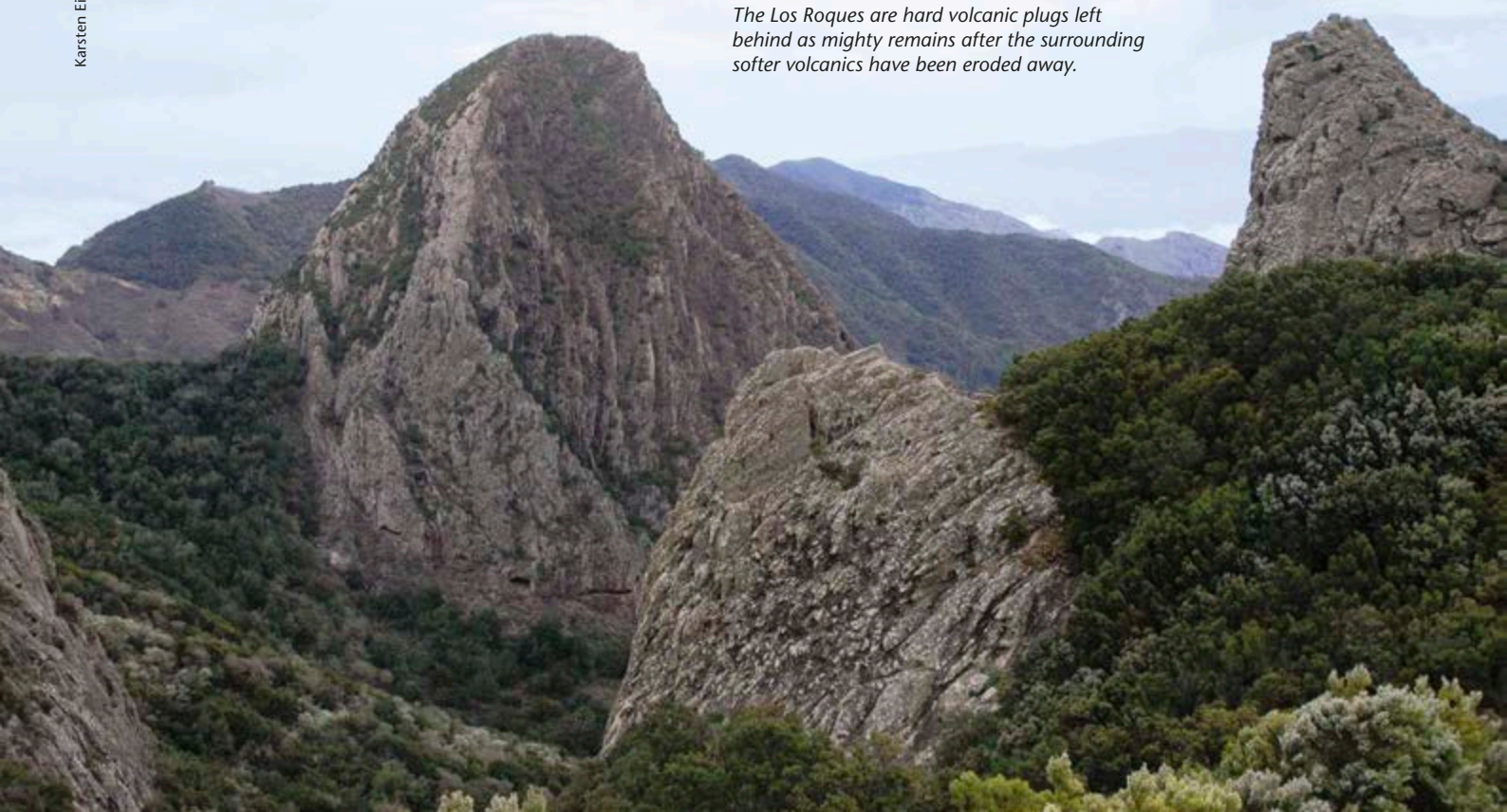
KARSTEN EIG

To most people, the Canary Islands is a place to go on a charter or low-fare plane where you can sunbathe for hours on beaches with white sand imported from the Sahara. But the Canaries have another face, with many natural features of interest to scientists, both above and below ground.

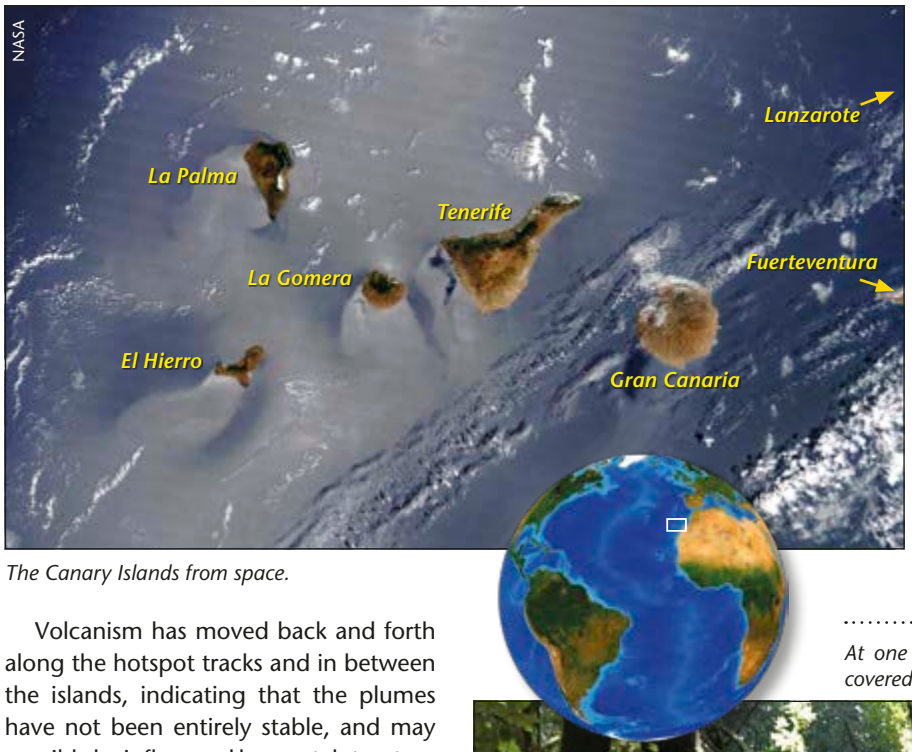
The volcanic origin of the Canary Islands is evident everywhere. Best known is the Pico del Teide, the mighty 3,718m tall active stratovolcano that rises above Tenerife, which last erupted, through a flank cone, in 1909. On Lanzarote, the Timanfaya national park encompasses a moon landscape of craters, formed during a long series of eruptions from 1730 to 1736. The last onshore eruption in the islands took place on La Palma in 1971, and a submarine eruption occurred south of El Hierro in the winter of 2011–2012.

The Canary Islands are located on the south-western end of a hotspot trace marked by seamounts that stretch in a gentle, anticlockwise arch along the African coast. The youngest volcanism is in the south-western islands of La Palma and El Hierro, while Lanzarote and Fuerteventura are the oldest Canary Islands at around 24 million years (ma.). Through submarine seamounts it is possible to trace volcanism back to the Lars seamount, around 69 ma. old. Notably, the Portuguese island of Madeira, which last erupted a few thousand years ago, is the south-western end of a similar hotspot track, which leads back to the 67 ma. Ormonde seamount.

Karsten Eig



The Los Roques are hard volcanic plugs left behind as mighty remains after the surrounding softer volcanics have been eroded away.



The Canary Islands from space.

Volcanism has moved back and forth along the hotspot tracks and in between the islands, indicating that the plumes have not been entirely stable, and may possibly be influenced by crustal structure along the African passive margin.

Eternally Green Forest

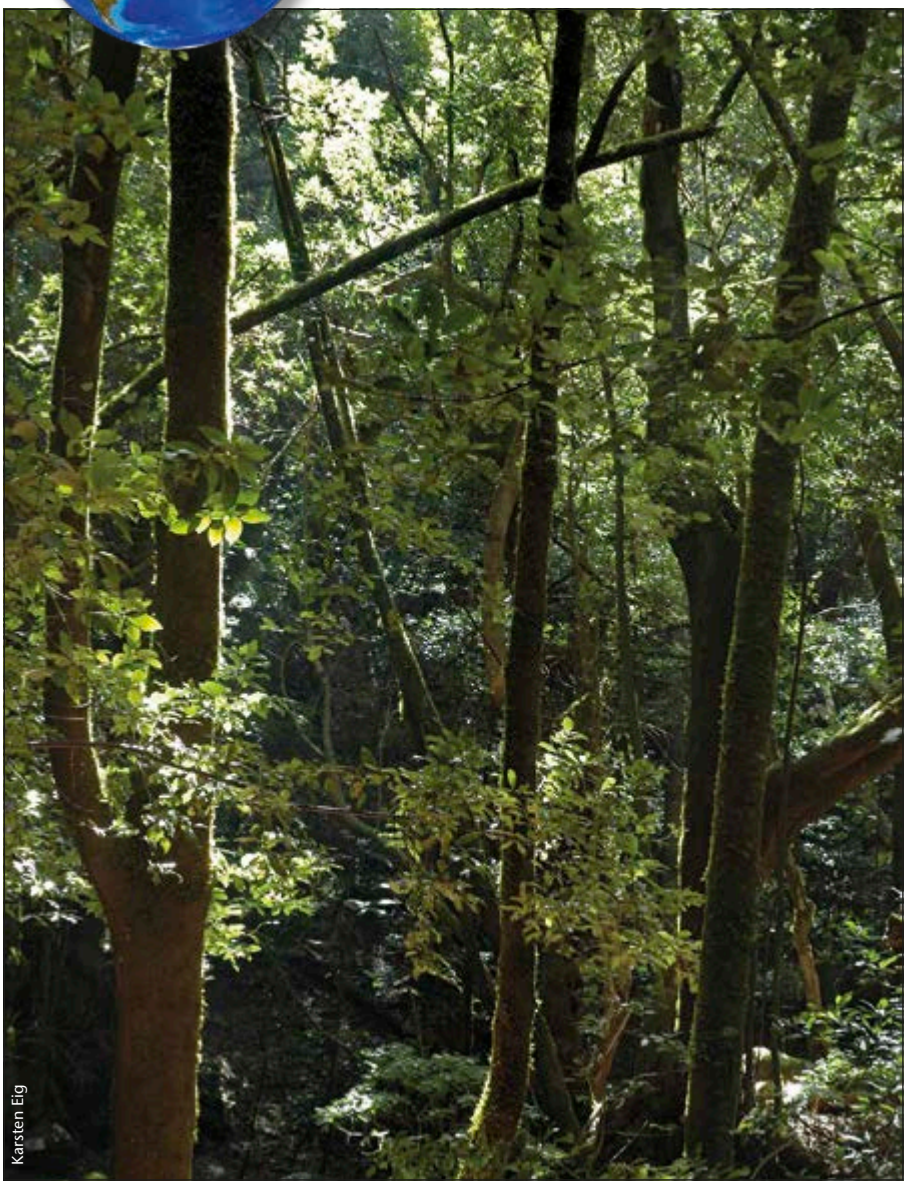
But let's leave both large scale tectonics and the busy tourist places behind, and go to a small island, just to the left of Tenerife: La Gomera, known as the green pearl of the Canaries. However, it may not look too green upon arrival in the capital San Sebastian, as the southern part of the island is a half desert of eroded volcanic rocks. But drive an hour, to the mountains and the northern side of the island, and an emerald paradise unveils – a thick, green, leafy forest where birds sing to the playful sound of running streams. This is the Laurissilva forest, eternally green and the life blood of the island.

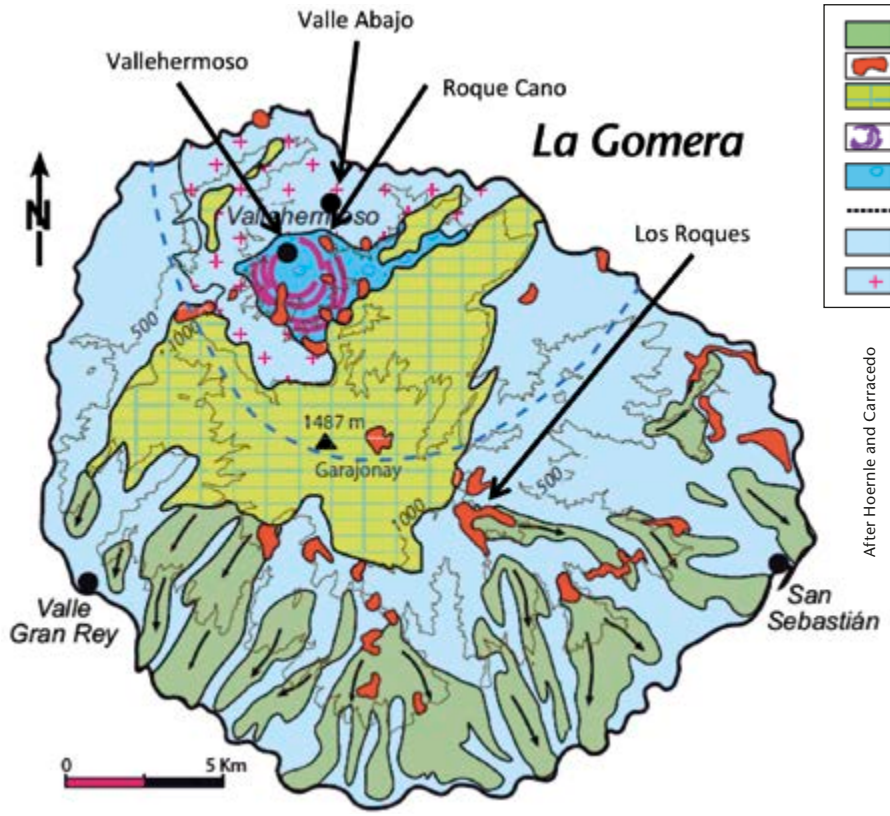
Laurissilva is unique, a humid subtropical evergreen forest, almost a rainforest. During warm and humid Cenozoic periods, such forests covered large parts of southern Europe. Today, with a dry climate dominating the Mediterranean area, the Laurissilva is limited to the Atlantic Macaronesian islands (a collective name for the Canaries, Madeira, Azores and Cape Verde islands). A total of 75 different plant taxa have been described as unique to the Gomeran Laurissilva forest, and it also contains 280 species that are only found in the Macaronesian islands.

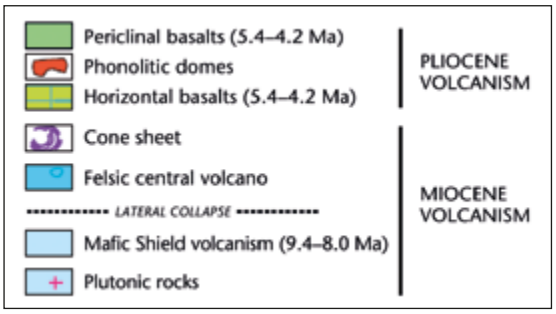
The Laurissilva forest is green not primarily as a result of rainfall, as the dry semi-deserts on the Canary Islands can testify. Instead, it catches the moisture which is carried to the island with the trade winds, which eternally blow from the humid north, touch the Canaries and then cross the Atlantic towards the Caribbean. In the morning, the mountains on the northern side of Gomera are often covered in fog – more reminiscent of a mystic place where hobbits could appear than a subtropical island.

The fog condenses on the trees, and drips to the ground, where the porous volcanic rocks deep below the island act as a large sponge and store the water. This water is the source for all the streams on La Gomera, and also supplies

At one time subtropical forests like the Laurissilva forest covered much of southern Europe.







After Hoernle and Carracedo

the drinking water. The precious forest is protected by the Garajonay National Park, named after the highest peak on Gomera. At 1,480m, Alto de Garajonay is easily reached by a short walk from the main road and offers a great view of much of the island. In the distance, the mighty Teide on Tenerife rises so high that one still has to look upwards towards the peak.

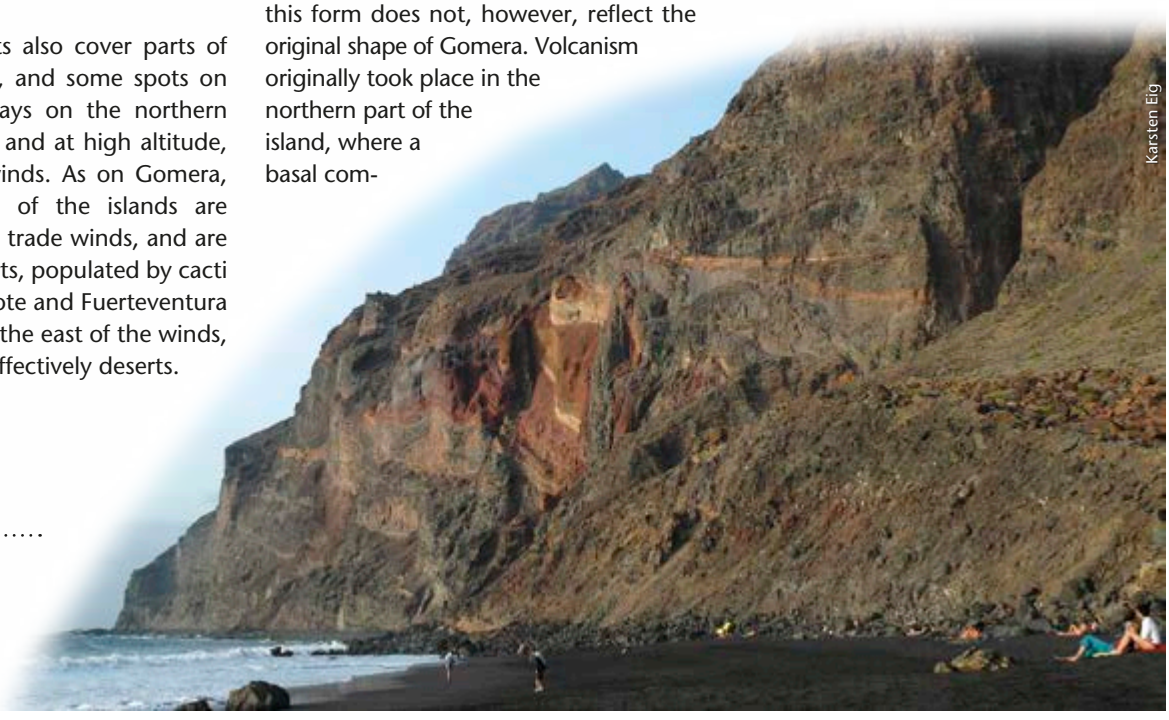
Laurissilva forests also cover parts of La Palma, Tenerife, and some spots on Gran Canaria, always on the northern side of each island and at high altitude, facing the trade winds. As on Gomera, the southern side of the islands are protected from the trade winds, and are therefore half deserts, populated by cacti and lizards. Lanzarote and Fuerteventura are too low and to the east of the winds, and are therefore effectively deserts.

Volcano-shaped Island

Now, let us look at the most interesting part for readers of *GEO ExPro*: the geology. From the map, one can easily recognise Gomera's characteristic outline. The island looks like a giant fruit squeezer, with steep valleys radiating from the centre. Reminiscent of the shape of a volcano, with a peak in the middle, this form does not, however, reflect the original shape of Gomera. Volcanism originally took place in the northern part of the island, where a basal complex with abundant volcanoclastics, conglomerates and intrusives is exposed. If you walk the footpath from Valle Abajo, north of Vallehermoso, up the steep valley side, you can admire the complex intrusive-extrusive relationships, and the kilometre-long dykes which cross the valleys.

Zeolites, which form where volcanic rocks and ash layers react with alkaline groundwater, are commonly found in the older volcanics. The vesicles are usually small, with analcime and hairy zaolites as the most commonly found minerals. If you pick up the rocks, be careful not to hurt the many lizards and geckos that hide in open fractures in the rocks.

Gomera rose above sea surface approximately 20 ma, at which time volcanism moved to the centre, covering the island in plateau basalts with interbedded tuffs. These basalts, often developed as columns, as well as red tuffs, are beautifully exposed in cliffs on



Karsten Eig

Half graben filled with red tuff above the black beach in Valle Gran Rey.

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the south-west coast, near Valle Gran Rey. The many cycles of eruptions can be seen by the interchanging of lavas and red and orange tuffs. To the north of Playa del Ingles in Valle Gran Rey (with real, black volcanic sand!), a large fault has developed a characteristic half graben filled with tuff.

Rocas – Volcanic Plugs

For the last five million years, Gomera has been in the post-volcanic erosion stage, which has dug out the present shape with steep valleys spreading out towards the coast. Before roads were built, these steep valleys isolated communities, and the people of Gomera developed a unique means of communication – a whistling language which combines various frequencies, and uses increasing or decreasing tone as substitutes for letters.

Due to erosion, today the 'rocas' which can be seen protruding into the landscape are now the main topographic evidence of volcanoes. These are steep-sided volcanic plugs, left behind when the surrounding, softer rock has been eroded, and they stand out as huge, thick obelisks above the landscape. Notable examples are the Roque Cano, standing guard in the hillside above the town of Vallehermoso on the north coast, and the four rocas at La Zarcita, which create a landscape from a science fiction movie – or to the more imaginative, as if four large trolls had been surprised by the sun and frozen to stone. ■

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Exposures of interbedded tuffs and basalts along the south-west coast of Gomera.

La Gomera: How to Get There

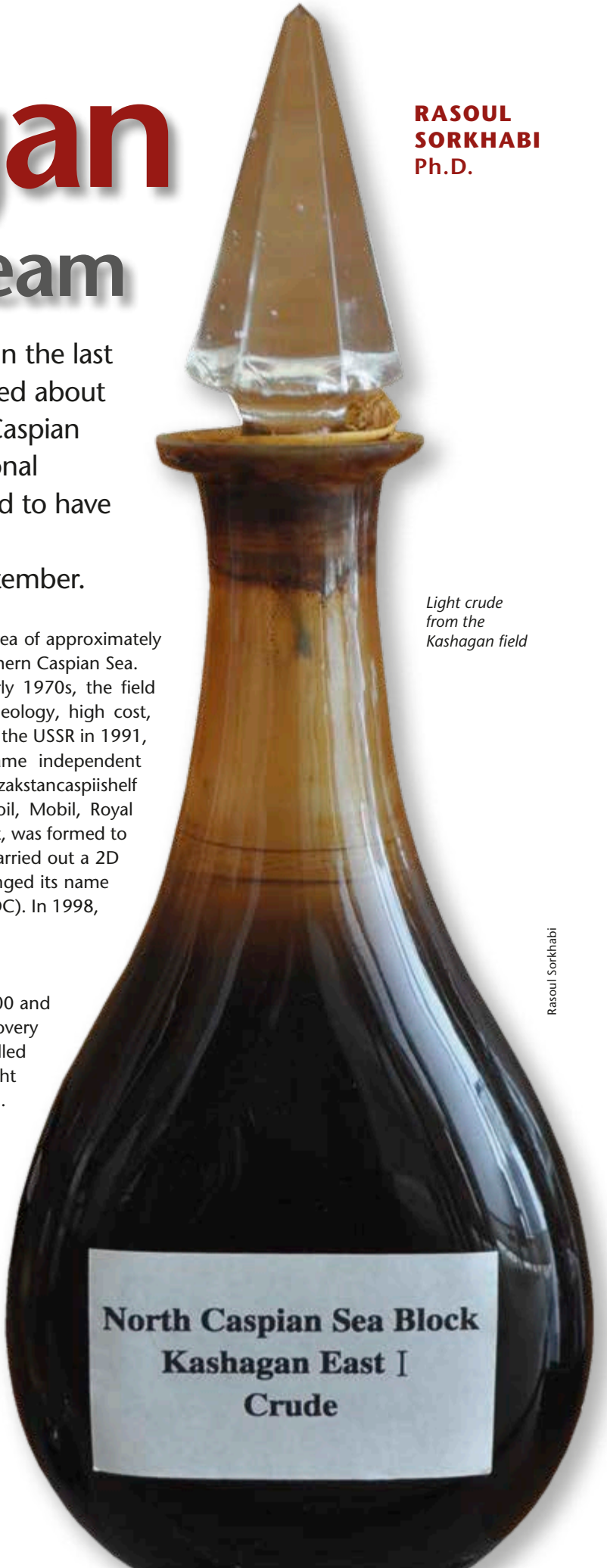
La Gomera is not as 'touristified' as its larger neighbours, but hotels are developed along the southern coast. Car rental is reasonable, and is recommended in order to get around the island. Gomera has only a small airport which connects it to the other islands. Many airlines and charter companies provide flights and travel packages to Tenerife. Ferries from Los Cristianos on Tenerife connect to San Sebastian on Gomera.

Kilometre-long dykes cutting through the basal complex in the geologically older part of Gomera, seen from the mountains above Valle Abajo.

Kashagan Comes Onstream

RASOUL SORKHABI Ph.D.

Hailed as the largest oil field discovered in the last four decades, the Kashagan field is located about 80 km offshore Atyrau in the northern Caspian Sea. Discovered in 2000 by an international consortium, the sub-salt field is estimated to have recoverable oil reserves up to 13 Bbo. Kashagan started producing oil this September.



Light crude from the Kashagan field

Rasoul Sorkhabi

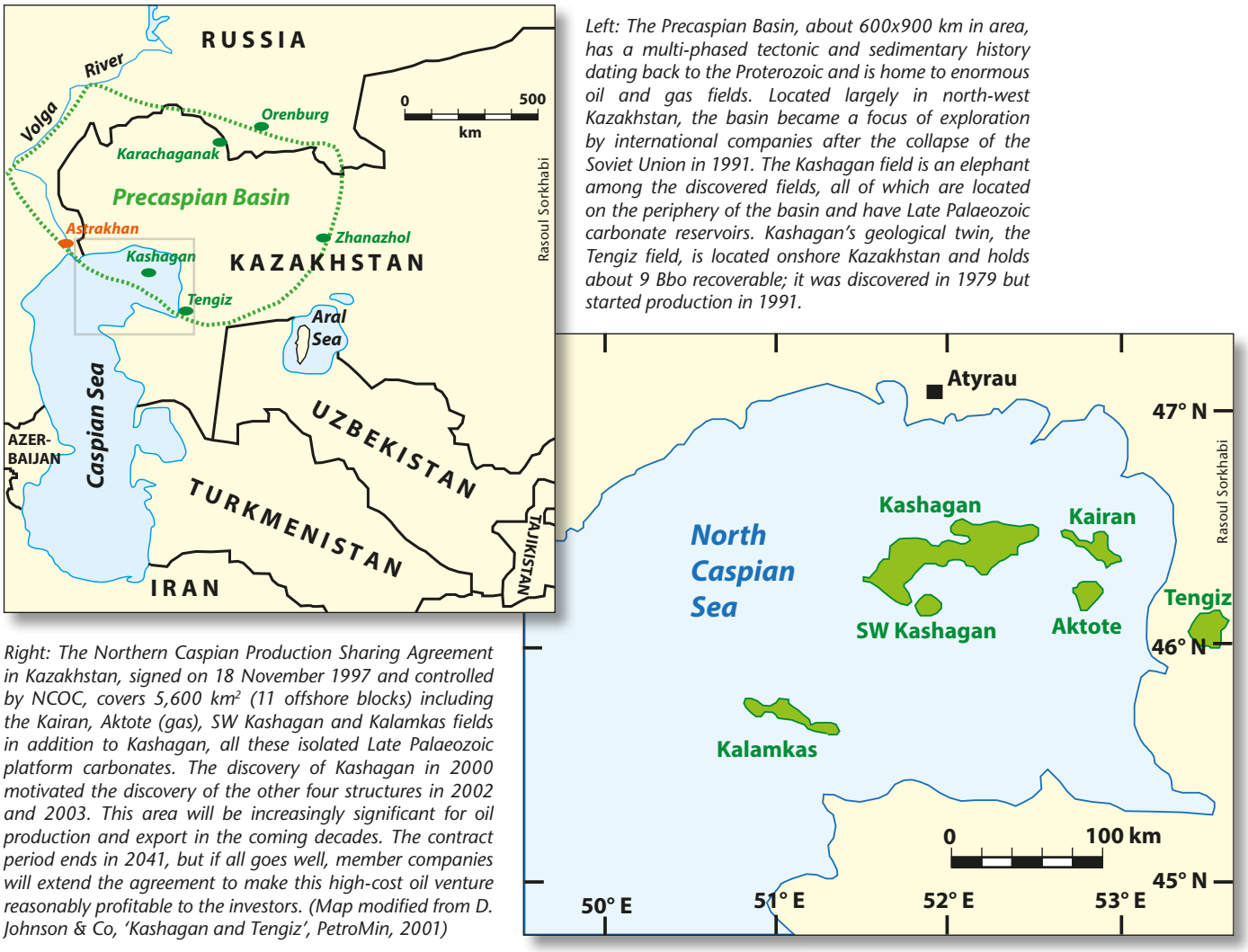
The Kashagan Carboniferous reef reservoir, with a surface area of approximately 3,375 km^2, lies below the shallow (<10m) waters of the northern Caspian Sea.

Although first identified by Soviet geologists in the early 1970s, the field remained unexplored and undrilled because of complex geology, high cost, and environmental and logistical issues. After the collapse of the USSR in 1991, Kazakhstan, like the other Central Asian countries, became independent and open to international oil companies. In 1993, the Kazakstancaspiishelf consortium, consisting of Agip (Eni), British Gas, BP, Statoil, Mobil, Royal Dutch Shell and Total, together with the Kazakh government, was formed to explore the Caspian sector of Kazakhstan. The consortium carried out a 2D seismic survey, completed in 1997. In the same year, it changed its name to the Offshore Kazakhstan International Oil Company (OKIOC). In 1998, Phillips Petroleum and Japan's Inpex joined the consortium.

Path to Discovery

The Kashagan field discovery was announced on 24 July 2000 and was named after a nineteenth-century Kazakh poet. The discovery well Kashagan East-1, spudded-in on 12 August 1999 and drilled in water depths of 3m to the reservoir at 3,960 m, hit light crude (42–44° API) and tested 3,700 bopd and 7 MMcfgpd. On 7 October 2000, another well, Kashagan West-1, was spudded-in about 40 km away from the discovery well. It was drilled in waters of 7m to a depth of 4,250m, and tested oil (42–45° API) at a rate of 3,300 bopd and gas at 7.5 MMcfgpd. Gas-to-oil ratios for these two wells were, respectively, 1,900 and 2,200 cfpbo. Within a decade, 10 appraisal and 11 development wells had been drilled.

Over the years, the Kashagan consortium has undergone many changes. In 2001, BP and Statoil sold their stakes to Total and in 2004, British Gas sold half its shares to the Kazakh government and the rest to the remaining partners. Kazakhstan's share was then transferred to a new state-owned company KazMunayGas. In 2009, the Agip Kazakhstan North Caspian Operating Company, which had been the field's operator since 2001,



Left: The Precaspian Basin, about 600x900 km in area, has a multi-phased tectonic and sedimentary history dating back to the Proterozoic and is home to enormous oil and gas fields. Located largely in north-west Kazakhstan, the basin became a focus of exploration by international companies after the collapse of the Soviet Union in 1991. The Kashagan field is an elephant among the discovered fields, all of which are located on the periphery of the basin and have Late Palaeozoic carbonate reservoirs. Kashagan's geological twin, the Tengiz field, is located onshore Kazakhstan and holds about 9 Bbo recoverable; it was discovered in 1979 but started production in 1991.

Right: The Northern Caspian Production Sharing Agreement in Kazakhstan, signed on 18 November 1997 and controlled by NCOC, covers 5,600 km² (11 offshore blocks) including the Kairan, Aktote (gas), SW Kashagan and Kalamkas fields in addition to Kashagan, all these isolated Late Palaeozoic platform carbonates. The discovery of Kashagan in 2000 motivated the discovery of the other four structures in 2002 and 2003. This area will be increasingly significant for oil production and export in the coming decades. The contract period ends in 2041, but if all goes well, member companies will extend the agreement to make this high-cost oil venture reasonably profitable to the investors. (Map modified from D. Johnson & Co, 'Kashagan and Tengiz', PetroMin, 2001)

transferred its activities to the new North Caspian Operating Company (NCOC).

Currently, NCOC comprises Eni, Shell, ExxonMobil, Total and KazMunayGas, each with a share of 16.81%, as well as ConocoPhillips (8.4%) and Inpex (7.56%). Last November it was reported that ConocoPhillips intended to sell its share to India's ONGC Videsh. This September, the Kazakh government announced it will sell 8.33% of its stake in the Kashagan field to China for about US$5 billion.

Tectonics and Depositional History

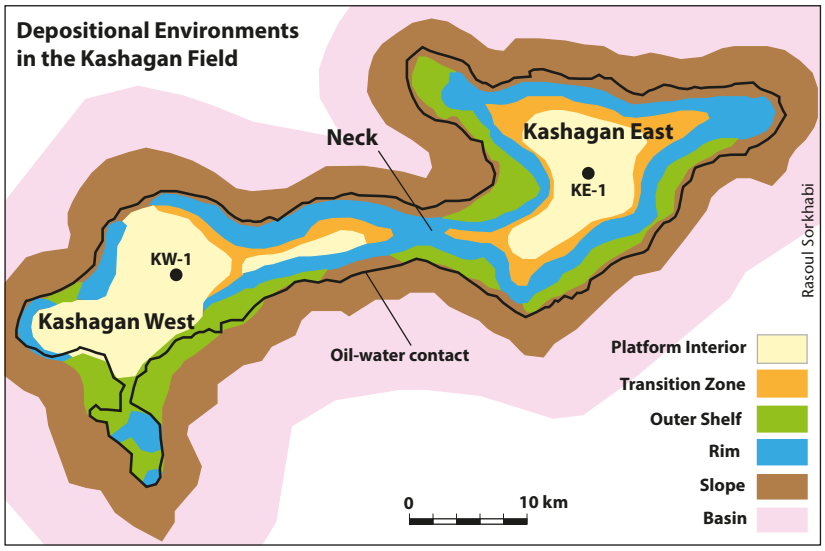
The Precaspian Basin is tectonically located on the south-eastern corner of the Russian platform (East European craton). The central Precaspian depression, filled with 20 km of sedimentary succession, sits on a remnant oceanic or a thinned lithospheric crust. Geologists do not have consensus on a tectonic model to explain the origin of the basin partly due to lack of access to the deepest sedimentary record in the central depression. It is bordered on the east by the Ural orogenic belt, which came to existence in Carboniferous-Permian times as the Kazakhstan continental block collided with the Eastern European craton (part of the Laurasian supercontinent).

The stratigraphy of Kashagan, like the other Precaspian fields, may be divided into pre-salt and post-salt successions separated by the Kungurian-age evaporites. The pre-salt succession (Middle Devonian-Lower Permian) is essentially carbonate and clay sediments, while the post-salt succession consists largely of Upper Permian-Cenozoic clastic sediments with several unconformities between various formations. The Kashagan lies in the pre-salt.

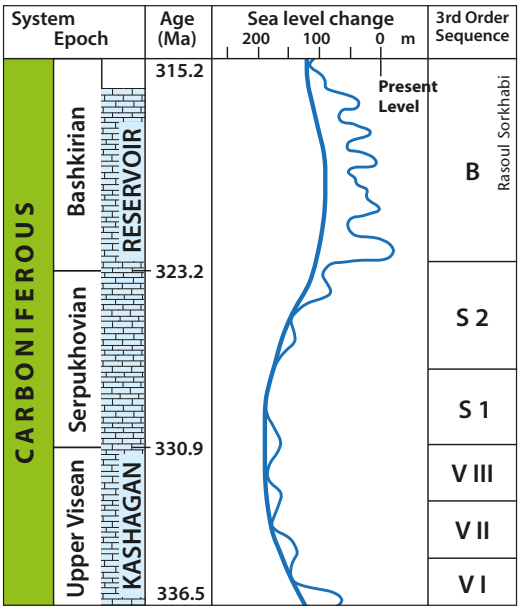
The Kashagan carbonate platform is divided into an eastern and a western part by a narrow 'neck' which rises about 200m higher than the flat interior of the platform. The field is tilted to the south-west so that depth to the top of the reservoir ranges from 3,800m to 4300m. The flanks (rims) of the field dip at angles up to 25° and are affected by syn-depositional faulting, with the northern flank having a steeper slope than the southern one.

The Carboniferous sedimentary rocks of Kashagan have been divided into Unit I and Unit II, separated by a very tight shaly tuff zone of upper Visean age called Tula Shale and depicted as HRZ (high-radioactivity zone) on the logs and seismic images. Unit I (upper Visean to Bashkirian) is the main reservoir with 800m of oil-bearing column. Eni geologists have interpreted Unit I as a prograding sedimentary system (upper Visean-Serpukovian) overlain by an aggrading system (Bashkirian). Unit II is Tournaisian-middle Visean in age.

Paola Ronchi and her colleagues at Eni have conducted a detailed study of the Kashagan carbonate reservoir based on analyses of 1,500 samples from 12 wells (*AAPG Bulletin*,



Depositional facies map of the Carboniferous carbonate build-up in the Kashagan field (modified from Kartmagambetova et al., EAGE, 2011)



Stratigraphy of Kashagan reservoir. Ages are from the 2012 geologic timescale (modified after Ronchi et al., AAPG, 2009)

September 2010). About 80% of these samples plot in the microporous zone (pores with maximum diameter of <25 microns) and the remaining 20% range from isolated vugs to connected pore zone. For 90% of the samples, porosity ranges from 1 to 15% and permeability from 0.001 to 10 mD. Samples with very low porosity (<4%) but high permeability (0.1 to 50 mD) exhibit microfractures.

Studies by Eni geoscientists also show that in contrast to the flat stratified reservoir of the platform interior, the rims of the build-up show petrophysical complexities and can be better characterised by a double porosity-double permeability reservoir model (Panfili et al., SPE, 2012). In the platform interior, average porosity is 7% and permeability is 3 mD, while in the platform rim these values decrease to 3.5% and 0.5 mD.

The source rocks are organic-rich shale horizons of Upper Devonian and Lower Carboniferous. The cap rock is Permian shale (Artinskian age, 290–279 Ma) and salt (Kungurian, 279–272 Ma). The black shale represents a Permian flooding of the carbonate platform after a period of hiatus associated with subaerial exposure and erosion. The Kungurian salt exhibits prominent salt diapirs on the seismic images.

Huge Reserves

Kashagan oil is light crude (43° API) but sour with 15–19% hydrogen sulphide and 4% carbon dioxide. Gas:oil ratio averages 2,850 cfgpbo. The reservoir has abnormally high pressures (11,000 psi).

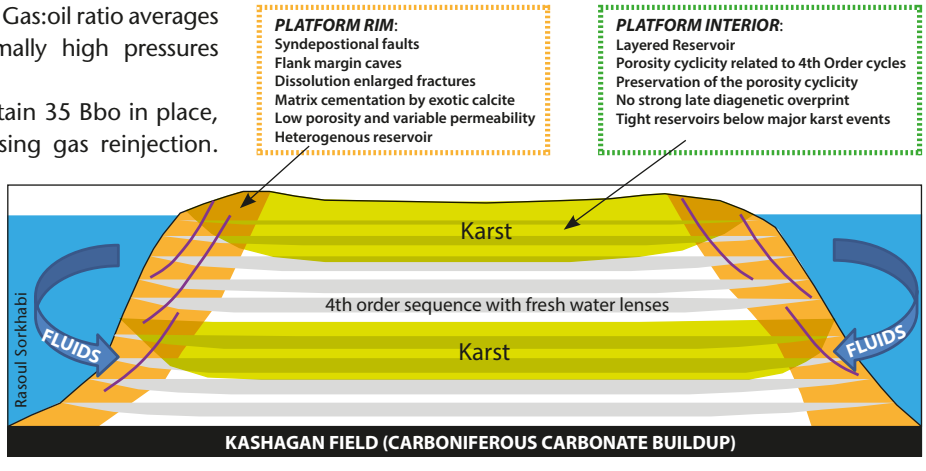
The Kashagan field is estimated to contain 35 Bbo in place, of which 10–13 Bb is recoverable oil, using gas reinjection. Kashagan is probably the largest oil field outside the Middle East and the fifth largest in terms of reserves, and may account for one-third of Kazakhstan's current oil reserves. (*The Oil & Gas Journal* placed Kazakhstan's proved oil reserves at 30 Bbo in 2012.)

According to NCOC, the Kashagan field also holds about 52 Tcf of associated gas. Most of this will be re-injected into the field both as a way of managing the highly corrosive and toxic H_2S and applying an enhanced oil recovery technique (through gas-oil miscibility process). NCOC has recently started the Kashagan Experiment Program to assess and test the gas-injection logistics (Albertini et al., SPE, 2013). Some of the gas will be sent to the Bolashak processing plant where hydrogen sulphide is extracted and the 'sweetened' gas is then used to generate electricity. NCOC also plans to produce sulphur for sale.

And Huge Challenges

Oil production from Kashagan is associated with particular challenges. Climatic conditions are extreme: -40°C in the icy winter and +40°C in the sweating summer, and sea levels fluctuate widely. During the Soviet years, the northern Caspian Sea was a nature reserve, and although the area has been open for oil and gas operations since 1992, its environmental sensitivity is still valid. Environmentalists are concerned about the impact of industrial operations on the ecological fragility of the area which

Reservoir sedimentology of the Kashagan field (modified after Ronchi et al., AAPG, 2009).



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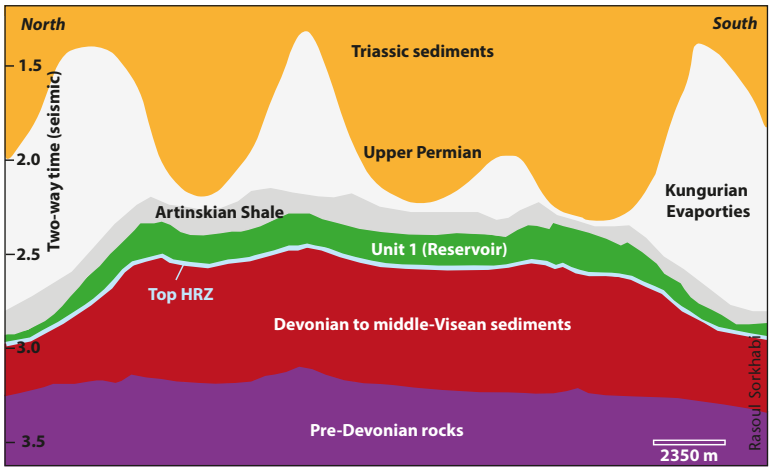
is a habitat for endangered Caspian seal, fish including caviar-yielding sturgeon, and migrating birds. Oil spills in such a shallow water environment (with little dispersion of pollutants) would indeed be hazardous to the local ecology. Although the official policy is a zero-discharge production facility, management of H_2S-rich hydrocarbon in an overpressured reservoir will continue to be a technological challenge. Even with the best practices of gas re-injection and sale of sulphur products, some of the sulphur will have to be stored onshore in enclosed or underground sites requiring particular care and facilities.

Mitigating industrial footprints on the local environment and preventing ecological and health disasters will be crucial for the success of the Kashagan field operations. Meanwhile, public education and access to environmental impact assessments, health risk reports and safety information will help the HSE objectives.



Simplified structure of the Kashagan field (based on seismic image in Ronchi et al., AAPG, 2010). This north-south section is for East Kashagan along the longitude of 52°10′ with depth to reservoir top at about 4,300m. HRZ is High Radioactivity Zone corresponding to a tight shale layer.

Transportation of oil from Kashagan to the international markets is another area of consideration. Several pipeline options are available including those via Russia, China, Iran, Turkmenistan, or across the Caspian to Turkey. Each of these routes has its own merits and disadvantages, but to gain access to markets in Europe and Asia more than one route may be necessary. Two pipeline routes are already available for Kazakh oil: The Atyrau-Samara pipeline delivers oil to the Russian pipeline system, and the Caspian Pipeline Consortium connects Kazakhstan via Russia to the Black Sea. A new pipeline from Atyrau to Alashanjou in China is under construction, and the planned Kazakhstan Caspian Transportation System can connect Kazakh oil to the Baku-Ceyhan oil pipeline.

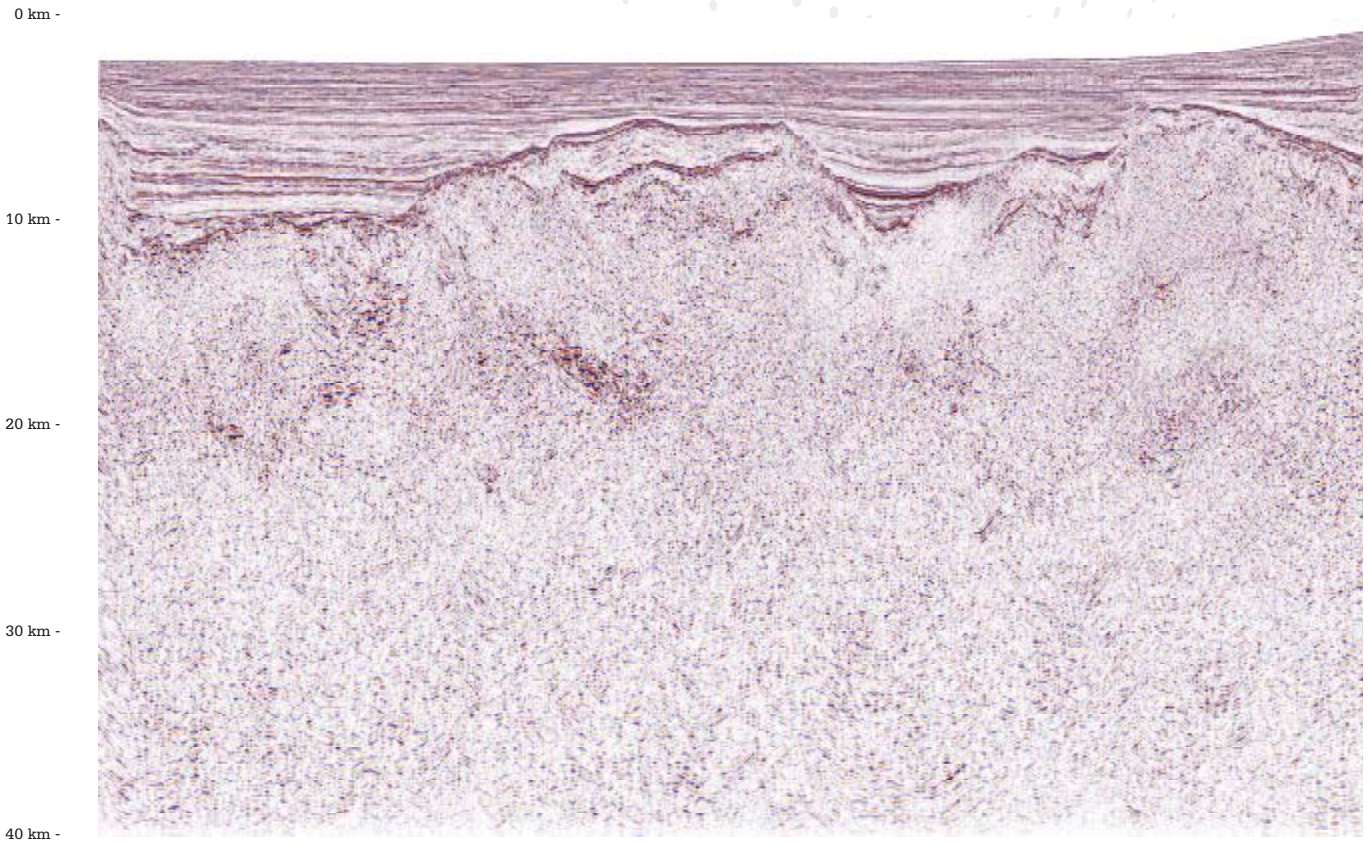
As of June 2013, a total amount of US$41.2 billion had been invested in Phase 1 of the Kashagan field development. During this phase, 40 wells were planned, half of which have already been completed. Initial production from these 20 wells is estimated to be 180,000 bopd, but the production is planned to increase to 370,000 bopd through the expansion of the gas handling facilities. Given the extent and volume of Kashagan, hundreds of wells will be necessary to effectively produce from this supergiant field. ■

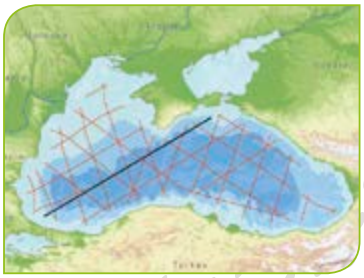
A full list of references is available at geoexpro.com

Two offshore man-made structures, Island D and Island A, are used for field operations in Kashagan. These massive rock structures were constructed using millions of tons of concrete. The produced oil from Kashagan is transported by a 92 km long pipeline to the Bolashak treatment plant near Atyrau.

NCOC

Explore the potential of the Black Sea.





ION's Black SeaSPAN™ is a deep 2D multi-client survey designed to better define the extent and potential of regional petroleum systems. The new high-quality data across the eastern and western Black Sea basins provides critical new insights into this complicated, prolific area, modifying existing theories about the basins. The study consists of more than 9,100 km of 2D data that ties existing wells and provides interpretation of key tectonic and stratigraphic elements. Explore deep sediments and formulate new play ideas. To learn more, visit iongeo.com/BlackSeaSPAN.

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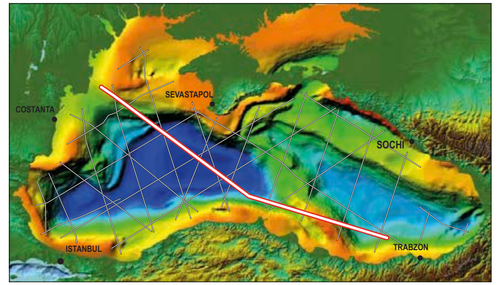
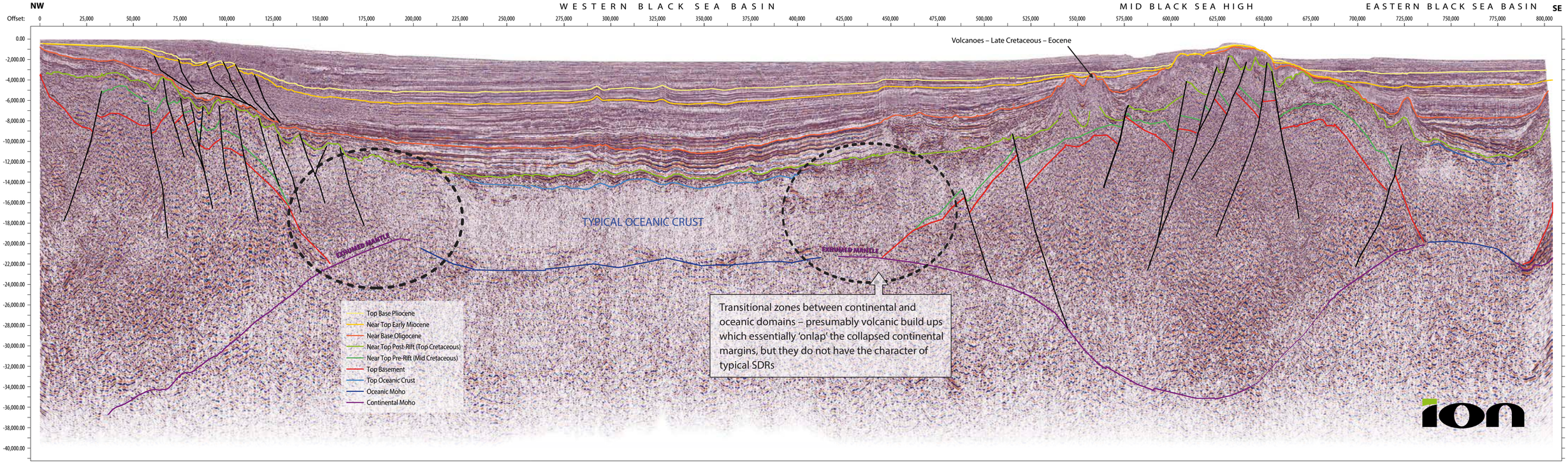
Revealing the Mysteries of the Black Sea

The foldout section crosses the centre of the Black Sea and lies north-north-west to south-south-east. Faulted continental crust is visible at the north-west end of the section. The deepest part of the basin is floored by 7 km thick oceanic crust recognisable by its thickness and seismic transparency above a semi-continuous Moho reflector. The transition zones between continental and oceanic crust (highlighted) differ somewhat from comparable transition zones in other parts of the world. East of the oceanic area is the Mid Black Sea High – a ribbon of continental crust intruded by magmatic rocks with volcanoes in the shallow section. In the extreme south-east of the line is the east Black Sea Basin, also floored by oceanic crust.



Geology Without Limits



The Black Sea: Something Different?

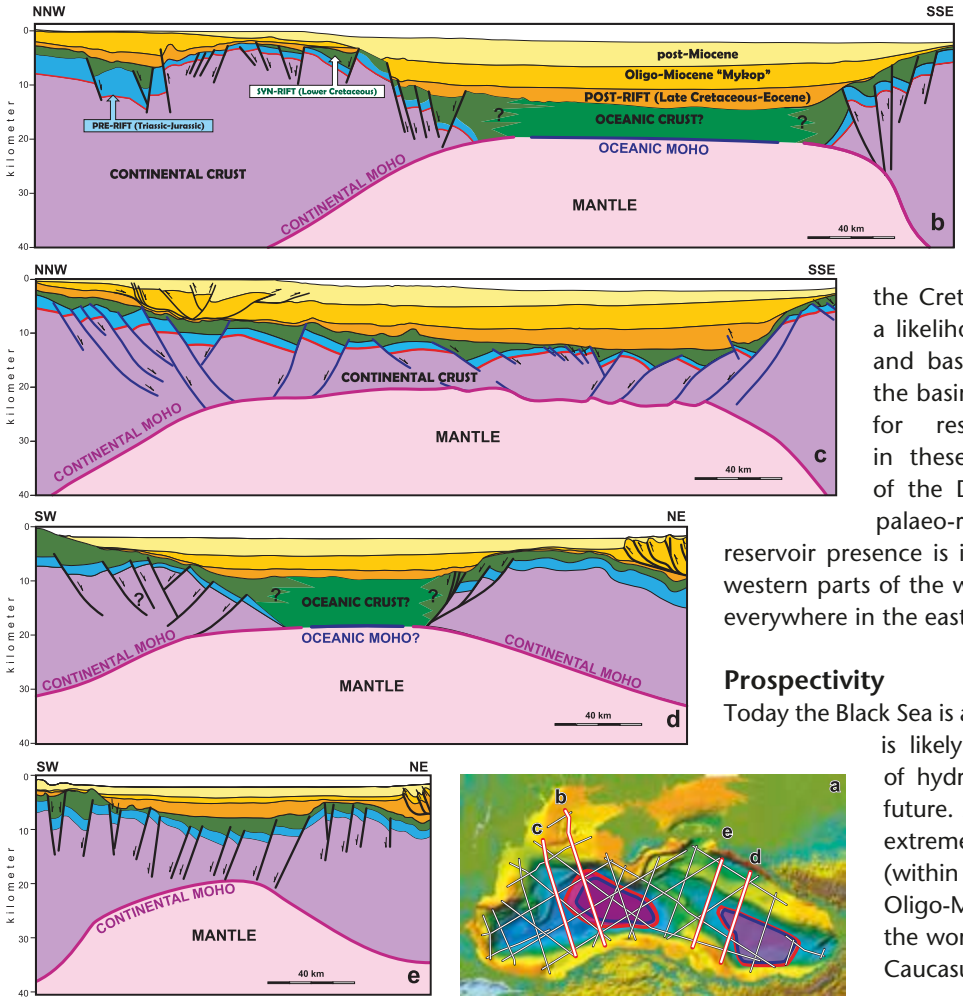
Black SeaSPAN data highlight unusual geometries that do not correspond to established general models of continental separation, leading to new ideas about the opening of the Black Sea. A range of potential hydrocarbon traps are revealed, including tilted fault blocks, stratigraphic traps and folds related to both gravitational and deep-seated tectonics.

ROD GRAHAM, NURETDIN KAYMAKCI,
ION Geophysical Consultants;
BRIAN W. HORN, ION Geophysical

The Black Sea comprises two distinct back-arc basins lying between the Eurasian continent and the accretionary collage of Anatolia. The western basin is mid-Cretaceous in age and the eastern one is late Cretaceous to Paleocene. The basins are separated by central en-echelon ridges – Arkangelski and Andrussov – which together form the Mid Black Sea High. With the exception of the north-west where the undeformed Russian Platform bounds the western Black Sea, both basins are surrounded by Tertiary fold-and-thrust belts (the Crimea, the Great Caucasus, the Pontides, and the Balkanides). In the north-east, the rift shoulder of the eastern Black Sea Basin forms a major submarine high, the Shatsky Ridge, which lies between the basin proper and the Tuapse Trough (the foreland basin of the Western Caucasus). The Eastern Pontides are essentially a volcanic arc. Interpretations derived from seismic data, gravity modelling and water depth all suggest the central parts of both the western Black Sea and the eastern Black Sea are small ocean basins (Bellusov *et al.*, 1988; Finetti *et al.*, 1988; and Görür, 1988).

Cretaceous strata are assumed to directly overlie oceanic crust, as rifting and ocean crust formation are interpreted to have occurred during this period. The lithology of the Cretaceous in the deep basins is unknown, but carbonate build-ups seem to exist on tilted fault blocks on the marginal parts of the continents. The 'tramline' Tertiary sequence which overlies the Cretaceous is shale prone with a likelihood of submarine channels and basin floor fans derived from the basin margins. The best chance for reservoir-quality sandstones in these sequences lies outboard of the Don, Dnieper and Danube palaeo-rivers. The highest risk for reservoir presence is in the southern and south-western parts of the western Black Sea Basin and everywhere in the eastern Black Sea.

Cartoon profiles of interpreted BasinSPAN lines through areas of stretched continental crust and oceanic crust in the eastern and western Black Sea basins.

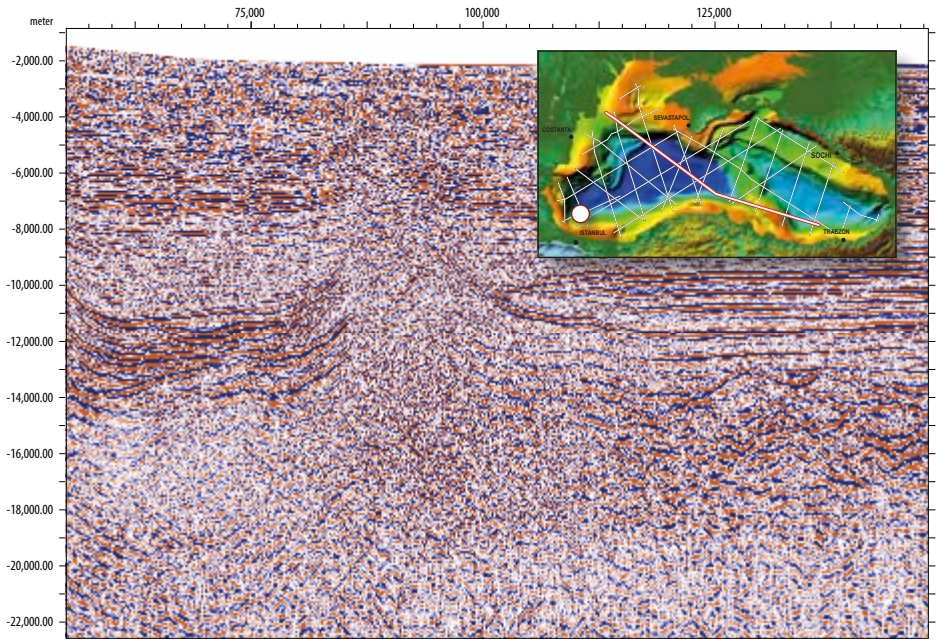


Prospectivity

Today the Black Sea is a restricted anoxic basin that is likely to generate vast volumes of hydrocarbons in the geological future. Although it is located in an extremely oil-rich part of the world (within the play-fairway area of the Oligo-Miocene Maykop Formation, the world class source of oil for the Caucasus and the Caspian), the

prospectivity of the Black Sea Basin is poorly known. The Maykop is almost certainly oil-mature beneath its 10 km thick blanket of basinal Neogene sediments, and mud volcanoes (right) testify to active fluid migration and significant overpressure. In addition to the Maykop, three separate Cretaceous horizons as well as Palaeozoic coals have been identified as source rocks (Görür, 1997).

Potential reservoirs include Cretaceous syn-rift clastics analogous to those known onshore in the Pontides, as well as Neogene channels and submarine fans and Jurassic and Cretaceous carbonate build-ups. Trapping potential exists in carbonate builds-ups, tilted fault blocks, a range of stratigraphic traps, gravitational structures and in the frontal structures of fold and thrust belts of the Tuapse trough offshore Crimea and the eastern Black Sea.



Mud volcano in the south-western Black Sea

In spite of these possibilities, the Black Sea basins have not delivered anything like their theoretical potential, which a relatively conservative estimate would put at more than 10 Bbo.

Deep Structure

ION Geophysical's Black SeaSPAN data provide unique images of the deep structure of the continental margins of the earth, but given the fact that we are looking 20, 30, or in some cases 40 km into the earth's lithosphere, it almost goes without saying that our ability to interpret the data relies partly on direct knowledge, and to a large extent on models. Using observations from ION data globally, the empirical analogue base is growing, but the Black Sea data set challenges existing models and may be something not seen elsewhere.

Ideally we recognise two types of passive margins – volcanic margins where spreading is fast, allowing decompression melting and the production of volcanic melt, and non-volcanic margins where spreading (and continental separation) is slow and there is no significant volcanism or underplating. Volcanic margins are characterised by seaward dipping reflectors (SDRs) that commonly develop between the continental edge and the true oceanic crust.

At non-volcanic margins continental separation is by faulting and ductile shear. Oceanic crust and associated spreading post-date the separation of the continents, and sub-continental mantle is 'dragged out' from beneath the continents to be exposed in the outer marginal zone (trough) between the continental edge and the ocean crust proper.

There are no clear SDRs or obvious exhumed mantle visible on the Black SeaSPAN data. The oceanic crust predicted by earlier works is obvious from the seismic character and thickness, but there are no magnetic stripes in the Black Sea to corroborate this interpretation. Both the continental and oceanic Moho are recognisable on the data. The continental Moho can be seen rising towards the oceanic areas, but it is unclear exactly how the continent gives way to the oceanic crust, as the reflectors of the ocean crust are more or less continuous with reflectors which onlap the continental edge. The map on page 61 shows the limits of oceanic crust and continental crust (red and blue lines). The area between them is presumably where the mantle has been exhumed and buried by volcanic or sedimentary sequences. How much of this material is volcanic and how much is sediment is uncertain. As we noted, the reflectors are not unequivocal SDRs and they seem to merge with oceanic crust *sensu stricto*. In the eastern Black Sea Basin there is virtually no transition zone and the transition from continental to oceanic crust is extremely abrupt.

New Observations

The western Black Sea is traditionally thought to have opened behind a continental fragment, the Istanbul Zone, which drifted south between two transforms – the West Black Sea fault and the West Crimean fault. The north-east to south-west trending lines in the south-western Black Sea show a strike slip fault and the inverted margin of Crimea is almost certainly oblique, but there is no indication of any transform on the lines through the centre of the western Black Sea Basin. Hyper-stretched continental crust in the south-western and south-eastern parts of the basin gives way to oceanic crust in the basin centre, implying a more complex opening pattern than previously thought. It seems that the western basin is comparable with the eastern Black Sea where stretched continental crust in the north-west gives way to oceanic crust south-eastwards (Shillington et al., 2008).

Future exploration will show whether the Black Sea basins are as commercially attractive as they are tectonically fascinating. ■

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East Africa: Riding High

East Africa is riding a wave of excitement and interest in the industry, with significant successes in offshore Mozambique, Uganda and Tanzania.

Bimbola Kolawole, Business Development Manager, Africa with Rystad Energy, reviews recent activity in the region.

East Africa is the latest oil and gas hub creating much buzz in the industry, thanks to increasing gas discovery success in offshore Mozambique. In addition, Uganda, situated not far from Mozambique, made its first oil discovery in 2006. Tanzania followed with the Zafarani discovery by Statoil in 2011.

As global energy demand continues to rise, it is important to know if supply will struggle to meet demand. The significant gas finds offshore East Africa have made the region a prolific one. Back in the 1960s, after limited exploration activities were carried out by some Western oil majors, the scale of the resource was not appreciated, and with only a limited local market for any gas discovered, the companies moved on to what they perceived as more promising prospects. A game-changing experience for the region became apparent after

Anadarko

Flow testing on Anadarko's Barquentine discovery in Mozambique

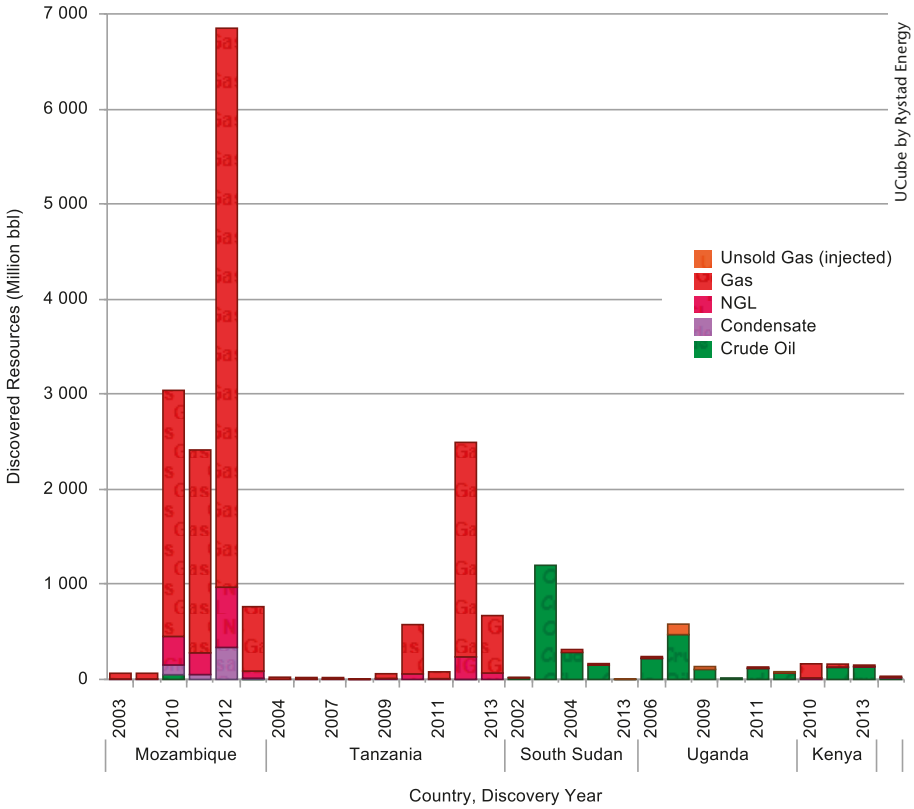
exploration activities increased, with companies discovering enough gas to mark the region as the next global LNG supplier, hard on the heels of Australia.

In fact, a vast region covering eight countries can be said to be still underexplored. Onshore activities are prevalent in South Sudan and Uganda, with production in the former having begun around the year 2000, while Mozambique and Tanzania are in tune with deepwater gas.

Many Recent Discoveries

Mozambique, Kenya and Tanzania are the countries that have dominated the headlines with discoveries in recent years.

The Republic of Mozambique, a south-east African country bordered by the Indian Ocean, Tanzania, Malawi, Zambia, Zimbabwe and South Africa, captured the world's attention following major offshore discoveries in 2010, 2011 and 2012. The last was an especially interesting year, recording high discovery activities in the top five offshore projects of Mamba South, Mamba North, Golfinho, Coral and Atum and providing a total discovered reserve in the year of 53.4 Bcf. The players that recorded success in these projects included Eni, Anadarko, Empresa Nacional de Hidrocarbonetos E.P (ENH – the state-owned oil company) and PetroChina, all of which have ambitions to continue to explore for further reserves. The development of these discoveries will have a significant, positive impact on Mozambique on a macro level.



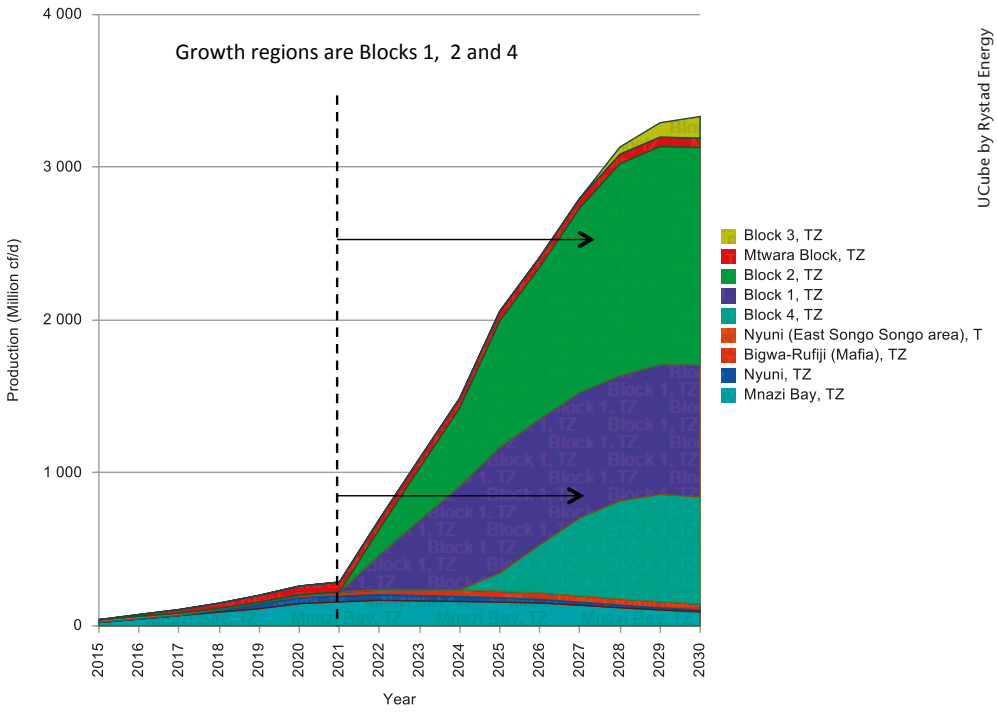
East Africa discovered resources by hydrocarbon content

Recently, ENI made a high impact discovery at the Agulha exploration prospect, which could contain 5–7 Tcf of gas-in-place. Agulha was drilled in 2,492m of water and reached a total depth of 6,203m.

Although no production has yet occurred in Kenya, exploration activities have been carried out since the 1950s. BP and Shell explored the Mandera Basin from 1950 to 1960. Between 1985 and 1990 Shell searched for hydrocarbons in the Tertiary Rift Basin, while Amoco and Total explored the Anza and Mandera Basins, respectively. However, recent exploration successes by Tullow Oil, Africa Oil Corp and Apache have resulted in a discovered resource of 500 MMboe in the last three years, 50% of which is gas. Kenya is now heading towards its first hydrocarbon production, scheduled for 2019.

The Nyuni-1 and Ntorya-1 discoveries in the Ruvuma Basin by Aminex in 2004 and 2012, respectively, as well as economic discoveries in offshore Blocks 1, 2, and 4, and Kiliwani North Production in the Songo Songo gas field, which started in 2004,

Prospects for growth in production in Tanzania



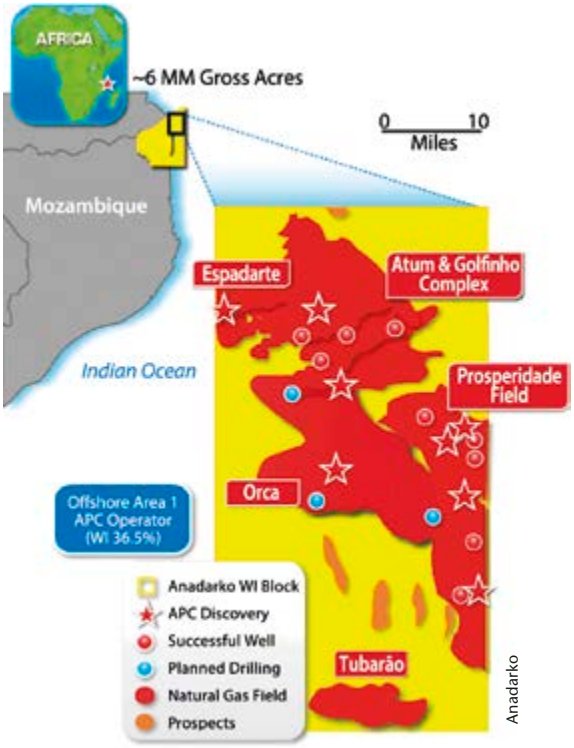
places Tanzania as the next to watch after Mozambique. With a relatively plateaued production expected from 2012 to 2025, the opportunities lie in discovered assets, which show a spiked growth potential from 2021 to 2030 according to Rystad Energy's UCube. The main drivers of the growth are Block 2, with a 200% spiked growth but which has facility and well capital investments to an estimated US$41 billion from 2014 to 2024, and Block 1 with a planned production start-up date of 2022.

Focus on Mozambique

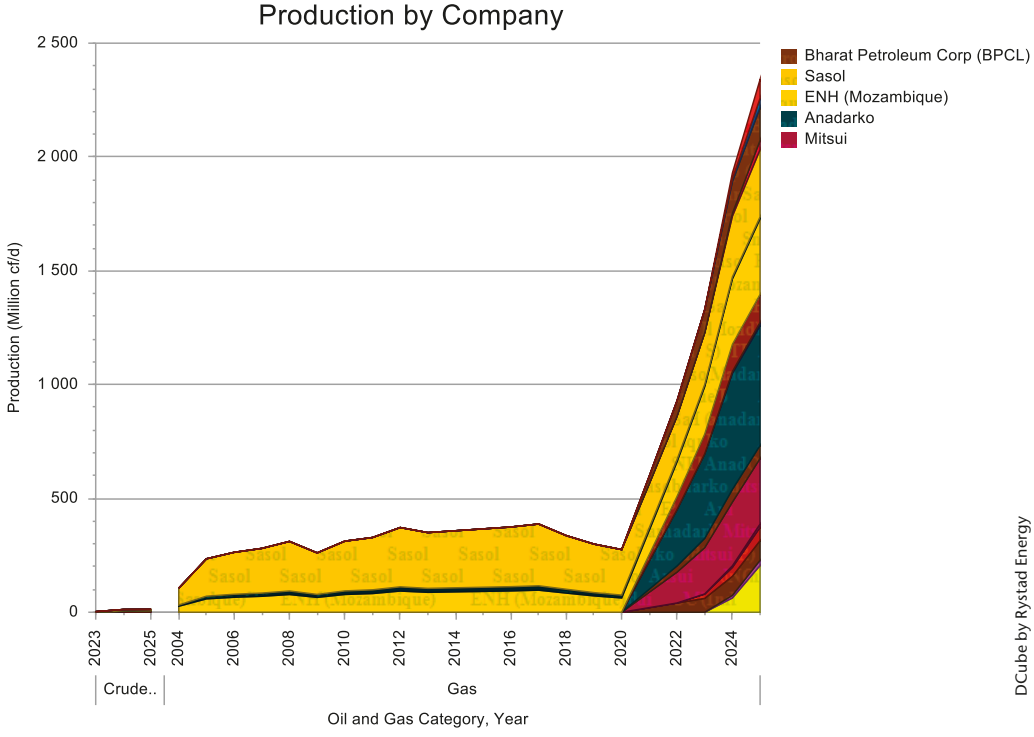
Sasol, currently the only producing company in Mozambique, is financed by the International Finance Corporation (IFC), which has 5% equity stakes in the Pande and Temane gas fields. Sasol has a 70% ownership on each field while ENH holds 25%. Sasol have proposed a two-train LNG plant, after signing an agreement with ENH to run a 30 km pipeline from Matola to Maputo and Marracuene to distribute gas to homes and small businesses. Estimated costs for this are US$40 million with an initial phase involving 5.5 Bcfgpy for a period of 20 years.

Since winning acreage in the competitive bid round for the Rovuma onshore and offshore, Anadarko has drilled 15 successful wells and exploited seven more discoveries in Offshore Area 1, which it operates with partners Mitsui E&P Mozambique Area 1 Limited, BPRL Ventures Mozambique B.V, Videocon Mozambique Rovuma 1 Limited and PTT E&P. The exploration activities in Area 1 resulted in six of the world's largest discoveries in 2010, 2011 and 2012; through its local subsidiary, Anadarko Mocambique, the independent and partners have discovered an estimated 40 Tcf of recoverable natural gas.

Anadarko is considering a joint venture to monetize up to 33% of its interest in the prolific Area 1, where it claims reported prospective reserves may be over 65 Tcfg. The Golfinho/Atum complex has an estimate of over 18 Tcf of recoverable reserves, while the Prosperidade complex (Windjammer, Barquentine, Lagosta and Camarao) is among the largest discoveries in Mozambique. These significant reserves drive home the exciting opportunity for Mozambique to become a major exporter of LNG globally.



The Italian giant Eni operates in the deepwater part of Mozambique's Rovuma Basin, where Mamba South was the largest discovery made in the company's operating history. It followed this success with more discoveries in Mamba North, where the Mamba North 1 well was drilled in 1,690m water



Production profile of a selection of companies by hydrocarbon type from 2004 to 2025. On-going developmental projects highlight Sasol's level of gas production activity as well as the future production start-up period for other companies such as Anadarko and Mitsui Bharat Petroleum Corp (BPCL).

depth. Another discovery was made in Area 4 in the Coral 1 exploratory prospect, raising the reserve estimate for the block from 75 to 80 Tcf.

Recently, Eni made a high impact discovery at the Agulha prospect in 2,492m of water in the southern part of Area 4, which could contain 5–7 Tcfg in place.

Leading LNG Exporter?

Predictably, the oilfield service market in Mozambique has witnessed growth in activities as a result of these recent discoveries. An estimated 25% increase in investment is expected from 2013 to 2025 with the majority going into offshore field development. An estimated US$22 billion will be invested in developing onshore and offshore fields by 2025. Eni and Anadarko have both awarded front-end engineering and design contracts to oilfield service companies such as Technip SA, Subsea7 SA, Saipem and Matt McDermott International Inc. for offshore infrastructural development.

However, the infrastructure challenge still looms in Mozambique. Though Sasol is currently the only producing company in Mozambique, Anadarko is confident that its first LNG sale will happen in 2018. The company credits itself for improving logistic resources since entering the country, but to achieve the speculated 2018 planned LNG export start date, more LNG infrastructural development will need to be carried out, costing at least US$40 billion, including a plant capable of exporting 175 MMboe.

Mozambique has the potential to become the world's leading global exporter of LNG, but the viability of this will hinge on demand and purchasing power, although the country's close proximity to both the Atlantic and Pacific markets will result in lower transportation costs as compared to the current LNG leading supplier – Australia.

Mozambique is about to experience a significant turn in revenue generation, employment opportunities, social improvement and infrastructural development. Will the rest of East Africa soon follow?

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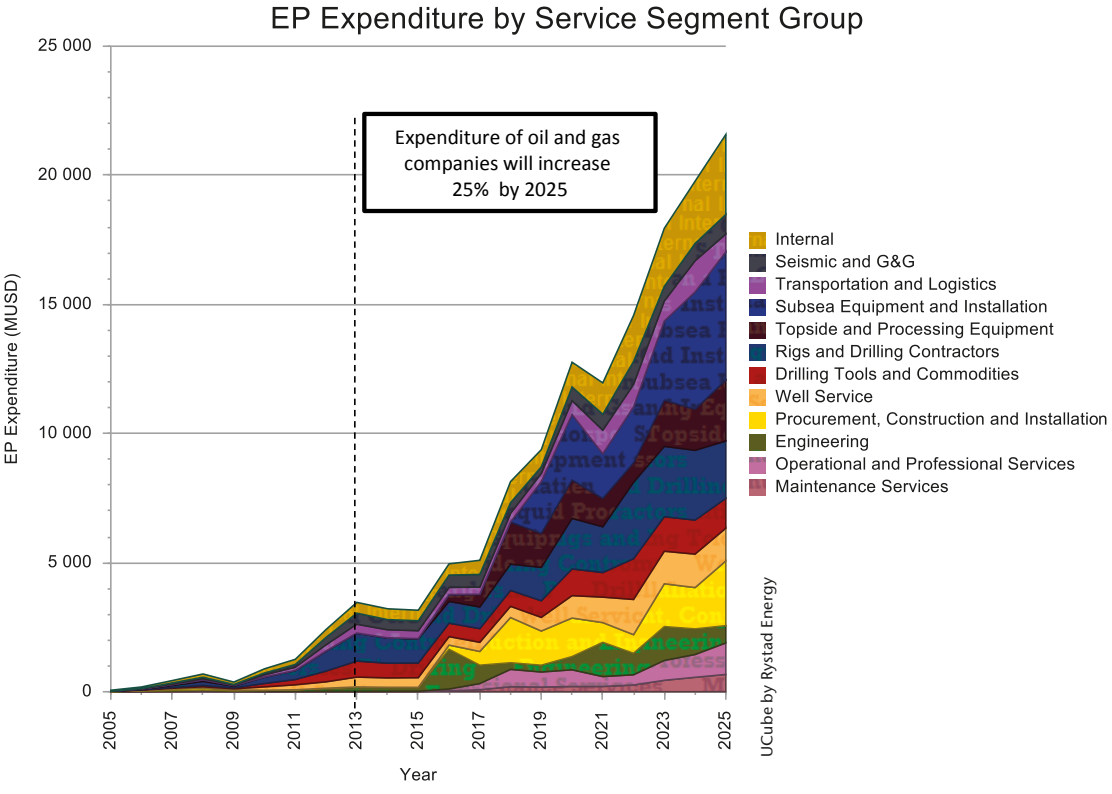
Bimbola Kolawole

Bimbola Kolawole is responsible for Rystad Energy's business development in Africa. Her expertise includes business analysis and development, strategy, risk management as well as project management. Bimbola commenced her career at Vmobile/Celtel (now Airtel Nigeria) and continued later at IHS as an Energy Account Manager covering the geographical areas of Africa, the Middle East and Europe. She holds a degree in Economics from University of Ilorin, Nigeria, an M.Sc. in Energy Finance from CEPMLP-University of Dundee, Scotland and an MBA from University of Leicester, UK.

Average spend of operators in the service sector from 2005 to 2025.



Broadband Seismic Technology and Beyond

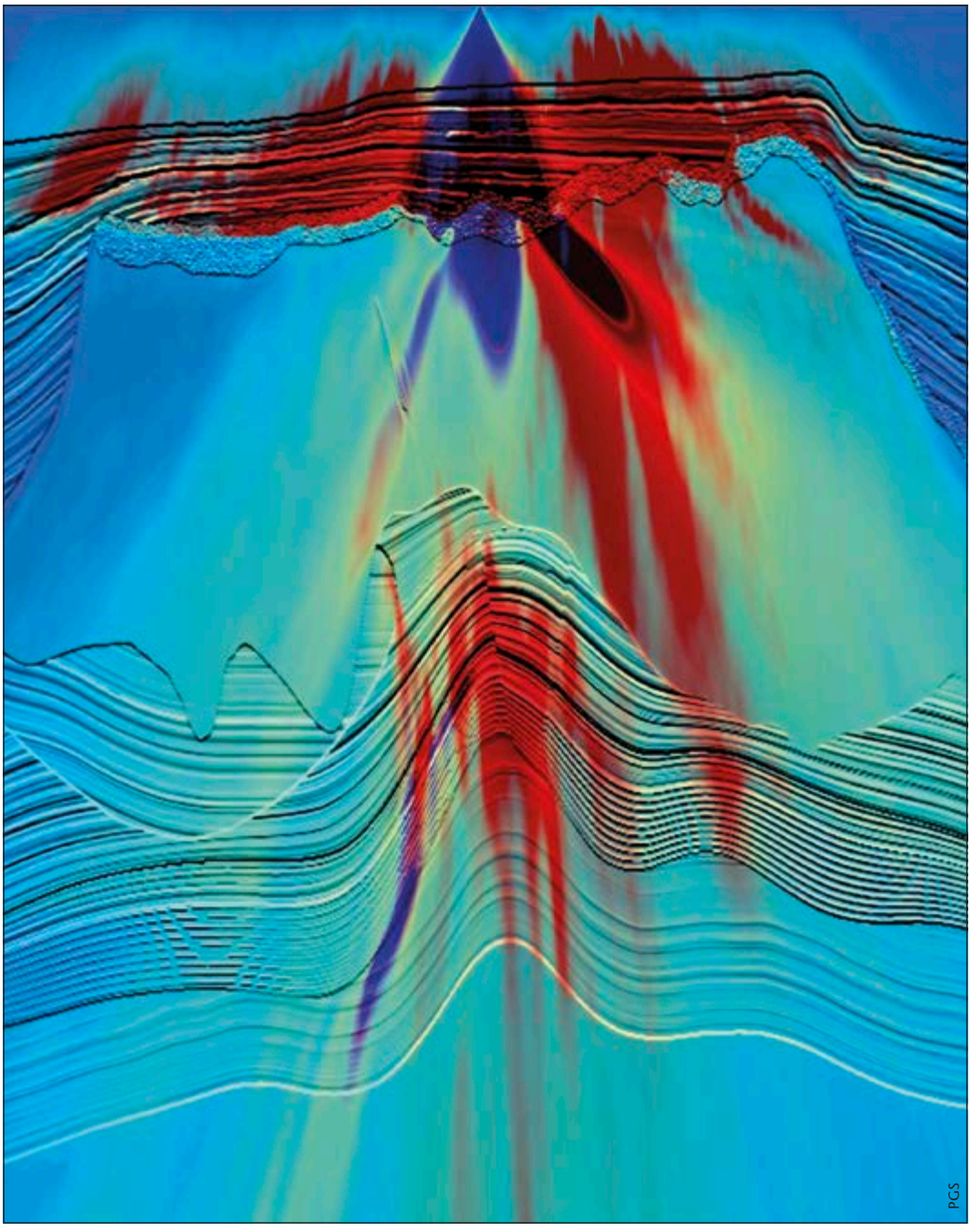
PART V: PGS's GeoStreamer – A Double Win

The GeoStreamer, launched in 2007, was the first seismic acquisition system to offer a 'broadband' solution that improves subsurface seismic imaging and interpretation in complex geological settings. It has allowed PGS to overcome many historical geophysical and operational challenges of conventional hydrophone-only streamers. The GeoStreamer is a 'double win'.

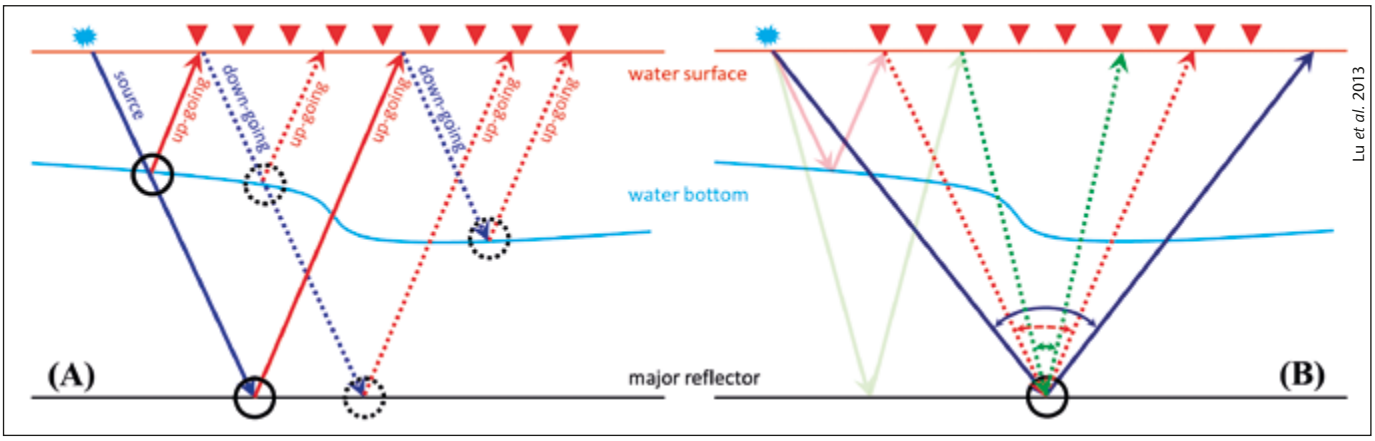
LASSE AMUNDSEN,
Statoil
and
MARTIN LANDRØ,
NTNU Trondheim

"Discovery consists of seeing what everybody has seen and thinking what nobody has thought."

Albert Szent-Györgyi (1893–1986) Hungarian physiologist, winner of the Nobel Prize in Physiology or Medicine in 1937.



Increased illumination from multiple energy: s ingle source illumination over the SEAM model. Red – multiple energy Blue – primary energy.



(A) Schematic diagram for subsurface reflection of primaries (solid lines) and sea surface related multiples (dashed lines). In seismic migration, red lines are used as receiver wavefield; blue lines are used as source wavefield. Imaging from multiples (dashed circles) has a greater extent of illumination than imaging from primaries (solid circles). (B) To image the same reflector (solid circle) by a single shot, imaging of primaries (solid lines) uses a larger reflection opening angle than that of multiples (dashed lines); therefore multiples produce a higher resolution image than primaries.

The first 'win' is that, by towing the GeoStreamer deeper than conventional streamers, it records very low ambient noise levels. Sea-surface swell motion (and thus induced noise on a seismic streamer) decreases exponentially with increasing streamer depth. If there was no geophysical compromise, seismic surveys would tow streamers as deep as physically possible, as the survey exposure to operational downtime would be reduced, survey windows would be longer in rough sea conditions, and project delivery would have less risk. With GeoStreamer technology, PGS can tow much deeper than conventional streamers, realising low noise and operational performance, thereby increasing both operational window and data acquisition productivity.

The second win is the dual-sensor design that allows unique data processing and imaging opportunities. This cascades through to better reservoir characterisation and interpretation, and more effective reservoir production monitoring.

The real strength of GeoStreamer technology is that it is shown to work in every setting. In this article, from the wealth of published applications of the GeoStreamer, we have selected two studies, one related to the use of multiples in imaging for improved near-surface mapping, important for geohazard analysis, and one related to time-lapse seismic.

SWIMming Through Multiples

Sixty years ago geophysicists argued over whether it was possible to see multiple reflections in seismic data or not. But as we know they are fascinatingly present, and the need to develop methods for attenuating multiples has remained over many decades. At the same time, speculation has occasionally surfaced as to if and how multiples can be used as a signal to image the subsurface, but success in this area has been limited until recently.

In case it is needed, here is a quick reminder on the meaning of primary signal and multiple. The seismic source sends pressure sound waves downwards into the earth. The pressure signals that experience only one single reflection at interfaces within the earth during their propagation from the source to the receiver are referred to as 'primary reflections'. Those signals that have a more complex journey, maybe reflecting three (up-down-up) or more times before they arrive at the streamer are referred to as 'internal multiples'. Those events that have reflected first in the subsurface, second at the sea surface and third again in the subsurface are given the name of 'sea surface-related multiples'. All events on their journey pass the streamer either in the upward direction or the downward direction. The downgoing events have the common name of 'receiver ghosts'.

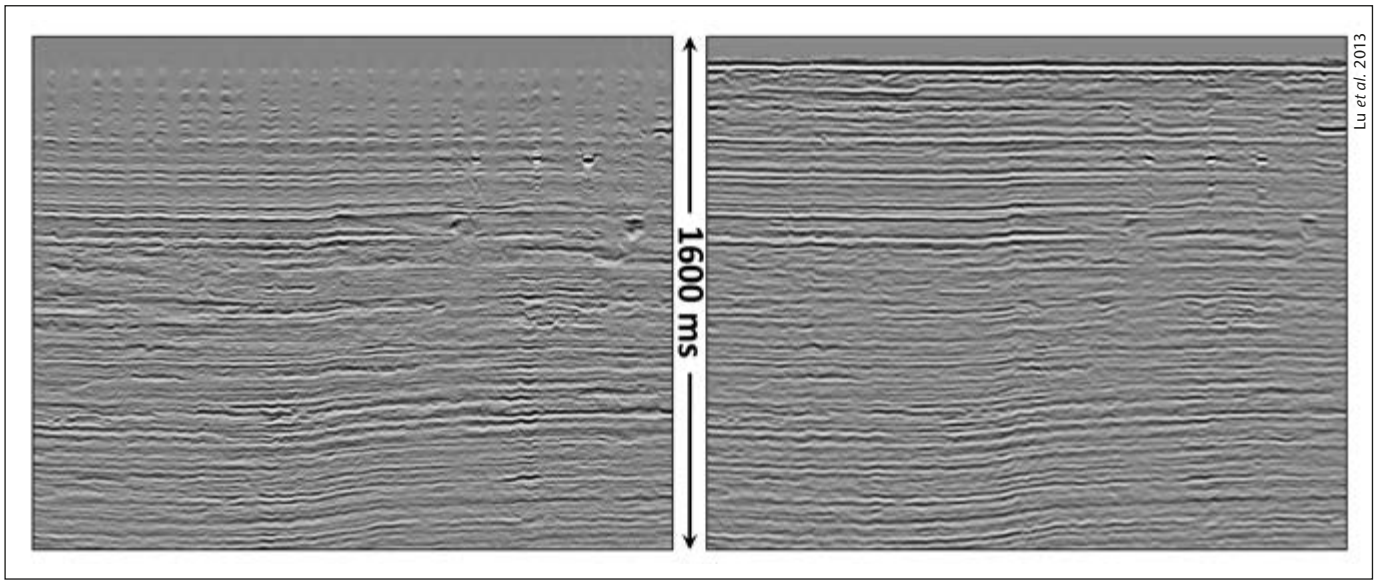
Conventional seismic data processing builds on one key assumption: that each reflection event recorded at the streamer level is a primary reflection. Hence, any recorded reflections propagating with other modes or travel paths are not dealt with appropriately during traditional seismic processing. It is primarily for this reason that geophysicists spend so much time pre-conditioning seismic data to meet the assumptions and requirements of the subsequent processes such as imaging or migration.

Conventional seismic imaging in particular assumes that all phenomena associated with reflections from the sea surface have been removed from the recorded data, including receiver ghost effects and surface-related multiples. Efforts during seismic data processing to remove multiple energy are always challenging and can risk damage to the underlying primary signals from the subsurface.

However, PGS have now demonstrated effectively that with GeoStreamer data the surface multiples can be used for seismic migration, since wavefield separation of such data into their upgoing and downgoing constituents is possible in processing. PGS use both the upgoing and the downgoing wavefields in a migration process called separated wavefield imaging (or SWIM) to yield seismic images based upon surface multiples. This innovation promises to provide complementary and useful images at all target depths. Incorporation of surface multiples into the imaging process demonstrably improves subsurface illumination, hence it opens up a variety of benefits and applications. Deep imaging around and below salt bodies and other complex geology could be improved, particularly for multi-vessel survey scenarios (wide-azimuth, full-azimuth, etc.).

Shallow Geohazard Analysis

In particular, by running SWIM on GeoStreamer data, shallow



Cross-line images from primaries (left) and from multiples (right). Imaging of multiples mitigates the strong acquisition footprint in the cross-line direction and generates a very high resolution image, including detailed information of the water bottom reflection.

geohazard analysis has proven successful. The examples in this section are from a shallow water case study from the Asia-Pacific region, where a 585 km^2 area has been extracted from a full 3D GeoStreamer survey using 12 cables, with 4,050m cable length and 75m cable spacing.

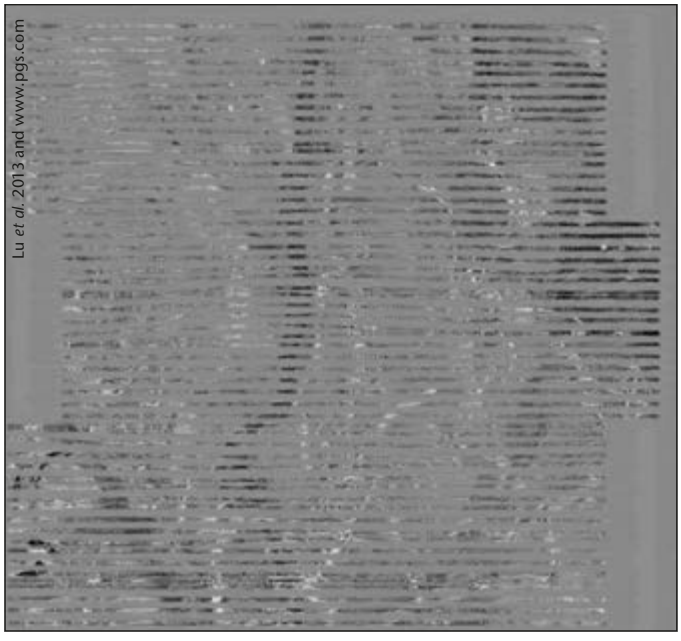
The cross-line acquisition footprint is a common issue for shallow water towed streamer seismic imaging. Imaging of multiples significantly helps to suppress the acquisition footprint, as shown in the figures on this page.

This example suggests nicely that 3D marine seismic survey efficiency can be increased (at lower cost) whilst the very shallow seismic images are in fact improved in terms of both vertical and lateral resolution. SWIM technology might be used to bridge the gap between standard site surveys and conventional 3D surveys. Potentially, marine 3D seismic could even replace conventional site surveys if the SWIM technology delivers according to its promise.

Time Lapse and Reservoir Seismic

In time lapse seismic a major focus has always been to repeat two or more seismic experiments as accurately as possible. If you change technology between the baseline and monitor survey, this change might be a challenge for optimal 4D seismic analysis. Much research has been conducted in order to analyse which parameters are most crucial for achieving high repeatable 4D seismic. An important issue has been to repeat

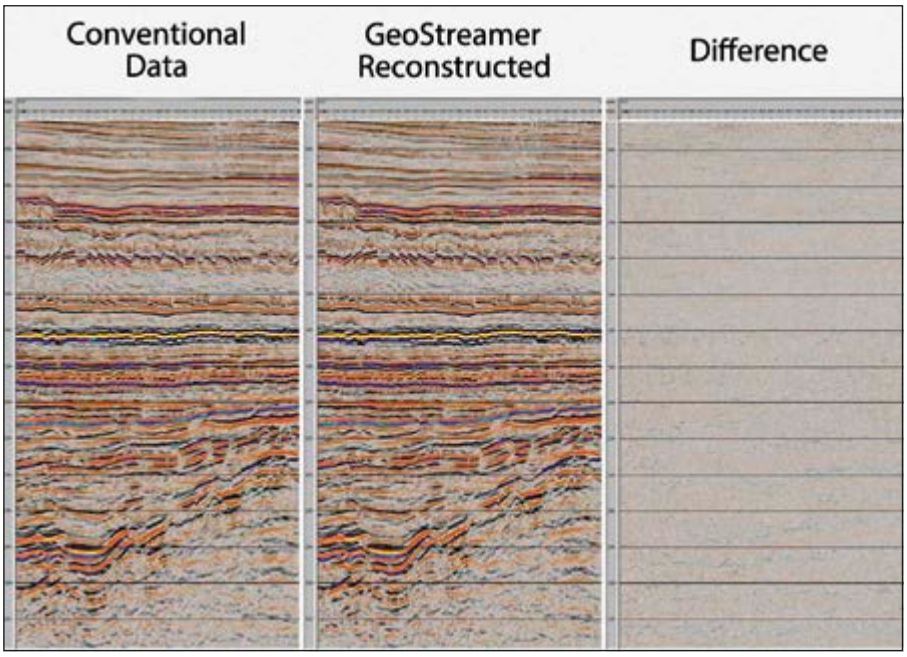
Comparison of two time slices of a region 25 km by 23 km at 120 ms TWT, corresponding to 105m depth below the sea bed. Water depth is 70m. The SWIM method applied to primary reflections (left) contains a pronounced cross-line acquisition footprint that precludes shallow geohazard interpretation. In contrast, SWIM applied to surface multiples (right) yields a remarkably continuous and high resolution final image after amplitude balancing because of the superior illumination from surface multiples. It is largely free of sail-line acquisition footprint.



the vertical source and receiver positions as accurately as practically possible. Whereas minor variations in source and receiver depths can be compensated for in processing, gross differences cannot, due to different ghosting characteristics.

In particular, with GeoStreamer technology PGS can use the dual sensor information to duplicate the parameters of any existing survey, thus allowing an operating company to perform 4D matching with its conventionally acquired survey data. For this to work, it is necessary to calculate the receiver ghost for the original survey depth and add it back into the GeoStreamer data to perform a comparison.

An example demonstrating that it is possible to use conventional data as baseline and a repeat GeoStreamer survey as monitor is shown to the right.



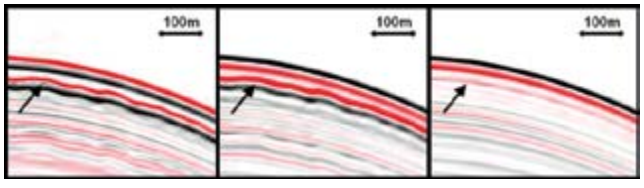
4D repeatability: conventional data (left), reconstructed GeoStreamer data (middle) and the difference between the two to the right.

In this particular test, an NRMS-repeatability error of approximately 11% was estimated for the target zone, which demonstrates that it is feasible to combine a conventional data set with a newer GeoStreamer survey and obtain good 4D seismic data. One should be careful when comparing NRMS-errors from various regions, because these numbers are strongly linked to the complexity of the reservoir and especially the overburden geology. Despite this, it is interesting to note that typical NRMS-errors for permanent 4D seismic receiver systems range from 5 to 15%. After all, at the final stage, it is not this NRMS-number that counts, but how accurately you are able to map production-related changes in the reservoir. So far, there are no 4D field examples where both the base and the monitor survey have been acquired using GeoStreamer technology. It will be interesting to see 4D field examples, hopefully in the not too distant future.

In this repeatability test the NRMS-error for the full stack case was compared to near, mid and far angle stacks. As expected, the repeatability decreases due to lower fold in the angle stacks (less data). Furthermore, there is no significant decrease in repeatability going from near to far offsets, indicating that the repeatability does not vary significantly with offset. Most algorithms designed for pressure-saturation discrimination from time-lapse seismic data rely on high quality repeated angle stacks, and hence this is an important observation from this experiment.

In some cases (especially in rough seas) the receiver ghost might appear as an undulating event following the primary reflection from the seabed, as shown in the figure below. Due to the fact that the GeoStreamer actually provides two measurements, it is possible to attenuate these undulations significantly. Although there are no practical examples so far demonstrating this on two time-lapse seismic surveys, it is reasonable to expect that this type of surface-related 4D noise will be handled better with GeoStreamers when compared to conventional streamers.

Common shot gathers for vertical particle-velocity (left), pressure (middle) and processed up-going wavefield (right). Notice that the undulating behaviour of the receiver ghost is not present on the up-going wavefield.



Since the desired accuracy of 4D seismic surveys is more demanding than for regular surveys, the weather conditions for 4D seismic surveys should be as close as possible to ideal. The example shown above is a strong indication that this narrow 4D weather window might be extended. There are two major reasons for this: firstly, that towing deeper means less noise and secondly, that the dual measurement (velocity and pressure) enables more effective removal of receiver ghosts. Assuming a rough sea surface, it is easy to imagine that the ghost signal will be less repeatable than the primary signal. An efficient attenuation of the receiver ghost signal will therefore lead to improved 4D repeatability.

Acknowledgement

We thank PGS for permission to show the data examples.

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Russian Oil and Gas: No Guarantees On Growth

NIKKI JONES

Russian production now equals that of Saudi Arabia and the country has massive undeveloped reserves. But are the headline figures misleading?

In 2013 Russia has come to equal Saudi Arabia in oil production, reaching a post-Soviet high of 10.4 MMbopd: in terms of total hydrocarbons, the figure is an impressive 21 MMboepd. The country now accounts for almost 13% of the world's oil supply, and there is clear further potential in its massive shale reserves and the Arctic, both of which are only just starting to be explored and developed. The Bazhenov Formation in western Siberia is vast, dwarfing the North American shale fields of Bakken, Eagle Ford and Duvernay, while the Russian Kara Sea alone holds the tantalising possibility of 100 Bboe. It would appear that there is much to be hoped for from Russia in terms of long-term supply and price stability.

False Impressions

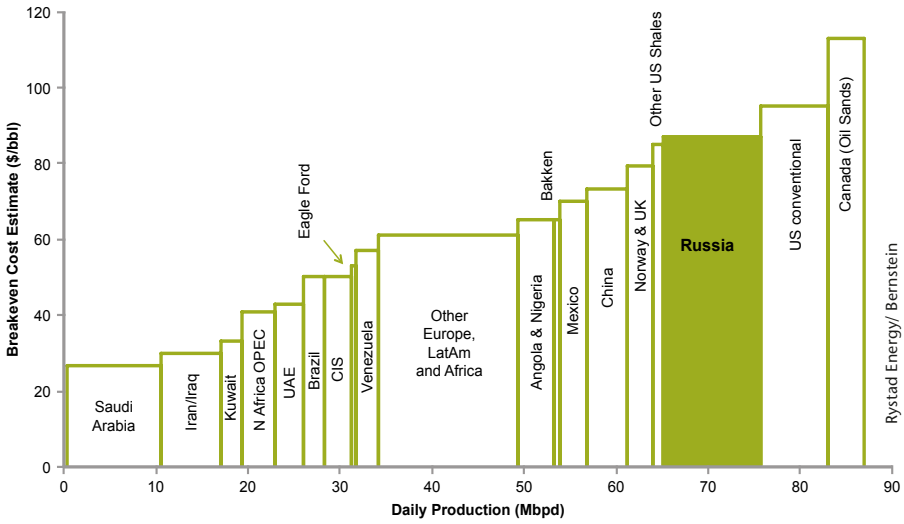
However, many observers argue that these headline figures are misleading and that production will begin to slip as early as 2015. According to Oswald Clint, Senior Analyst at Bernstein Research, Russia is having to run fast just to stay still, relying on ageing fields with declining output. Russian oil now comes mainly from Soviet-era fields, with new fields contributing approximately only 12%. Typically, older wells are now producing only 50–70 bpd, with a water cut of over 90%. In consequence, these fields are being worked hard and companies are drilling many more wells in order to maintain production levels. According to analysis by Bernstein Research, Lukoil now has to drill thousands of wells to achieve a volume equal to just 80 or 90 wells in the Gulf of Mexico.

The cost curve has risen dramatically. Companies now need a price of $90/bo simply to make a 10% return. However, this is not just the cost of physical production, which remains relatively low at approximately $3 per barrel. Long-distance transport adds a further $8/bo and other factors bring the physical cost of getting oil to market close to $20/bo. The largest additional cost is the export duties, currently over $50/bo. Together these factors place Russia's marginal rate of supply below only US conventional production and Canadian oil sands, but above those of every other region, including Nigeria, Venezuela, the North Sea and US shale.

It is not just the tax rates that make Russia a less-than-attractive investment opportunity. Onshore fields typically have a longer ramp-up period than fields in the North Sea and elsewhere: Russian fields typically take 40–50 years to reach peak production compared to just two to three years in other

The Kharyaga field in the Russian far north demonstrates the harsh environments in which the exploitation of hydrocarbons is conducted in much of the country.

Svein Are Enes /Statoil



While Russia is one of the world's largest producers, it is also one of the highest cost crude producers.

parts of the world. Despite this, it is high levels of capital expenditure that are currently supporting Russian production: according to Oswald Clint, CAPEX is now approximately $6 per barrel compared to just $2 six or seven years ago. All costs are rising.

Little Appetite for Exploration

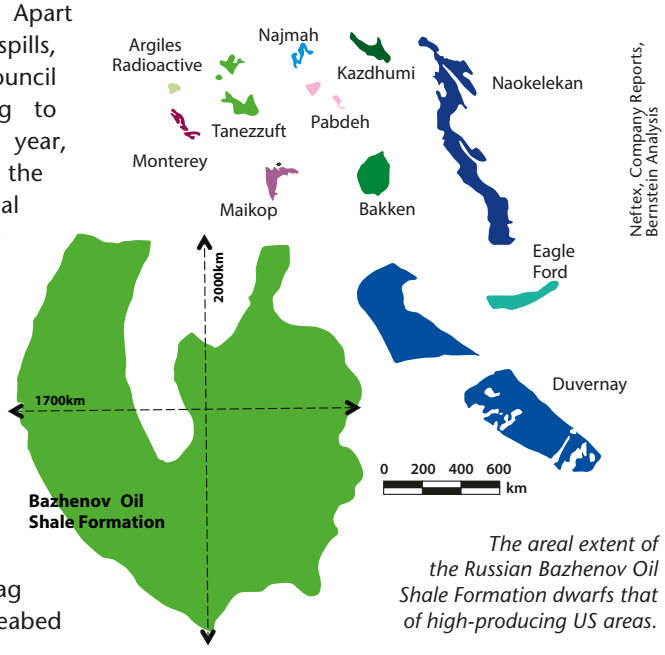
Because of a combination of tax and political factors there has been little appetite for exploration, although this may be changing. Legal restrictions apply to all 'strategic deposits', i.e. those of more than 500 MMbo or 1.77 Tcfg, which are reserved for the state backed companies. But foreign companies are moving in and hundreds of smaller blocks are being auctioned monthly in a fairly transparent manner, despite the major disincentive that bidding companies risk not being given a production licence if they make a significant find. As Julian Lee, Senior Energy Analyst at the Centre for Global Energy Studies, points out, often there are no bids for blocks – apart from the licensing risk, companies face a high level of bureaucracy, limited geological and geophysical information and the prospect of working in very challenging terrain with poor transport infrastructure.

New technology may bring some hope but, according to Clint, much of the 'low hanging fruit' in terms of enhanced recovery has already been picked. There is a potential two trillion barrels of oil in the 2,300,000 km^2 of shale formation and currently the Russians are only using conventional seismic technology to identify suitable natural fractures for drilling, which leaves the potential for further recovery through US-style fracking. However, the inhospitable environment, the need for expensive site clearance, and the lack of infrastructure all add to the cost of development in this area. In terms of environmental costs, as yet the Russian people appear relatively unconcerned but it is possible that international pressure may become a factor as climate change calculations add in the high levels of methane that are being released.

Similarly the Arctic, for all its promise, comes with great costs and high risks. Despite the polar cap's melting, there is still only a limited drilling window of a few summer months. Apart from the possibility of spills, for which the Arctic Council has been attempting to agree a treaty this year, the current rush for the Arctic has the potential to become a military engagement. The 1982 Law of the Sea gives each state an Exclusive Economic Zone of 200 nautical miles for fishing and fossil fuels but lack of international law beyond this point led Russia to plant its flag in the North Pole seabed in 2007. Both Russia and Norway have made submissions to extend their EEZs on the basis of their continental shelves: Norway's bid has been accepted but Russia has been told to come back with better data. Canada and Denmark are likely to submit soon with bids that may overlap Russia's. It has been noted that Russia is building up its military capability in the area, and other states have made similar moves.

Oil Price is Critical

The price of oil is critical if investment is to continue. As many observers have noted, technology is not only *not* bringing the cost of production down but it is increasing supply, which brings the threat of weaker prices. There appears to be little room for cost reduction although the government has said it will waive some taxation in order to encourage investment in shale. However, it is likely to remain reluctant to significantly reduce its fiscal take since its sovereign wealth funds are weak compared to other oil-producing states or China. However, interestingly – and possibly inadvertently – Russia has been supporting a high Brent price this year by exporting less to Europe, refining and consuming more at home and rapidly increasing its exports to China. This Asian pivot has been made possible with the new Eastern Siberia-Pacific Ocean pipeline and in June, Rosneft signed a deal to double shipments. Russian oil

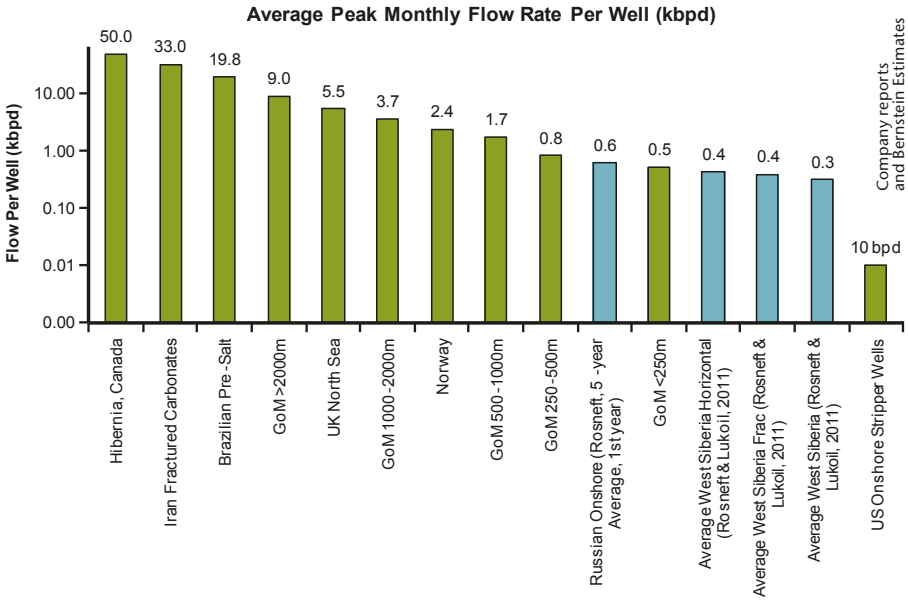


The areal extent of the Russian Bazhenov Oil Shale Formation dwarfs that of high-producing US areas.

has, in the past, generally traded at a discount to Brent, reflecting its poorer quality, but this summer it has traded at a premium as European refineries have seen supplies cut. Russia's reorientation towards the East is effectively pushing up the global benchmark and possibly making investment more secure.

Gas Investments Dubious

However, 50% of new Russian production is gas and Russia's market – and international prices – have appeared less secure over recent years as America has developed its shale reserves and Europe has threatened to follow. Last year, Gazprom was forced to abandon the Shtokman gasfield in the Barents Sea when its US market dried up, and similarly Total and Statoil abandoned Snøvit: the two developments have thrown long shadows over all gas investment. However, the threat to prices is not simply from global over-supply but from LNG connecting hitherto disconnected producers and consumers and creating a global market. Russia – as keeper of 18% of world gas reserves – is threatened with the end of long-term bilateral contracts that have standard take-or-pay clauses and are indexed to oil. In 2012, Gazprom was forced to make significant concessions to customers, and the EU Commission began an anti-monopoly investigation of the company, forcing it to pay substantial amounts to European utility companies.



Well productivity an order of magnitude lower at Russian fields drives the need for more wells.

However, as long as Japanese demand remains high in the aftermath of the Fukushima disaster (they are the main spot purchasers), and Europe remains tentative about developing its own shale, Gazprom appears secure in its investments. Last year, it increased its average daily production by 30,000 b/d and has attempted its own Asian pivot, although Putin remains fearful that gas will find its way back to Europe and undermine Gazprom's market there.

Unexpectedly, a significant threat to Gazprom comes from Rosneft, the only Russian company that is truly performing well. Under the presidency of Igor Sechin, KGB veteran and confidant of President Putin, the company has taken over TNK, moved into the Gulf of Mexico, begun 'tight oil' production in Siberia and, since 2012, a drilling programme in Russia's Kara Sea. In 2012 Rosneft replaced 130% of its reserves, and 200% each year between 2009 and 2011. Increasingly looking like a 'supermajor', Rosneft now produces 4m b/d, more than ExxonMobil. In July, Rosneft took control of Itera, an independent gas producer, signalling that it aims to move into the gas business in a significant way, and break Gazprom's monopoly on gas exports. Exactly how that will work out in terms of Russian politics is unclear, as are the implications for future gas investments.

President Putin has asserted that Russia is able to maintain production at over 10 MMbopd at least until 2020. This looks unlikely given the current investment climate and the formidable physical challenges faced by companies. As much as the world may welcome successful exploration and production it appears that there will be considerable environmental costs, since the main areas of focus are the Arctic and shale. But given the size of Russia's contribution to world supplies, falls in production – which appear likely from 2015 – will have a significant impact on prices. ■

The research vessel Academik Mstislav Keldysh *surveying the Russian Arctic Shtokman field in 2010.*

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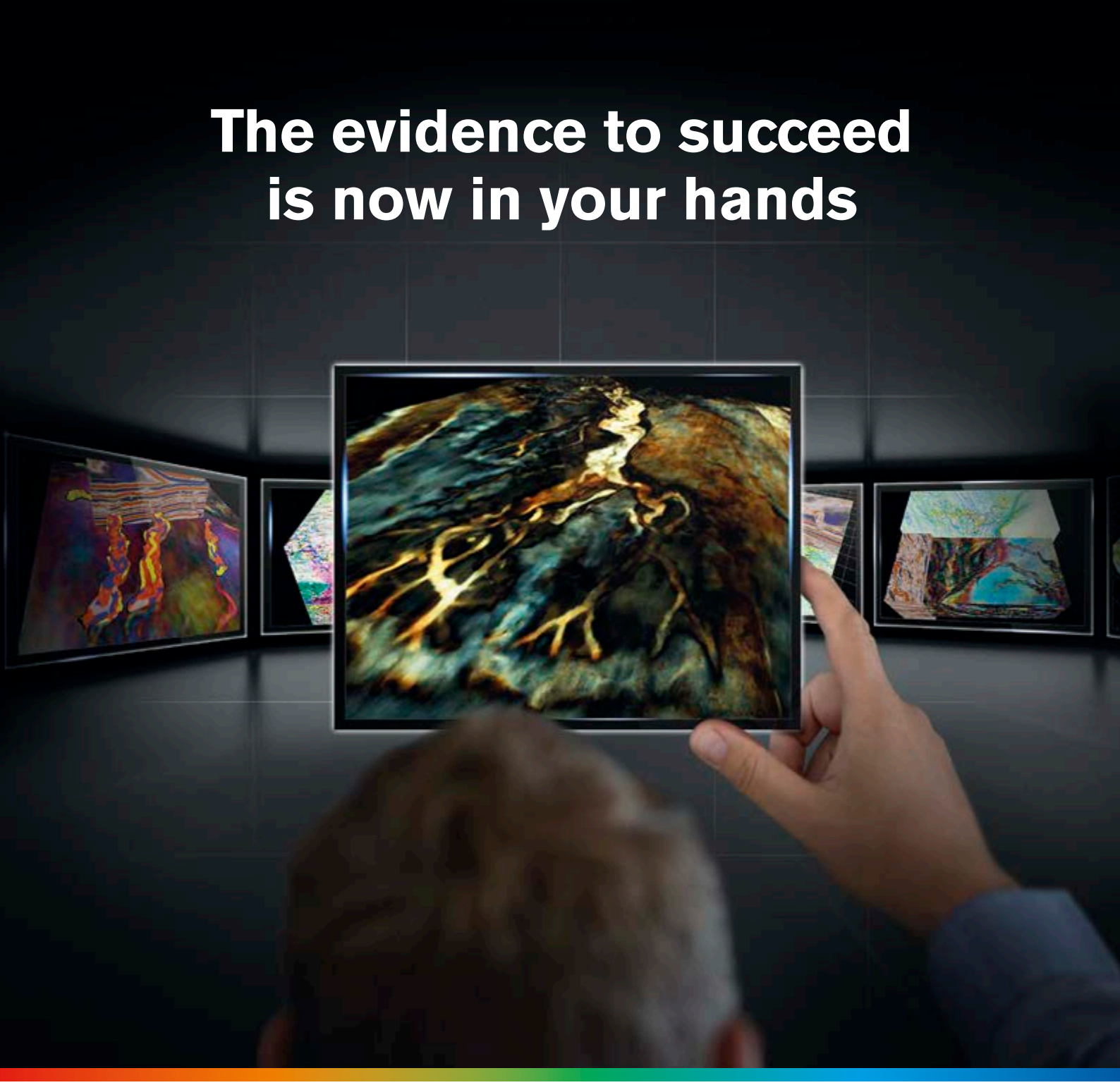

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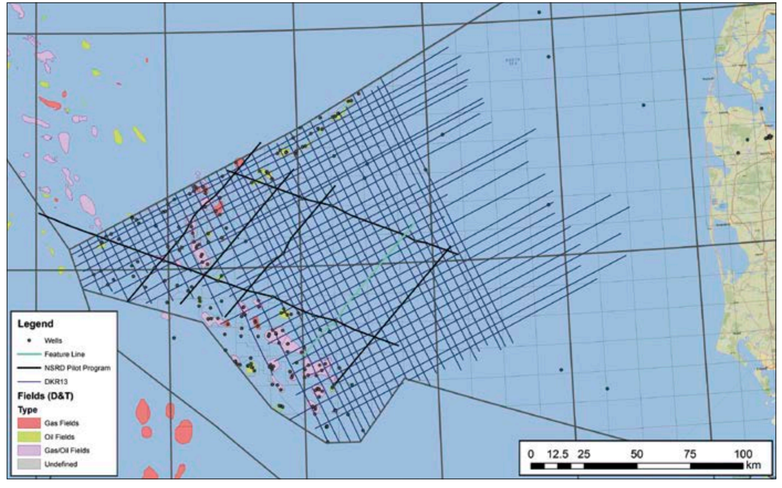
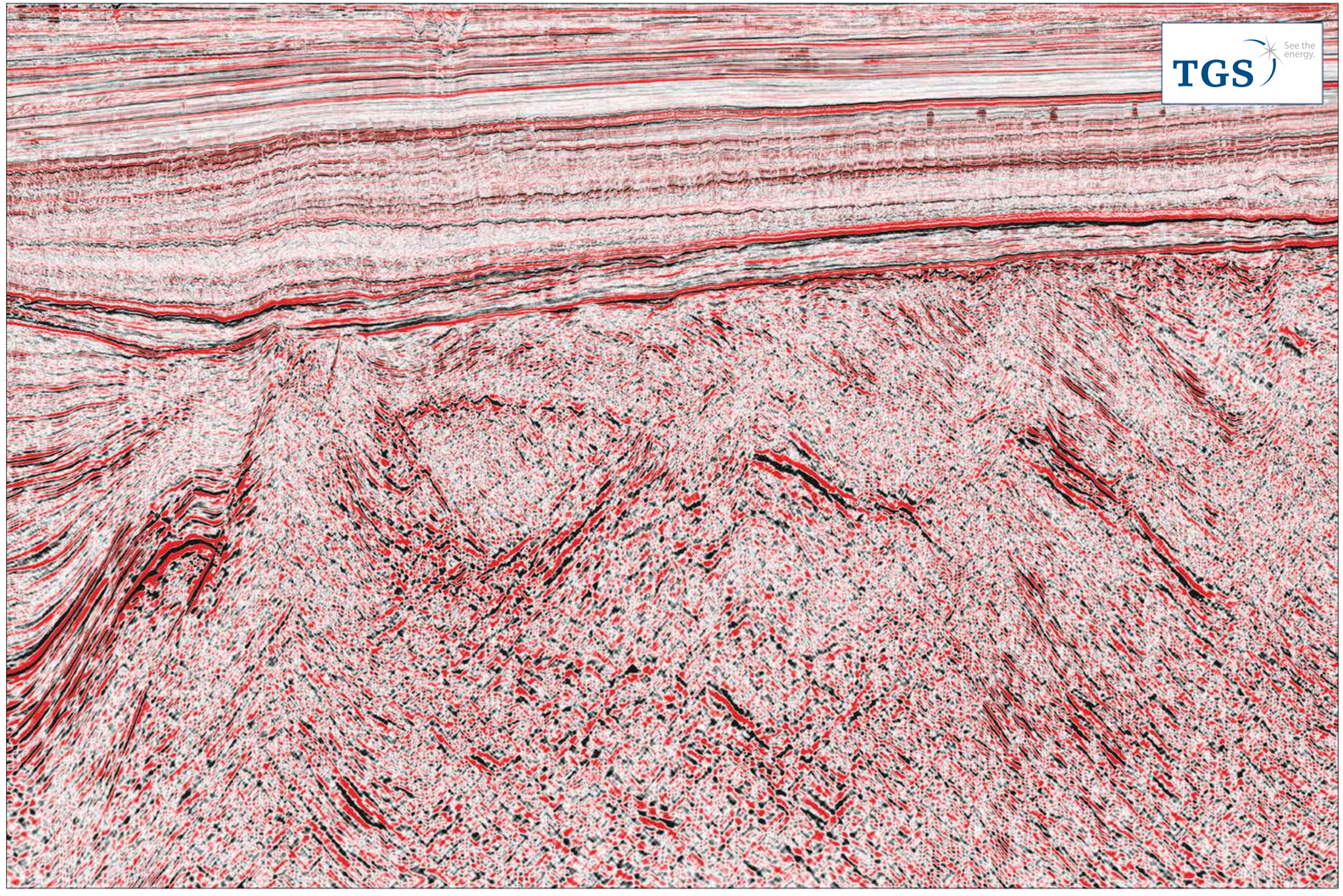
Danish Sector:
Insight into Mature and Deeper Plays

TGS' new regional 2D long-offset seismic survey of the Danish sector employs innovative processing techniques already proven in the North Sea and around the globe. The new data will enable explorationists to assess opportunities in underexplored areas within the Danish sector and gain deeper insight into the more mature plays.

This 2D long-offset line is orientated north-east – south-west and has an overall length of 85 km from the hangingwall of the Coffee Soil Fault through the Roxanne-1 well over the high between the Central Graben and Horn Graben north of the Luna-1 well.



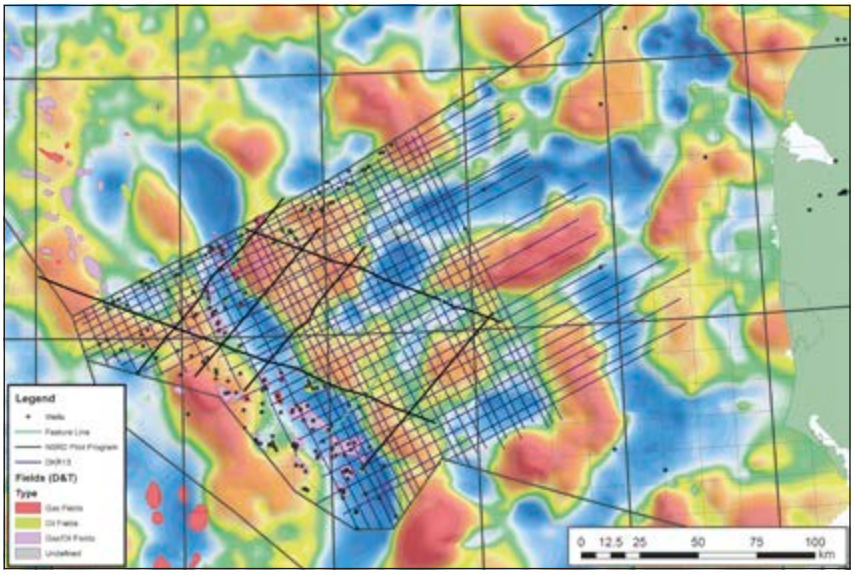


Danish Sector Revealed

Most exploration in the Danish sector has been focused within the Central Graben area and the north-east – south-west border with Norway. The foldout on the previous page presents a 2D long-offset line acquired during a 2012 test survey. This pilot programme is an extension of TGS's successful NSR grid into the Danish sector and line provides deeper and clearer imaging over both underexplored areas and more mature regions within the sector.

WILL BRADBURY, STEVE DREWELL, GULNARA HICKMAN

This article focuses on the areas of the Danish sector which are considered to be most prospective, yet largely underexplored. The map on the right shows the pilot programme location and current distribution of wells, discoveries and producing fields overlain on the satellite gravity data. It also shows the newly acquired DKR13 long-offset survey currently being processed ahead of the 7th Danish Licensing Round announcement.



Pilot and new DKR13 location and gravity map.

The principal areas of current and historical exploration and production focus on the Cretaceous within the Central Graben and the Paleocene close to the north-east – south-west border zone with Norway, the Siri Fairway. However, exploration over the past ten years has resulted in the opening of a HPHT (High Pressure High Temperature) play in the Jurassic of the Central Graben. Additional prospectivity and new play concepts may also be present within the gravity lows of the high between the Central Graben and Horn Graben, here referred to as the East North Sea High (ENSH) to the east of the Coffee Soil Fault, an area which is underexplored and difficult to image. These pre-Mesozoic basin areas are currently receiving increased attention from the petroleum industry. A detailed discussion of the Palaeozoic petroleum system can be found in Pedersen, 2007. It is clear though that better understanding of the deeper structural framework from new long-offset seismic will assist in the assessment of early rifting, basin evolution and prospectivity.

Significant Potential

The line presented on the foldout has been chosen for its imaging of the deeper section, specifically the Jurassic of the Central Graben and the pre-Permian sections of the basins delineated by the gravity map on the ENSH, highlighting the significant potential of this dataset for exploration and regional understanding. Danish Central Graben Jurassic-Cretaceous structural evolution and basin formation has been discussed by many authors (Møller and Rasmussen, 2003), but there has been less focus on the earlier Carboniferous to Permian rifting. Good insight on this earlier rifting comes from the 26s TWT MONA LISA lines discussed in Lyngsie and Thybo (2006) and Viejo et al. (2002) and references therein. These lines image the deeper structure at the near basement level, influencing the development of the trapping structures seen on the presented seismic foldout.

The newly available data represents a significant uplift in imaging of the offshore Danish sector area over existing exploration seismic data and the specialist research data. The presented line images up to 2.5s of Palaeozoic sediments in the gravity lows of the ENSH area. Large tilted fault blocks approximately 15–20 km on section highlight the potential for more well developed trapping structures beneath the BCU. The sediments within the tilted fault blocks are proven to contain a Permian section (Luna-1 well) but also probably comprise Carboniferous (as evidenced from seismic analogues close to the Danish-Norwegian border) and older Palaeozoic strata. A significant proportion of this is likely to be Silurian clastics sourced from the Caledonian Highlands. The shallower section shows wedges of potentially syn-rift Permo-Carboniferous stratigraphy and an unconformity identified as Permian in age in Viejo et al. (2002). Basins on the gravity map to the north and south of the basin intersected by this line may also contain structured sediments of a similar age.

The Jurassic and deeper section in the Central Graben has also been targeted in the pilot programme and the new DKR13 survey. This follows increased industry interest in the HPHT prospectivity in this region. Over the last 10 to 15 years wells such as Hejre, Gita, Maja and Svane have all proven successful in Jurassic sands of the HPHT terrain sourced from the Farsund Formation, while Middle Jurassic coals prove the existence of two petroleum systems (Petersen et al., 2000, 2010). Hejre-1 and Svane-1 prove good reservoir porosities at depths approaching 5.5 km (Johannessen et al., 2012), indicating the significant current and future potential of these plays and the need for more data to support understanding of the development of the petroleum systems.

The new data described in this article provide explorationists with access to a previously unseen level of detail within the major structural features of the Danish sector. The test line survey was the precursor to a new 8,500 km, long-offset 2D survey, DKR13, acquired during summer 2013. The new dataset will benefit from processing workflows developed during the test line programme.

Seismic Processing

Initial passes of noise attenuation in different time-offset domains were applied to target the removal of coherent and incoherent noise. Once the dataset was relatively clean of incoherent noise, TGS' Clari-Fi™ technology was applied to de-ghost the data, removing the source and receiver ghost notches seen in the amplitude spectra. The corresponding enhancement of low frequencies towards the first notch at 0Hz significantly improved the imaging of the Permo-Carboniferous section.

Due to the shallow water depths in this region (typically 30m), the data suffered from strong, short-period water layer reverberations. These were attenuated during the Clari-Fi de-ghosting process, which includes a 'giant' statistical deconvolution averaged over a large number of shot points and common slowness planes.

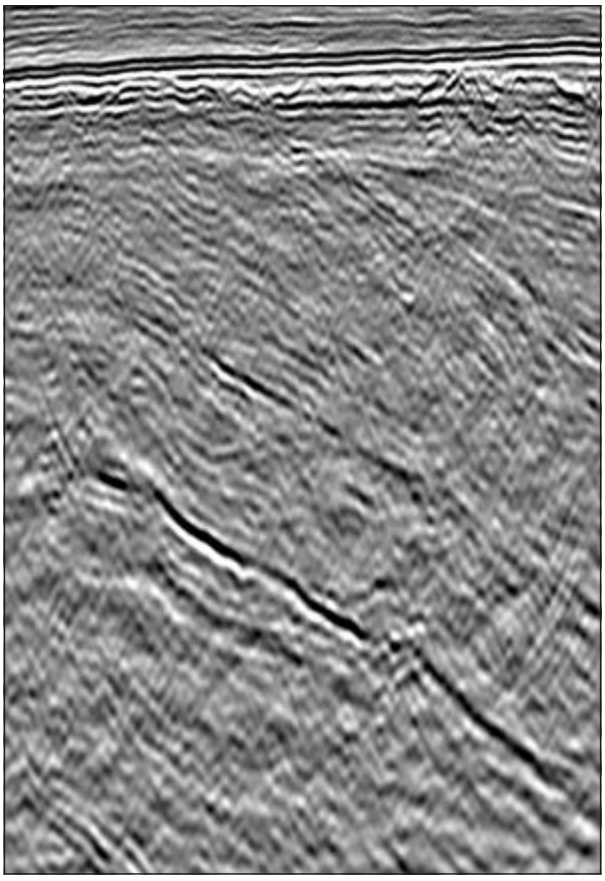
Once the data were de-ghosted, further multi-domain noise attenuation was applied which consisted of velocity-driven muting in both the shot tau-p and receiver tau-p domains. Following this, hi-resolution Radon de-multiple was applied and another pass of noise attenuation performed prior to pre-stack Kirchhoff time migration.

A second pass of hi-resolution Radon de-multiple was performed post migration, followed by additional noise attenuation prior to amplitude inverse-Q correction. Internal multiples, generated within the high velocity chalk layer and having little residual moveout, were addressed through a targeted technique in the offset domain prior to final stack. Post stack processing was limited to time-variant scaling and targeted dip enhancement.

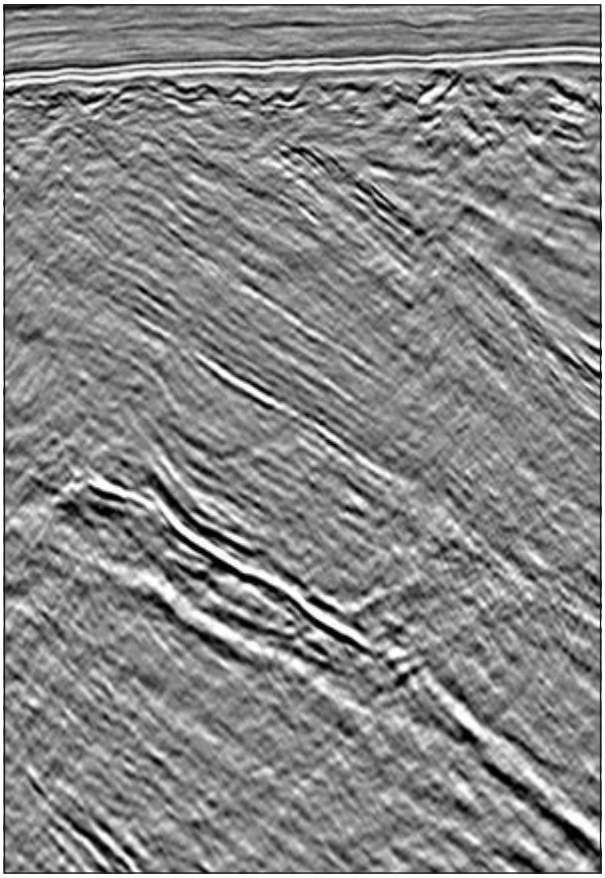
A full list of references is available at geoexpro.com ■

New Dataset

Considerable improvements have been seen during the processing of the test lines, allowing TGS to develop better processing sequence focused on the deeper Jurassic section in the Central Graben and the pre-BCU sequence in the ENSH area. DKR13 is the first modern long-offset, regionally consistent seismic survey in the Danish Sector, which will be an important tool for explorationists for the upcoming 7th Licensing Round.



NSRD pilot programme before application of Clari-Fi.



Applied Clari-Fi processing sequence enhances deeper imaging and broadens frequency content of the data

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Anatoly Zolotukhin
International Specialist

JANE WHALEY

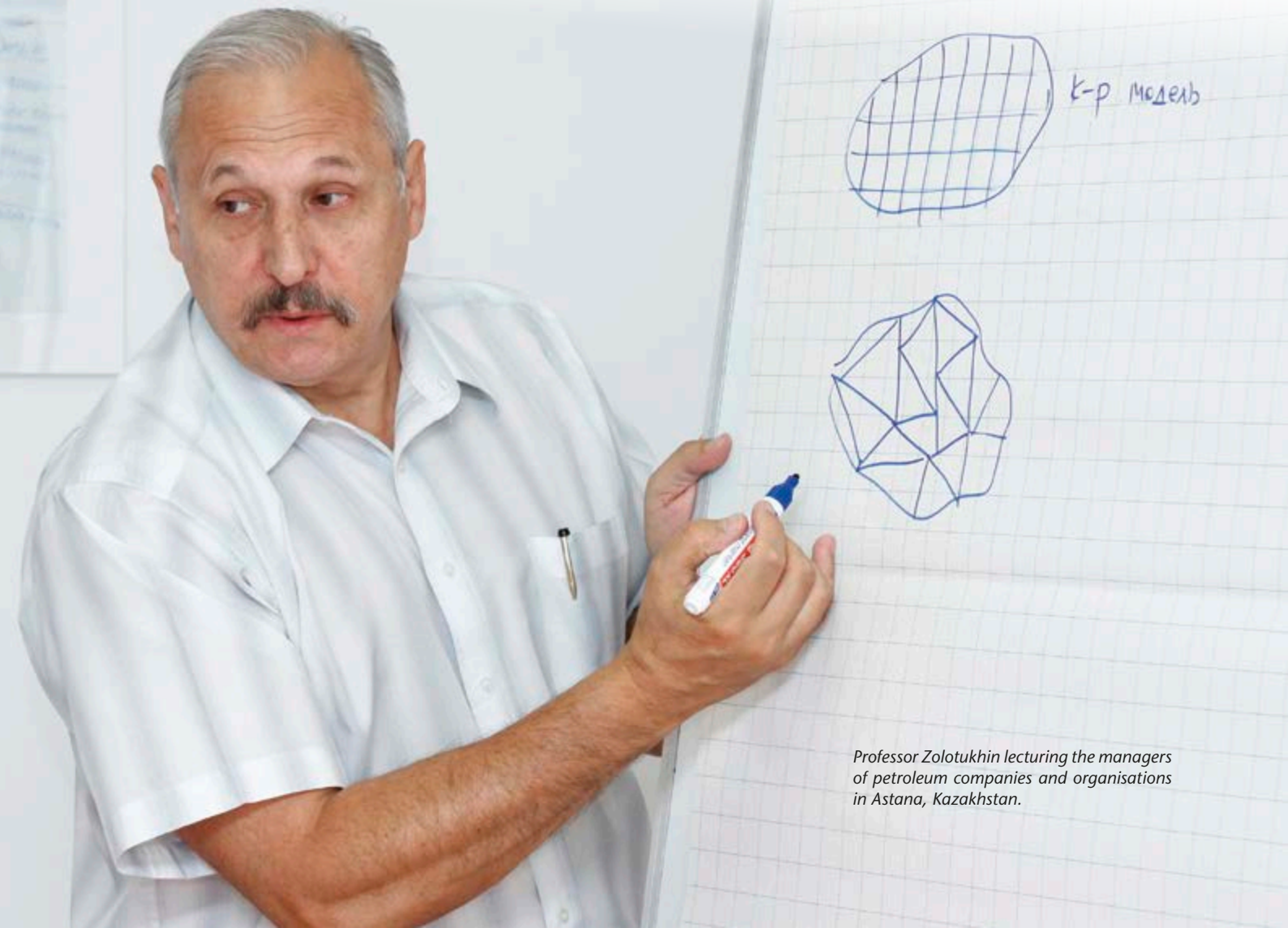
Dr. Professor **Anatoly Zolotukhin** is the Deputy Chancellor on International Affairs at the famous Gubkin Russian State University of Oil and Gas. A world renowned expert, he is a dedicated teacher, with a firm belief in the importance of international communication at all levels in the petroleum industry.

Professor Anatoly Zolotukhin is the child of two petroleum engineers, so the oil industry is in his blood – but as a youngster, he had no intention of following in his parents' footsteps.

"Believe it or not, when I was young, I just wanted to be a musician! However, my parents soon persuaded me away from that, and I've had a great life in the oil industry, so I am grateful to them," he says. "I followed the normal career path from school into university: I strongly believe that the education system in the Former Soviet Union was one of the best in the world, because it promoted education and encouraged good students to get on."

Research and Industry

He started his long career at Gubkin University as a student in 1964 and five years later graduated as a petroleum engineer, followed, in 1972, with a PhD in fluids, gases and plasma. He then studied at the Moscow State University, where he obtained a Masters degree in Applied Mathematics, before moving back to Gubkin University, where he gained a Doctor of Science in Reservoir and Production Engineering. In 1978 he was selected as one of the best scientists in the Former Soviet Union (FSU) for an internship



Professor Zolotukhin lecturing the managers of petroleum companies and organisations in Astana, Kazakhstan.

at Stanford University in the USA.

"I was a visiting scholar at Stanford, where my work was very much theoretical," Anatoly explains. "I enjoyed my research into reservoir engineering there and I also had the opportunity to lecture to and consult with some of the finest young minds in the country, many who later became famous, such as Michael Economides and Christina Ehrlig-Economides.

Although most of Professor Zolotukhin's career has been in research – he is proud to have been associated with Gubkin State University for nearly 50 years – he has also worked in the industry he serves, and has a long connection with Statoil. "In 1991 I was invited to teach at the University of Stavanger (at that time Rogaland High School) for one semester as a visiting scholar. This resulted in more than 22 years of relations with Norway, the first nine years as a full professor and since 1999 as a visiting professor at Stavanger University, a post I still hold." The shift to a part-time professorship was due to joining Statoil on a full-time basis as a project manager, working on Russian projects (1999-2004), and, from 2004 until retirement from Statoil, in the capacity of Technical Director of the Statoil Moscow office. During all this time Anatoly continued his engineering research and participated in dozens of projects, including Shtokman and Vankor.

But education, and advancing and improving the teaching of petroleum geoscience and engineering, is Dr. Zolotukhin's passion, together with disseminating innovative thinking and research beyond international boundaries, and that is the arena in which he has been expending considerable energy since he officially retired from Statoil in 2008, as he explains.

Professor Zolotukhin at the Institute of World Economy and International Relations in August 2012.

International Cooperation

"After I left Statoil, the Rector of Gubkin University, Albert Vladimirov, invited me to become Deputy Chancellor of International Affairs for the university, with the remit to make Gubkin State an international centre for petroleum studies, with qualifications which are recognised throughout the world. Working with other renowned institutes, such as the Institut Français du Pétrole (IFP), which was the first to join us, then University of Stavanger, Royal Technical University of Stockholm, Texas A&M, and Imperial College in London, we now have students graduating with excellent dual degrees. They are taught predominantly in English and usually spend a year in Moscow and a year in the participating university. This works very well for the students and for the institutions and is a good example of truly international cooperation.

"A broad petroleum education is very important, particularly if it encourages people from different backgrounds and nationalities to align their understanding and mentalities," he continues. "You hear this a lot, but words can be different to actions. At Gubkin we strongly promote this idea, so our young graduates not only have a good grounding in the petroleum sciences and engineering, but also in health and safety matters and in environmental concerns.

"Gubkin is the Russian state university of oil and gas, so obviously all the courses offered are concerned with hydrocarbons, even if the student is studying law, economics or management," Dr. Zolotukhin explains. "International cooperation is where the dual degrees offered by Gubkin come into their own. The students are exposed to people from many different countries, and that is an important aspect of the joined international Master programmes.

"In addition to cooperating with distinguished academic institutes from around the world, we work with many international companies, and all the students are obliged to undertake internships with them. I think this is very important, especially for Russian students, as they get to see a range of modern data, which is not usually easy for them – since the end of the FSU ownership of data which previously belonged to the state has become an issue. It also gives the Russian students the chance to find employment with foreign companies; Schlumberger, for example, has taken on about 1,000 petroleum specialists from Gubkin in recent years. Experts from both IOCs and service companies also teach courses at the university."

Rational Use of Resources

While teaching the next generation of oil industry specialists the skills they will need to find and extract hydrocarbons, Dr. Zolotukhin is very keen that they are also taught to take care of our resources. As he says: "We are all members of the international community, so a rational use

of resources must be part of everyone's way of life.

"The net energy balance means that we must not produce one type of resource at the expense of another, and we should also develop technology aimed towards the idea of rational use of resources. Environmental, political and social issues are all involved in making the right decisions. For example, it is important to work closely with the indigenous communities in an area, because they consume what nature provides, and therefore know how to care for it and how much can be taken out of an ecosystem without damaging it."

Dr. Zolotukhin believes that these issues must influence exploration of both conventional and unconventional hydrocarbon resources, with more research needed into extracting shale gas with less water and minimal pollution, and into the possibility of safely exploiting the huge potential of gas hydrates in Russia and worldwide.

"To be successful, Russia needs investment into its many different hydrocarbon resources," he adds. "The industry was almost destroyed by perestroika. State-owned enterprises were abolished, regional links disbanded and oil recovery figures dropped dramatically – but we now produce more than the FSU delivered. The remaining potential for hydrocarbons in this country is huge; not only do we have over 2,500 Bboe of identified conventional reserves, but we have about 15 Tboe in oil shales. In terms of natural resources Russia is blessed by God and is the richest country in the world. However, a rational use of this enormous potential is the strategic task of our country."

Dr. Zoloktukhin is a great believer in the potential of the Arctic, and is the Director of the Institute of Arctic Petroleum Technologies at Gubkin University, which he has led since its foundation in 2008. "We need to invest in the Arctic, but I think this must be done by international companies, and above all it must be transparent and safe from national interests. It is fascinating for companies to move into new areas like the Arctic, as they can develop their own specialised systems and transportation mechanisms to solve a variety of new issues.

"We know that the Arctic holds huge resources. The vast Shtokman gas field, for example, in the Arctic's South Barents Sea, has reserves estimated to be in the region of 130 Tcfg. This could be powering much of Europe but despite many discussions the exploitation of the field is still on hold; we lack the political will to make a decision.

"The problem here and throughout the industry in many cases is lack of diplomacy and transparency, which is where my role as Rector on International Affairs comes in."

Enjoying Many Roles

Professor Zoloktukhin has had a very illustrious academic career and has been honoured with degrees and many awards over the years. As well as his Gubkin University roles, he is a Member of the Russian Academy of Natural Sciences and of the Academic Council of the European Energy Forum, in Berlin, Germany, Vice-President of the World Petroleum Council (WPC) from 2008 to 2011 and a member of its Executive Council since then. Author and co-author of 15 books and more than 100 articles, in 2002 he was awarded (together with co-editors) the Gubkin Prize (the highest award in the Russian Petroleum Industry) for the book *Basics of Offshore Petroleum Engineering and Development of Marine Facilities in the Arctic*, and in 2006 he was awarded the Vernadsky medal of the Russian Academy of Natural Sciences for achievements in Science and Research.

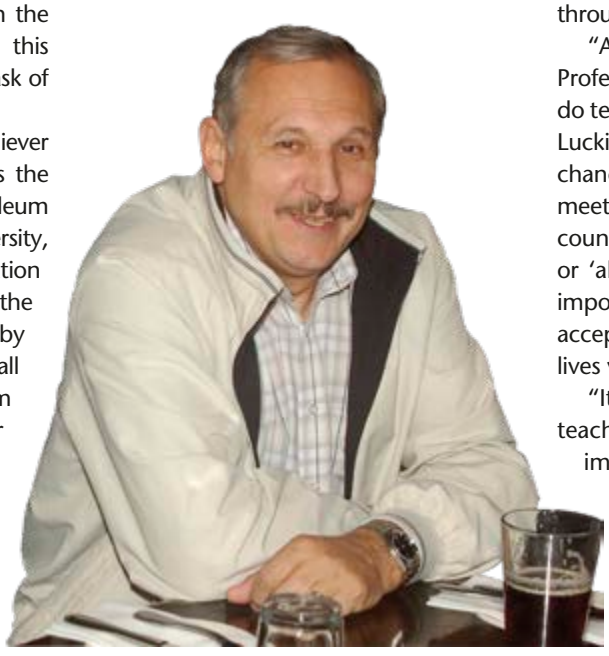
A fascinating speaker, he is frequently in demand to make presentations and keynote speeches at a huge variety of conferences, meetings and seminars throughout the world. He is very knowledgeable about the hydrocarbon industry, and happy to share his knowledge and thoughts, and is particularly keen that the global oil industry realises that it is just that – global. "Look at the world map and the way consumers and producers work together," he says. "They should be much closer, and international society needs to be convinced of this and cooperate to find the best supplier."

With all the travelling associated with his role as Deputy Chancellor on International Affairs, Dr. Zolotukhin finds himself with little time to follow up his research interests, which vary from the practical, such as reservoir and production engineering and field development planning and EOR/IOR, to the more theoretical and esoteric realms of uncertainty, risk and decision-making and fuzzy logic. Instead, he enjoys mentoring young talented students who are doing research projects under his guidance, as well as teaching and evaluating various courses.

"I enjoy all these roles," he says. "Teaching, evaluating courses, research and supervising students – all are fascinating. As a mathematician, I am particularly interested in new approaches, such as ways of increasing recovery through new EOR and IOR methods.

"And I love being an international Professor, as I love travelling – although I do tend to live much on my life on planes. Luckily, I find them peaceful, giving me a chance to catch up on work. And I love meeting people from many different countries, who I don't think of as 'foreign' or 'alien', but just potential friends. It is important to have an open attitude and accept as normal cultural customs and lives very different from your own.

"It is important that the students I teach understand these ideas and the importance of diplomacy in the oil industry. We must not live at our neighbour's expense, but instead our neighbour must be pleased to have us there," Dr. Zolotukhin concludes. ■



Dr. Zolotukhin visiting Harvard University, 2005.

Baku
Ten Centuries of Oil

ELEANOR ARCHER

"Near the Georgian border there is a spring from which gushes a stream of oil, in such abundance that a hundred ships may load there at once. Men come from a long distance to fetch this oil, and in all the neighbourhood no other oil is burnt."

— Marco Polo

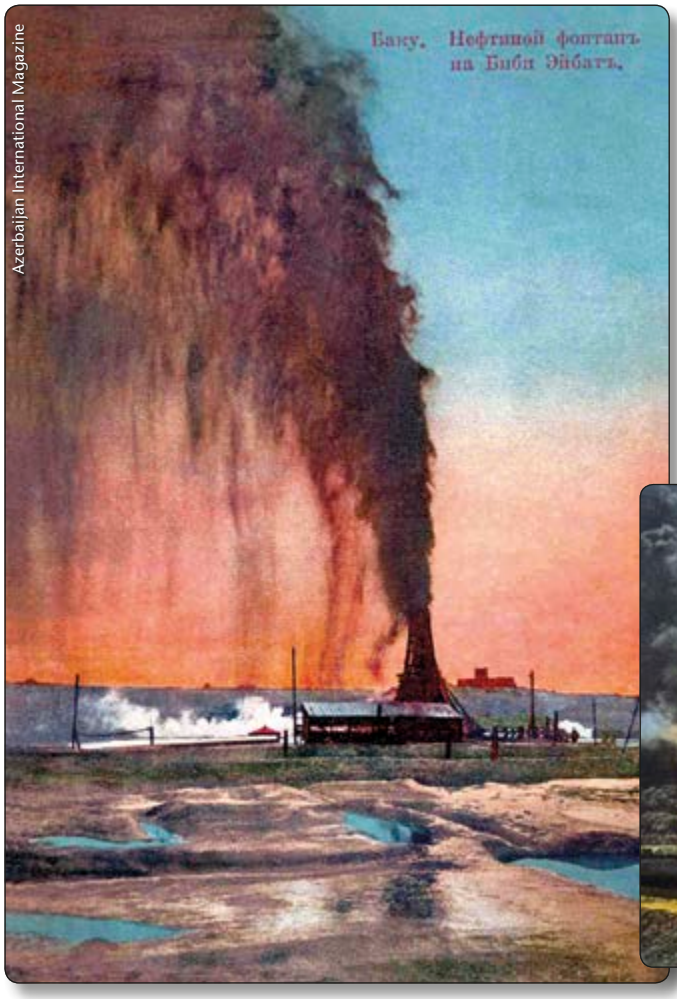
As Marco Polo, renowned Italian traveller of the 14th century, so clearly depicts, oil has long been the currency of life in Baku, the modern-day capital city of Azerbaijan. Records of oil date back even to the 10th century, such as those by historian Istahri-Abu Iskhak, who described how the people of Baku used soil soaked in oil as fuel.

However, it was natural disaster rather than natural wealth that caused Baku to first become the central point of modern-day Azerbaijan. In the 12th century a crippling earthquake in Shamakhy, the capital of Shirvan (part of the modern Azerbaijan Republic), caused Shirvanshah's court to move to Baku. Over the next two centuries, the people of Baku built huge fortifications to protect their city, some of which on the western and northern sides still stand today. Indeed if you walk through the inner city, down the labyrinth of winding alleys lined with street-vendors, it is easy to think yourself transported back to medieval times. The old city holds many of Baku's finest pieces of ancient architecture, including the Maiden Tower, an eight-storeyed structure, the first three levels of which are thought to date back as early as possibly the 6th century BC. It is claimed that the site may have originally been used during the Sasanid era as a Zoroastrian temple. The rest of the tower was built in about the 12th century and historians have estimated that it may have been used during this period as an astronomical observatory, because of stone protuberances which correlate to the days of the month. As well as the Maiden Tower, the inner city also holds the Palace of the Shirvanshahs, built during the reigns of Shirvanshah Khalilulla I and his son, Faruk. Today, the magnificent building still contains many beautiful and authentic inscriptions and structures, giving us a window into the past.

Baku continued to prosper as a city in the centuries following, and by the 17th century its oil industry had been firmly cemented. A Turkish scientist of this period, Evliya Celebi, who travelled to Baku to study the oil fields, reported that "the Baku fortress was surrounded by 500 wells, from which white and black acid refined oil was produced".

Paris of the East

In 1723, after a long siege and widespread chaos, Baku was forced to surrender to the Russian Empire. The Russians took control of oil production, forming the 'otkupschina' lease system, by which exclusive rights to produce oil were given to certain individuals. Oil extraction in these times was simplistic, made up mainly of shallow, hand-dug wells. Because of the monopoly of the system, there was relatively little improvement on this, as the individual



Azerbaijan International Magazine

Old postcards of wells and oil fires in the vicinity of Baku at the end of the 19th century .

owners had no reason to increase production.

By the early 1870s, however, the otkupschina system had been abolished in favour of the land being auctioned to local and Russian-born investors; in Balakhani, a suburb of Baku, for example, more than 149 parcels of land were sold. As a result of this, oil drilling began on a massive scale, creating the first oil boom of Azerbaijan.

This caused a huge financial boom within Baku, largely influencing the architecture seen today. European design influenced many of the buildings that cropped up during the early 20th century, earning the city its nickname of 'Paris of the East'.

In 1898, the Russian oil industry exceeded the US oil production level and by 1901 Baku produced more than half of the world's oil – 212,000 barrels of oil per day – and 55% of all Russian oil. During this period there was much improvement in well-drilling practices, so that techniques such as rotary drilling using electrical drive, metal derricks and compression during transportation of oil and gas became commonplace.

However, the prosperity of Baku did leave it vulnerable within the wider world. During World War II, because the Soviet Union supplied Nazi Germany with oil produced in Baku, Allied Forces planned 'Operation Pike', a major offensive to bomb the city's oil fields and storage tanks. The plan appeared easily accomplishable, as Baku was particularly vulnerable to air attack because it could be approached from the sea. However, due to the fall of France in May 1940, the plans collapsed, as the Germans found secret documents detailing the plans for 'Operation Pike' in boxes evacuated from Paris.

Leading the World

Today, the extraction of hydrocarbons still leads the economy of Baku and, just as it always has been, Baku is a key part of development within the oil industry. In 2006 the second longest pipeline in the world, the Baku-Tbilisi-Ceyhan, was officially opened, delivering oil to the European markets by transporting crude oil from a terminal close to Baku all the way to Turkey. As well as this pipeline, further technical advances have been made, with the development of the Azeri-Chirag-Guneshli field and Shah Deniz gas field, and the expansion of the Sangachal Terminal.

Modern Baku today is a busy metropolis, home to two million people, around 25% of the country's population. It is a city of old with new, and east with west, all-glass buildings such as the Azerbaijan Tower standing side-by-side with the medieval walls of the old city. It is a city of many faces, a UNESCO World Heritage Site, as well as being (according to a Lonely Planet ranking) among the world's top ten destinations for urban nightlife. Ultimately while oil and gas flow from the region, it will continue to grow and develop.

As Professor A. V. Williams Jackson of Columbia University concluded in 1911 in *From Constantinople to the Home of Omar Khayyam*, "Baku is a city founded upon oil, for to its inexhaustible founts of naphtha it owes its very existence, its maintenance, its prosperity". ■

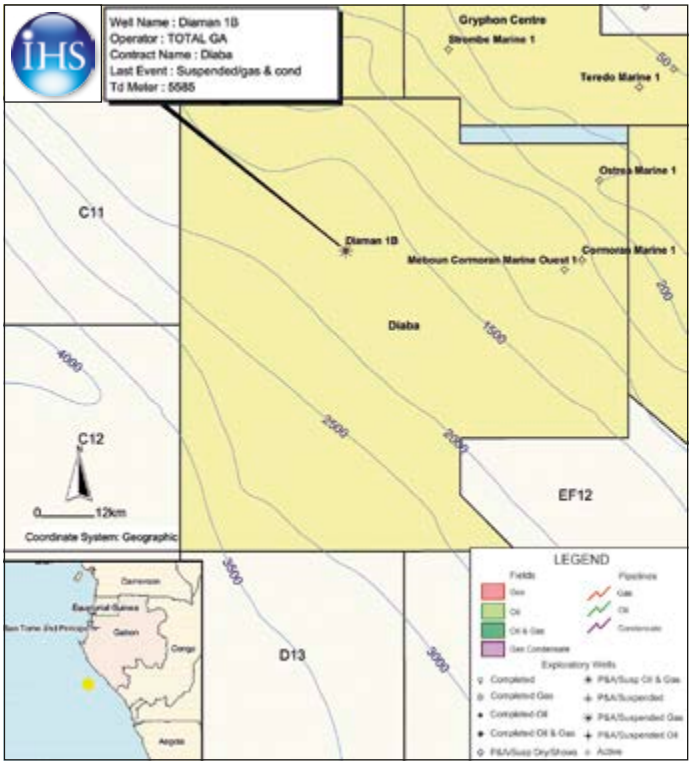
The old and the new: Central Baku's futurist glass Icheri Sheher Metro station stands next to the medieval city walls.

© David Massie/Dreamstime.com

Gabon: First Deepwater Pre-salt Strike

Operating the 9,075 km² Diaba permit in the South Gabon Sub-basin (Gabon Coastal Basin), Total is claiming its Diaman 1B wildcat as Gabon's first deepwater pre-salt discovery. Located around 70m south of Diaman 1A, the well was drilled to a total depth of 5,585m using the Ocean Rig *Olympia* drillship. Part of a two to four well exploration programme, it encountered at least 50m of hydrocarbon pay of natural gas with condensate, successfully confirming the presence of a working pre-salt petroleum system. Pre-drill resources potential for the Diaman prospect is reported to range from 250 to 800 MMboe. The interests in the Diaba block are shared between Total Gabon (42.5%), Marathon (21.25%), Cie Gabon Diaba (21.25%) and the State of Gabon (15%).

Diaman-1B was drilled around 97 km from any other commercial pre-salt discoveries, suggesting the wider potential of the West African pre-salt margin. Shell and Ophir Energy also plan to drill exploration wells in Gabon's pre-salt in the coming months. Total's gas discovery will surely add further interest to a potential upcoming pre-salt bid round, which the government said it intends to hold before the end of 2013. Longhorn, Pioneer, Western, Alamo, Wendover, Mandalay, Boulder, Red Rock, Fiesta, Aztec or Ellis are the other pre-salt prospects identified by Total. The average estimated mean net pay thickness for all pre-salt and Albian prospects in the Diaba block, including Diaman, is 164m. ■

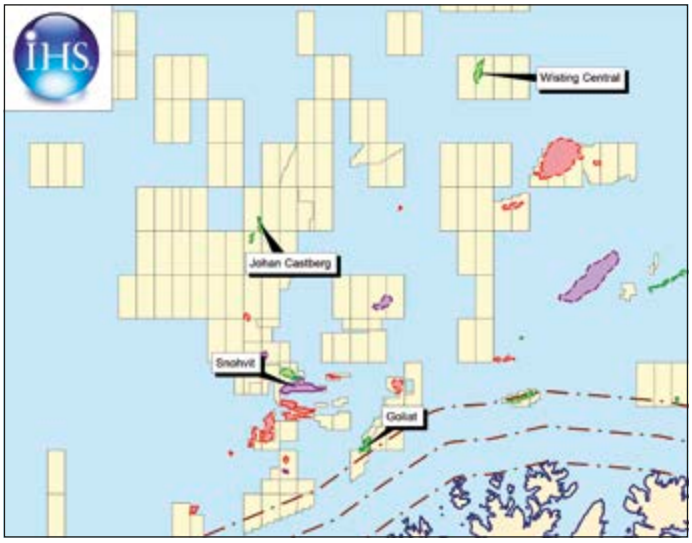


Norway – Breakthrough Discovery

Described as a breakthrough discovery, OMV revealed that its Wisting Central exploration well, 7324/8-1, offshore Norway, has made the first ever oil discovery in the Hoop-Maud Basin in the northern Barents Sea, thus opening a new shallow play. The well was drilled using the Leiv Eiriksson semi-submersible rig to a total depth of 905m in 373m of water approximately 170 km north-east of the Skrugard/Johan Castberg discovery well and was seeking a Jurassic Realgrunnen Group objective. The significance of the find is further underlined by the fact that light oil was found in relatively shallow waters, the combination of which makes it particularly attractive in an otherwise high-risk drilling environment. Results of drilling, wireline logs and samples of reservoir fluids show that the well has encountered 50–60m of net light oil pay in good quality, relatively shallow Middle to Lower Jurassic reservoir rocks. The Wisting Central discovery is located in PL537 and is operated by OMV (25%), partnered by Tullow (20%), Idemitsu (20%), Statoil (15%) and Petoro (20%).

The find, with reserves of between 63 and 164 MMbo and up to 40 Bcf of gas, is a big boost for the region after Statoil put its 600 MMbo US$15.5 billion Castberg project on hold this year because of rising costs. Statoil said it would instead study a new development concept for Castberg and drill more, hoping to find additional oil to improve the project's viability.

OMV said its licence, including the new find and potential future discoveries in adjacent prospects, could hold up to 500 MMbo. The company will shortly spud a new wildcat targeting the Triassic Kobbe and Snadd formations. Statoil is also drilling more in the region, planning to explore its Apollo and Atlantis prospects next year, approximately 50km north of Wisting, potentially adding more resources to its Barents find. These results will further spur interest in the upcoming East Barents Sea licensing round. ■



Kazakhstan: Shallow Water Discovery

In what may prove to be a significant find for the shallow waters of the Caspian Sea, Zhambyl Petroleum's ZB-1 on the Zhambyl structure has tested oil and gas. Located in just a few metres of water, the well was drilled using the *Caspian Explorer* barge to a total depth of 2,200m. Two Middle Jurassic intervals were tested, flowing a combined 843 bopd.

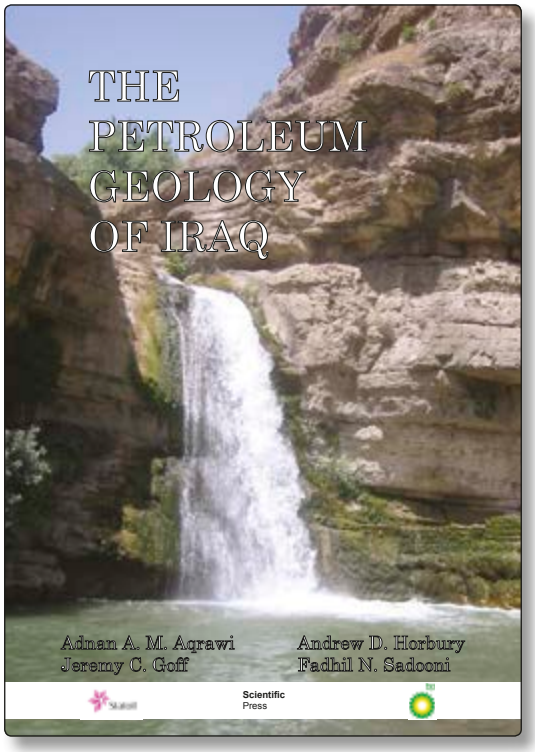
The Zhambyl exploration block is located in the north-western Caspian Sea, east of the border with Russia and north of the Kurmangazy block, 130 km east of the city of Atyrau and 300 km east of the major Russian industrial city and port of Astrakhan. The contract area has two main structures, Zhambyl and Zhetysu, as well as four smaller ones (Tuigyn, Bibigul, Eleonora and Gauhar). Its territory falls mainly within the North Caucasus Platform Basin and its prospectivity is associated with Mesozoic plays, including Jurassic and Cretaceous clastics at depths not greater than 2,100m. The project is operated by Zhambyl Petroleum LLP which is 73% owned by KazMunayGaz (KMG) and 27% owned by KCK, the KNOC-led (35%) consortium of South Korean companies. The mandatory exploration programme includes the acquisition of 2D seismic and the drilling of two exploration wells. The second obligation well will test the Zhetysu prospect (ZT-1). KMG estimated the contract area's pre-drill resources at around 1.26 Bbo. However, total anticipated reserves of around 880 MMb were estimated in August 2013 by the Agency for Research of Investment Profitability.

This success is welcome news for oil minister Uzakbai Karabalin who has made boosting exploration as part of a plan to dramatically increase reserves a priority. ■

The Petroleum Geology of Iraq

A comprehensive, up-to-date appraisal of the reservoir rocks, source rocks, seals and traps that control Iraq's petroleum resources is reviewed by **Munim Al-Rawi**, an expert in the regional petroleum geology of the Middle East.

The Petroleum Geology of Iraq
Adnan A. M. Aqrawi, Jeremy C. Goff, Andrew D. Horbury and Fadhil N. Sadooni
Scientific Press Ltd (2010)



This book on one of the most important and prolific petroleum countries in the world reflects the varied and deep experience of the four authors and their respective organisations.

The layout and style follow the recently published books *The Geology of Iraq*, by Jassim and Goff (editors) 2006, and *Sequence Stratigraphy of the Arabian Plate*, Sharland et al., 2001. The book contents list ten chapters, references, index and authors' biographies, but lacks a list of figures. Chapters are organised in four sections. These cover the history of oil exploration in Iraq and the region's tectonic evolution; stratigraphic elements; petroleum systems, and a final section on future challenges in the petroleum geology of Iraq. The reliance on published material is obvious in the many referenced statements and figures.

The history of oil exploration in Iraq, presented in chapter 2, is very informative and enjoyable to read and includes a review of the work of the authors of the *Stratigraphic Lexicon of Iraq*, namely H.V. Dunnington, D.M. Morton and R.C. van Bellen.

The tectonics of Iraq are excellently reviewed in chapter 3, particularly the palaeostructural elements of Iraq, with very informative sections and photographs. However, the section on the tectonic evolution of Iraq is based on the evolution of the northern margin of the Gondwana and the Arabian Plate, and as a result this section is best described as theoretical. The authors themselves state on p43: "The geological history of Iraq has been strongly influenced by the events along this margin. Much of the data for interpretation of these events comes from allochthonous tectonics units whose geology is complex and poorly understood."

The stratigraphic elements, presented in chapters 4 to 8, discuss the Precambrian and Palaeozoic, the Middle Permian to Middle Jurassic, the Middle to Upper Jurassic, and the Cretaceous and Cenozoic. The theme of the presentation is based on the sequence stratigraphic arrangement given by Sharland et al., 2001. The material is well illustrated with figures, charts, tables and superb photographs and the chapters are supplemented with excellent accounts of the petroleum system components at the end of each chapter.

A comprehensive review of petroleum systems is presented in chapter 9, and is divided into four long sections, which include an informative introduction followed by a detailed description of the components of the petroleum systems of the Palaeozoic, Jurassic, Cretaceous and oil migration and leakage in the Tertiary.

The book concludes with a chapter on the future challenges facing the petroleum geology of Iraq, including important questions on the stratigraphy and structure of Iraq, issues associated with exploration and production, and challenges related to particular stratigraphic intervals.

Two extensive lists of references are provided, which cover almost all the relevant bibliography.

A Few Comments

In my view, *The Petroleum Geology of Iraq* is an excellent contribution to the subject. However, there are a few comments which may be helpful in future published editions of this book.

On the history of oil exploration in Iraq, there were other very important contributors to the stratigraphy and petroleum geology of Iraq who should have been reviewed. Notably, these include the late K.M. Al-Naqib, who published major works on the Kirkuk oil field and southern Iraq; the late Prof. A. Al-Sayyab, who contributed to the stratigraphy, sedimentology and petroleum geology of Iraq in teaching, research and publications; and lastly, the late Prof. C.M.G. Bolton, who in addition to his early work in Kurdistan Iraq, published with others in 1960 the first *Geologic Map of Iraq*. In addition, his teaching in the Department of Geology at the University of Baghdad between 1958 and 1970 cannot be forgotten, where his foremost students became the leading oilmen in the three decades that followed the nationalisation of the oil industry in Iraq.

On the stratigraphy of Iraq in general, it is suggested that the establishment of a Country Stratigraphic Committee incorporating experts from both academia and industry would

be advantageous, in order to outline guidelines for stratigraphic unit nomenclature.

Looking at the Palaeozoic sequence stratigraphy in chapter 4, I would suggest that the illustrations from Sharland et al., 2001, could cause some confusion. For example, the charts show locally published Jordanian unit names in one place, and quote different names for the same units elsewhere. The valid Palaeozoic units names in Jordan are considered to be those used by the oil industry as advised and directed by the Petroleum Department of the Natural Resources Authority and as used by their staff in international journals, such as Keegan, et al., 1990 (which incidentally does not appear in the reference list).

In the chapter on tectonics, an important Caledonian uplift movement in western Iraq, which is reported in Numan, 1997, does not appear to be discussed in the book, or referenced. There are also some important public domain articles on the Palaeozoic and Triassic hydrocarbon potential of North West Arabia, including Iraq, known to international oil companies, which have not been used or referenced.

But these are minor issues. *The Petroleum Geology of Iraq* is a well-researched, informative and detailed book, compiled by experts, which will be of great assistance to anyone interested in petroleum exploration in this important region, and I would like to congratulate the authors for this tremendous effort.

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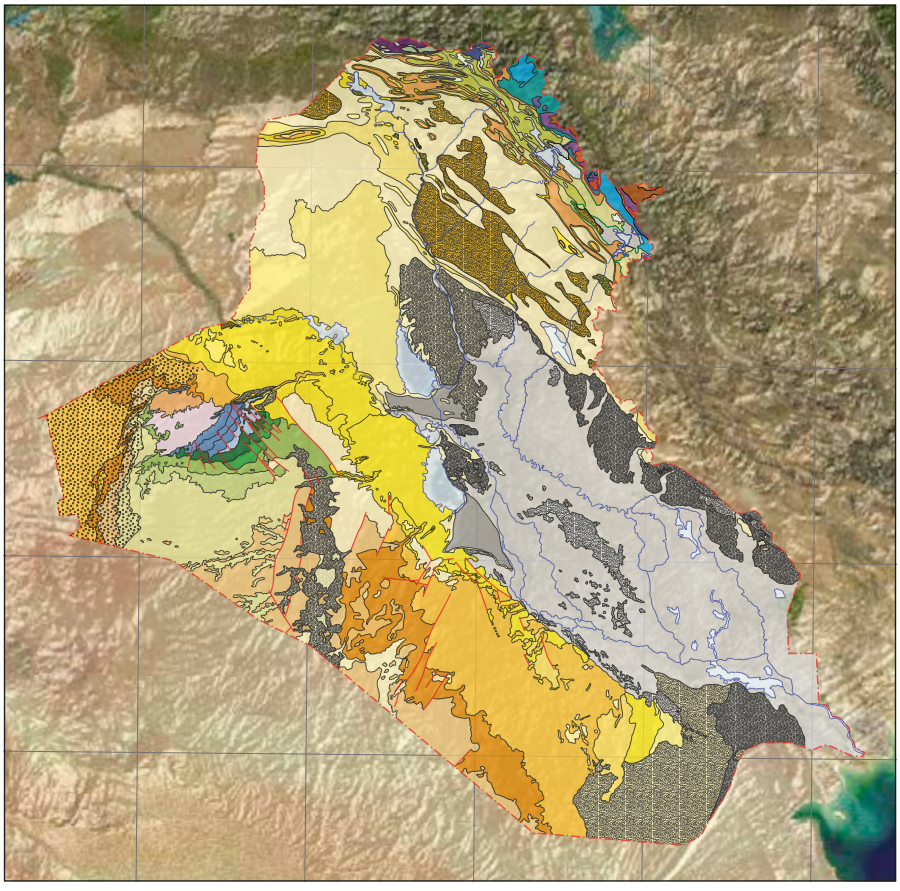
Sharland, P.R., R. Archer, D.M. Casey, R.B. Davis, S.H. Hall, A.P. Heward, A.D. Horbury and M.D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia, Special Publication 2, Bahrain, p. 371. ■

Map from the back cover of 'The Petroleum Geology of Iraq'.



What's the Point of Conferences?

More and more conferences on every facet of the petroleum industry seem to be appearing. What purpose do they serve, and what makes them effective? We talk to **Ben Sayah**, conference manager with events company **Terrapinn**.

Tell us a bit about Terrapinn.
We are a global events company with offices in Australia, the US, Singapore, South Africa and the UK, and we organise conferences and exhibitions across a number of industries. My area of interest is energy and resources; we cover a wide array of events from the World National Oil Companies Congress to technical exhibitions on unconventional energy at Shale Gas World conferences.

Does the oil industry have a communication problem?
Just look at the newspapers. As a primary means of global sustainability, energy is naturally going to attract considerable debate from sourcing to usage. The ease of communication in the modern technological era hasn't made things easier either. Now the industry must work harder to communicate to a wide audience of partners, regulators and consumers. This is necessary – it's important that the industry is scrutinised and it can justify its activity.

Are conferences important in the O&G industry?
All the above concerns can make the message difficult, and its communication even more so. Events not only give the industry a platform on which to speak, but also to listen, thus helping solve the problem of communication and debate. Communication is only one aspect, however, as the energy industry is formalised by partnerships and collaboration. Conferences allow participants direct contact with senior prospects in a type of engagement unreplicated in any other environment. It is important that these people meet, and more valuable that they meet in one room. A good conference can offer this.

Why are your conferences different?
Terrapinn work from a very specific, open, and interactive model that no other organisation replicates. We know that there are influencers key to the decision-making process who cannot justify spending large amounts of money to attend. We give local government representatives, lobbyists, and academics a chance to join the debate. This is what makes our content interesting and our events valuable.

Alongside this, our content and the opportunity we provide for the industry to respond and communicate with all sides make these events valuable. It's rare you get the chief scientist of GreenPeace Doug Parr and the director of the Manchester Tyndall Centre for Climate Change Research Kevin Anderson, sitting and debating alongside the CEO of Cuadrilla Francis Egan and the Chair of the Unconventionals APPG Dan Byles MP. But we managed it in Manchester at 'Shale Gas World UK' and it can make a difference for the industry, campaigners and consumers.

How can you encourage informed enthusiastic contributions from the floor?
If you're a delegate, engaging with those on stage is an imperative. No conference should simply be a lecture or quiet case study. It's important and valuable for attendees to be active participants and engage or question the theories of those on stage. Our format leads to enthusiastic contribution. The old style of presentation, presentation, presentation is replaced by open-floor discussions, debates with senior representatives, and hosted workshops with a technical or policy-driven stance. In my opinion, the best of these are large-scale multi-disciplined roundtables. Inviting senior table moderators and ensuring discussion provides informed enthusiastic contribution, but also a great networking opportunity.

What have been the most popular conference topics recently?
For me it's just the one. Shale. It's everywhere, and everyone has an opinion on it. To some it can have the potential to change the global energy mix, to others it can prove the most poignant enemy of the environment. Either way it can make a staggering difference. Searching beneath the rocks and discovering all arguments, theories, and data for or against the subject is something I don't get to do too often and has made my job quite exciting. For a conference organiser whose lifeblood is content, it's a fascinating subject. What the topic of shale offers is an air of the controversial, uncommon in most technical subjects. Conferences must now be arenas projecting openly throughout social media and the internet – just look at TEDx to see what is possible. Topics and events now have to reflect this.

How else can we encourage engaged debate in the industry?
It's a prevalent theme throughout this interview, but put simply, online. It's incredible what direct access we have to the industry thanks to the professional use of social media. There is so much to get from YouTube, Twitter, and even groups on Linkedin which provide a great platform for discussion. We are lucky that this industry is a technical one, they all see themselves as academics, and enjoy being an authority on their subject. If you look, there is always a forum or a feed already engaged in the debate. It's a great, underutilised opportunity. ■


Ben Sayah
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MINERAL RESOURCES

Keep your Eye on NWAAM

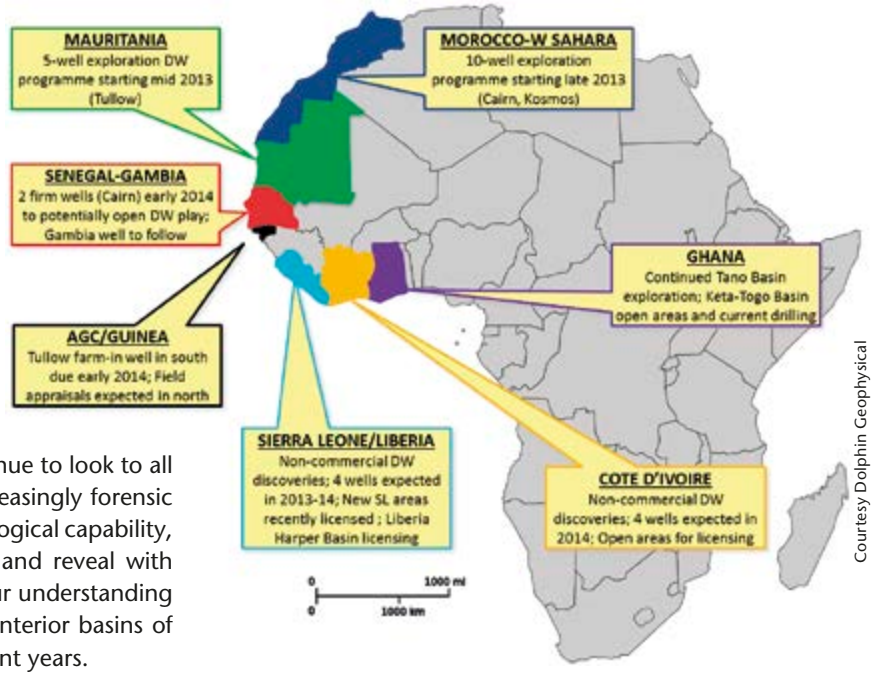
The North West African Atlantic margin (NWAAM) is entering a new phase of activity.

WILL THORNTON

Despite the fact that many of the established petroliferous basins of Africa are entering the mature stage of exploitation, it is true to say that the potential for African sedimentary basins to continue to attract the interest of international oil and gas companies continues unabated. The well attended, and increasingly unmissable, annual PESGB/HGS Africa conference, hosted this year in London, is testament to that.

Almost in spite of continued exploration successes in a number of established and emerging plays, common consensus says that the hunt for new resources will get harder. With this in mind explorationists continue to look to all corners of this massive continent with an increasingly forensic approach. Advances, driven by leaps in technological capability, continue to increase the fidelity of the data and reveal with increasing clarity the subsurface, improving our understanding of the evolution of the prolific marginal and interior basins of Africa, seemingly almost exponentially, in recent years.

However, that knowledge and understanding continues to be patchy, and has led many analysts, like Adrian Robinson, consultant to Dolphin Geophysical, to conclude that, while the industry continues to look further and further from established markets and infrastructure, some areas of Africa should probably be better explored, yet remain underexplored and still offer massive potential to deliver world-class hydrocarbon resources.



2013–14 Exploration Drilling: Morocco to Ghana. Apart from some minor hydrocarbon production in Côte d'Ivoire and the well documented deepwater production in Ghana, there is currently only production in the shallow water offshore Mauritania and onshore Senegal. This production, limited though it is, coupled with recent drilling successes, provides abundant evidence of working petroleum systems that can be extended into frontier areas offshore.

Plenty of Opportunities

One such underexplored province is the North West African Atlantic Margin, where industry interest has always been high but activity has, to some extent, waxed and waned over recent years, or as Ian T. Edwards, VP Global MC Surveys and New Ventures, Dolphin Geophysical, stated recently during promotional roadshows, '…it is a region neglected by the industry for over 20 years'.

Fresh discoveries and newly acquired datasets, like the recent seismic survey by Dolphin and TGS (*see page 18*), are leading to renewed interest and an increased level of activity in the region. Over the next 12–18 months we can expect to see in excess of 20 new exploration wells to complement the increasingly dense patchwork of seismic and other remote sensing datasets in the region.

The Mauritania-Senegal-Gambia-Bissau-Conakry (MSGBC) Basin continues to be a key area of exploration. With its history since the Triassic, the basin provides multiple candidate source rocks, many already tested. The onset of sea floor spreading in the Middle Jurassic, with the development of associated salt basins and carbonate platforms, provides the potential for the deposition of ample reservoirs and the creation of multiple traps, similar to those seen in analogous hydrocarbon basins the world over. Major Cretaceous and Tertiary clastic input to the basin provided further targets for frontier exploration.

With over 40 companies now participating in the hunt for oil, the region is entering a new level of activity. Whilst many of the blocks are now taken there are still plenty of opportunities for entry to the basins, as evidenced by several active farm-outs and acreage deals completed in recent times.

Most countries in the region are offering an 'open door' policy to investors and there is a bidding round planned for Mauritania in the next 12 months. In addition to this many of the blocks are sizeable with significant relinquishment areas that will no doubt attract some interest when they become available. Evolving legal and fiscal regimes reflect the increasing maturation of the region in terms of political and social development, with many of the countries in the region now undertaking democratic elections and putting in place production sharing programmes analogous to other emerging areas in the region.

With so much activity on the horizon, now would not be a good time to take your eye off this underexplored but evolving area. ■

West Africa

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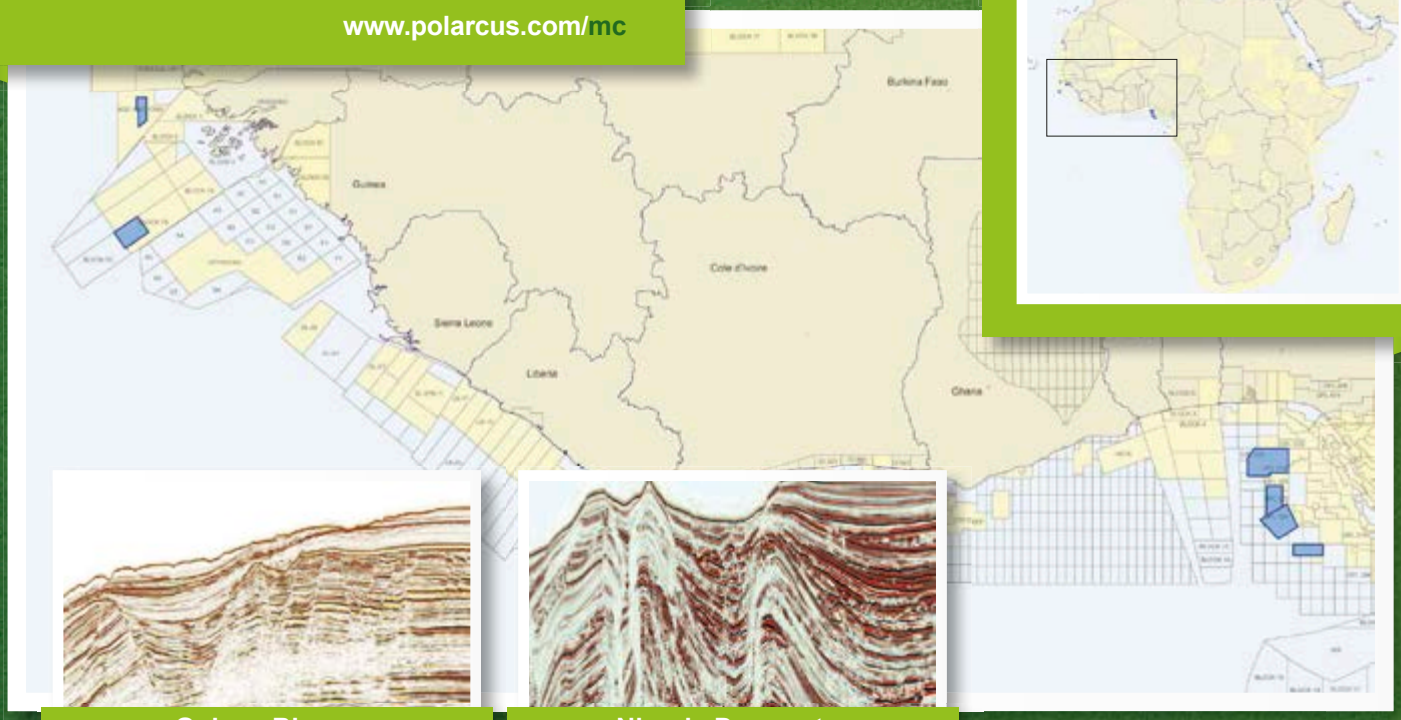
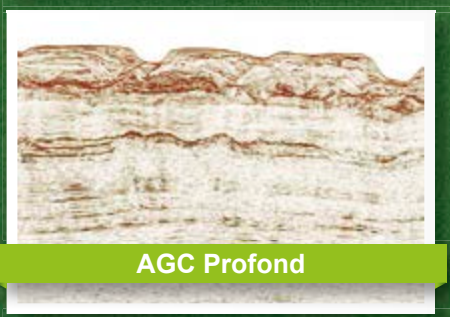


Guinea Bissau

Nigeria Deepwater



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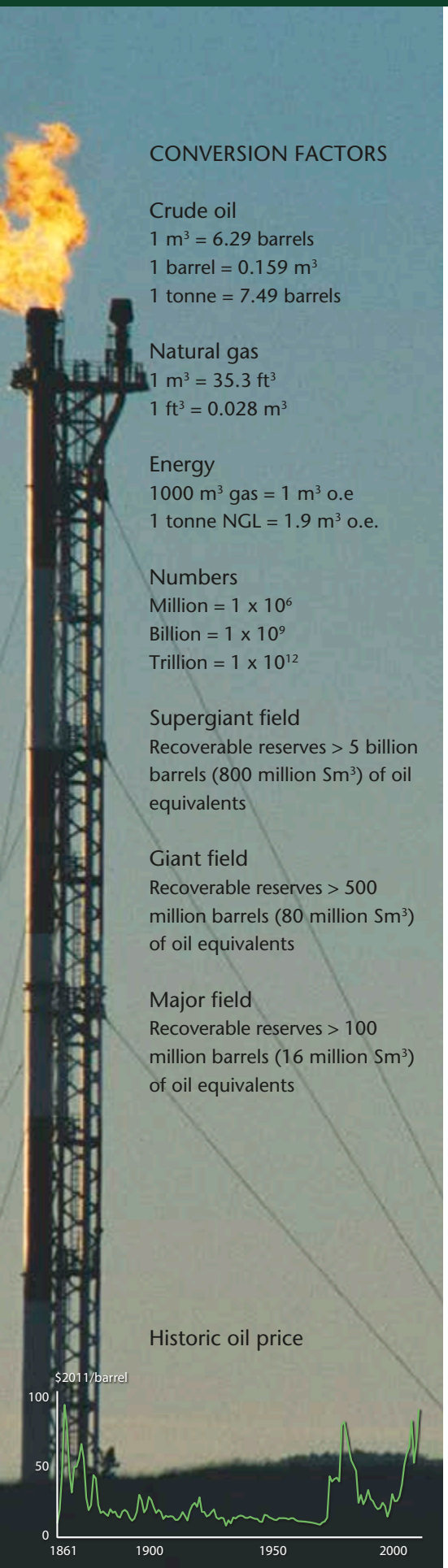


CONVERSION FACTORS

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

A New Oil Province?

A recent well in the Barents Sea may define a new oil province with several billion barrels of oil to be found.

The OMV-operated Wisting oil well (7328/8-1) in the Barents Sea, north of the 73rd latitude, came in as a surprise discovery to everyone who did not possess all the available geophysical data, particularly 3D seismic and CSEM. The discovery was made about 310 km north of Hammerfest on the Finnmark coast, meaning that this is the northernmost discovery on the Norwegian continental shelf ever.

The well encountered a 50–60m oil column in Middle and Early Jurassic reservoir rocks with good reservoir properties. Preliminary calculations estimate the size of the discovery at between 60 and 150 MMbo recoverable. The big surprise was that oil was hit just a few hundred metres below the seabed, which is 373m at this location.

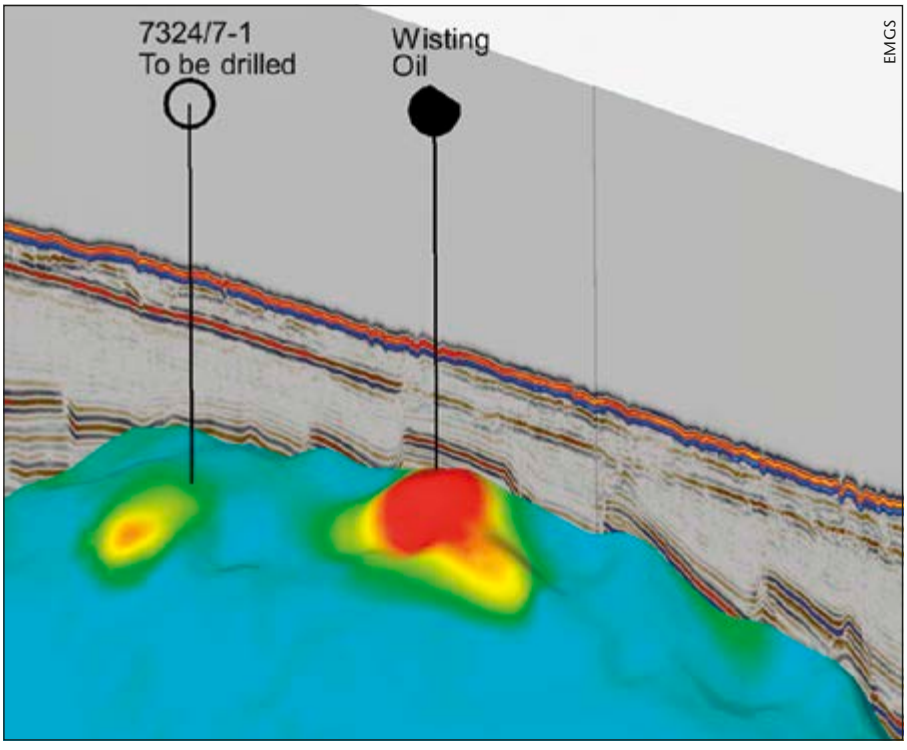
The Wisting prospect was identified by dedicated geoscientists in Tullow Oil (partner in the licence) and was regarded as medium risk due to a combination of soft kick flat spot, as well as AVO- and CSEM-anomalies, although some – not having access to the full set of data, and possibly with a different geological model – were alarmed by the shallow depth of the closure at Jurassic level. Adding to that risk was the chance of encountering gas or heavy oil. While the former would not be economic, the latter may have been caused by bacterial activity due to low temperatures.

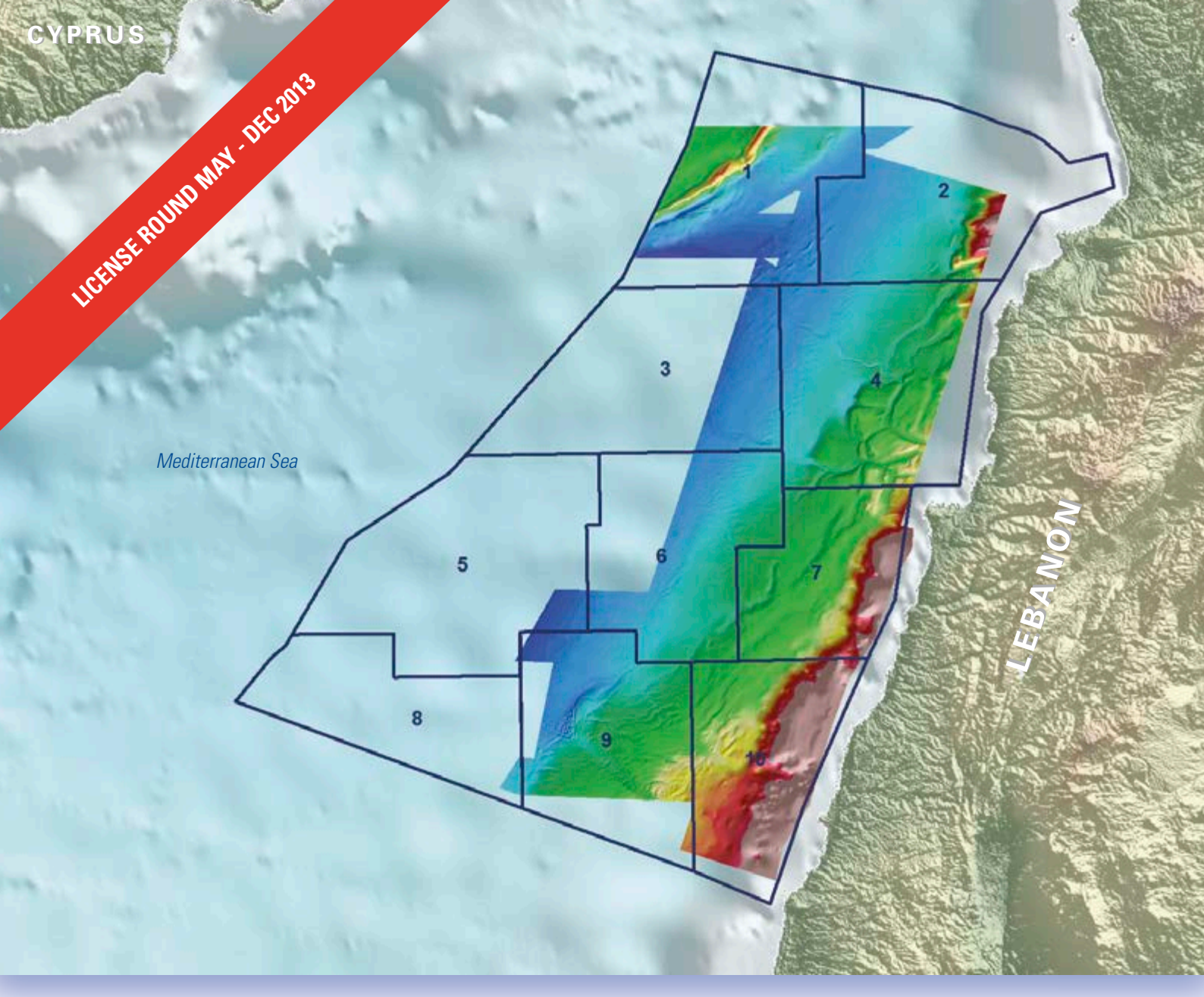
The results confirm a play model in the Early and Middle Jurassic age, according to the Norwegian Petroleum Directorate. This is substantiated by 3D seismic and CSEM, according to TGS and EMGS, which have surveyed the larger area extensively. According to these companies, there are numerous prospects with similar characteristics to be drilled, giving the potential for several (tens of?) billion barrels of recoverable oil to be found.

The Triassic is now being tested, and if oil is also encountered in the deeper section, we may face a real bonanza in the Barents Sea. Stay tuned! ■

HALFDAN CARSTENS

By combining 3D seismic and CSEM it was possible to de-risk the Wisting prospect sufficiently to drill it.





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New MC3D PSDM enables Block assessment in Lebanon

In cooperation with the Ministry of Energy and Water in Lebanon, PGS has acquired more than 8,700 line-km of MC2D and 9,900 sq.km of MC3D seismic data. All the MC3D data has been processed in PSDM to comprise one continuous 3D volume, enabling detailed evaluation of each block.

The 1st Offshore License Round of the Lebanese Republic is closing in December. Blocks 1, 4, 5, 6 and 9 are open for bidding. All data is available now.

Contact us to book a data review meeting at one of our offices in Oslo, London, Houston or Singapore.

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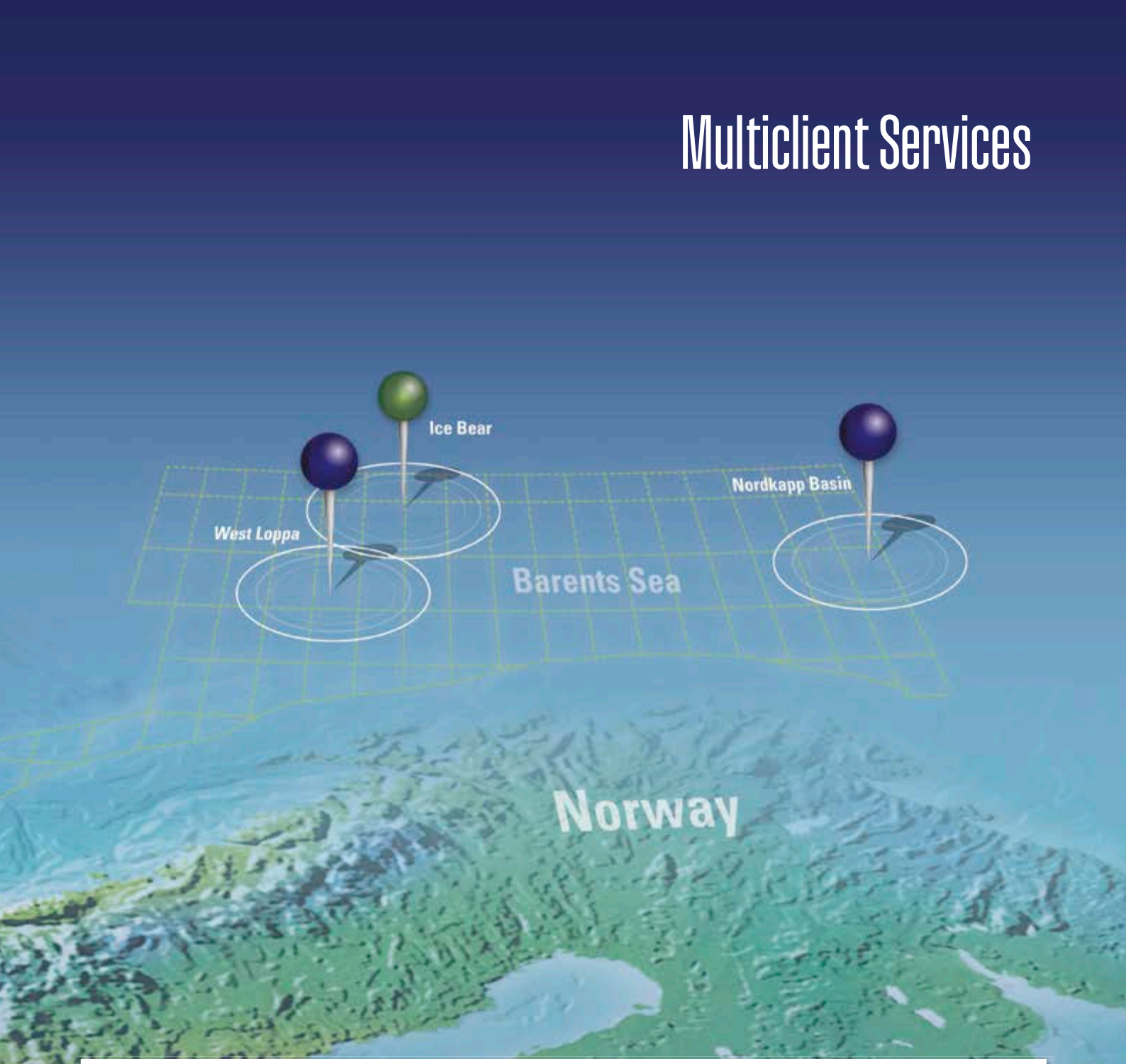

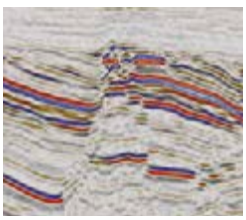

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