VOL. 10, NO. 4 – 2013

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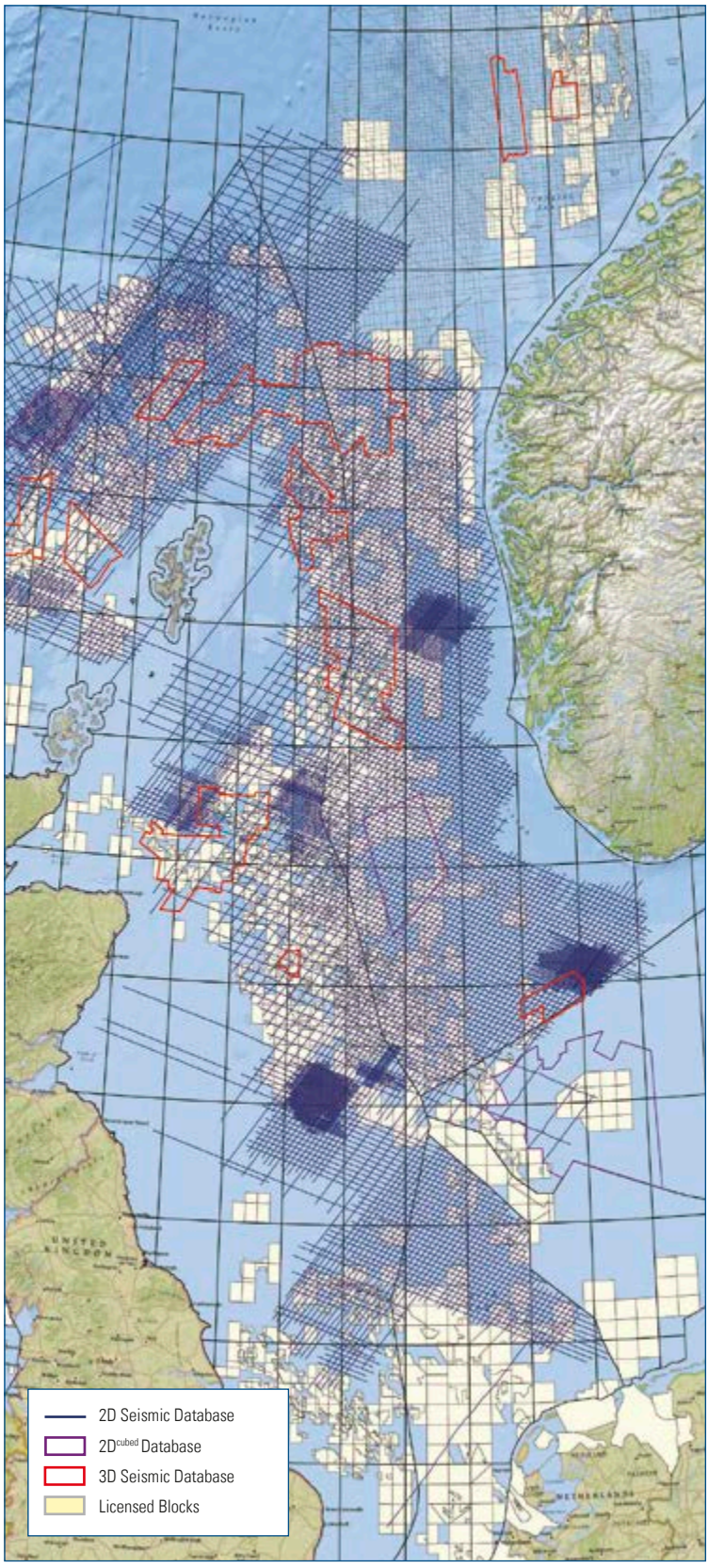
UK 28TH LICENSING ROUND



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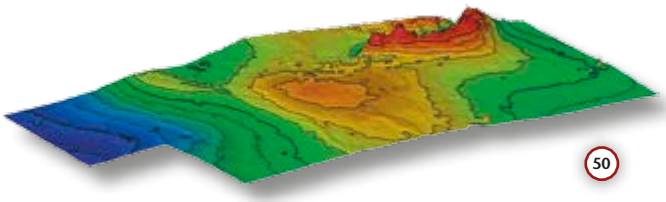

Archimedes Consulting

Using magnetics to identify unconventional horizons

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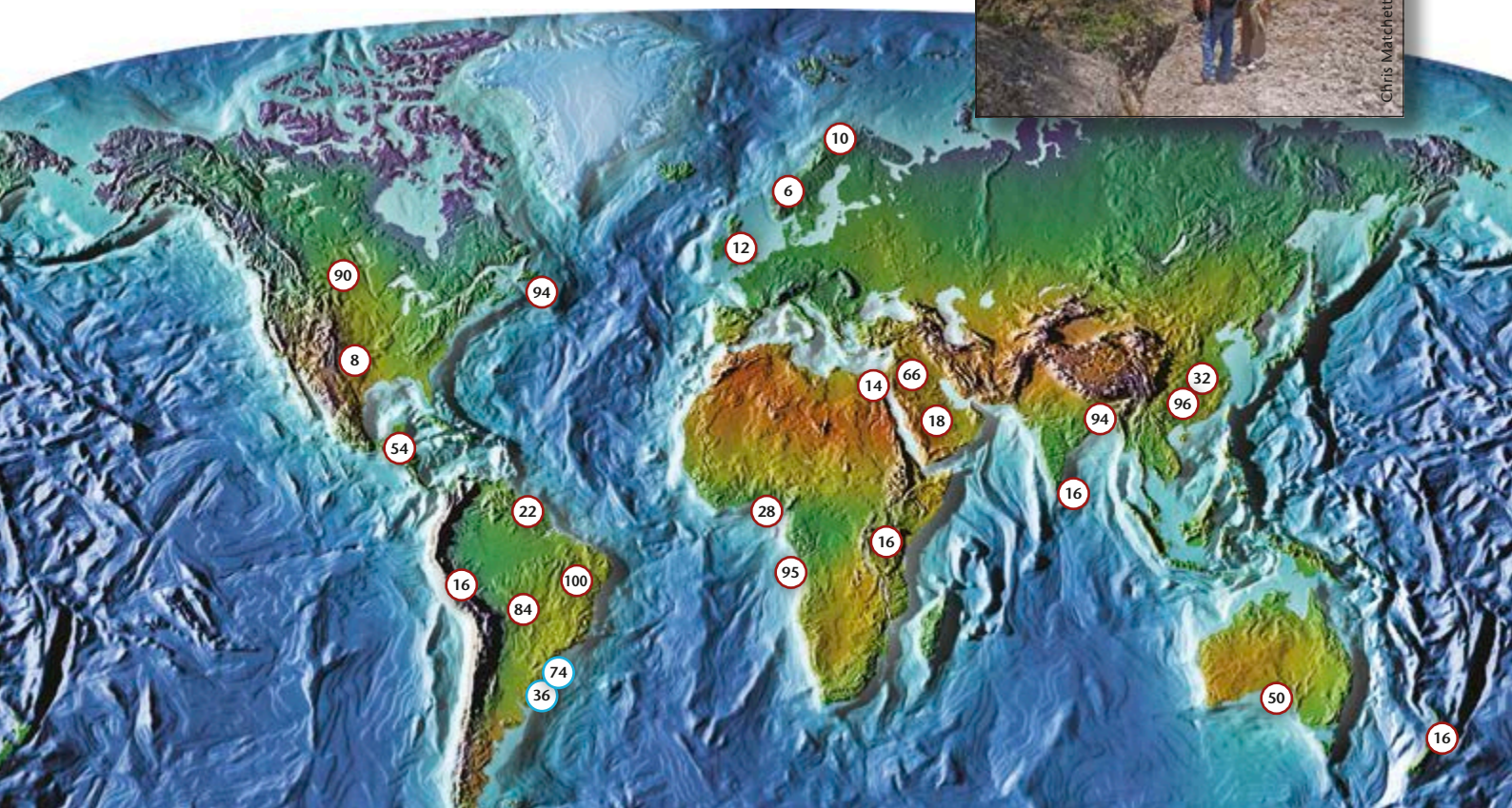

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Frack Off! But Where To?

Only someone who has spent the last five years in the remote Amazon rainforest could be unaware of the influence of unconventional hydrocarbon resources on the economy of the United States. The shale gas/tight oil boom means that the country is on the verge of self-sufficiency and possibly energy security, and is soon to be overtaken by China as the world's largest importer of oil.

Yet even though the US has benefitted from this boom, there is still considerable opposition, particularly to fracking. Several states, including New York, New Jersey and Vermont, have passed laws prohibiting the practice – despite the fact that it has been undertaken for decades. Impassioned arguments are being put forward about the possible environmental and health effects resulting from shale gas and tight oil extraction.

Occupy Wall Street protesters in 2011.

The frenzy has now passed to Europe, with France leading European nations with a complete ban on fracking. In the UK, despite support for shale gas extraction from the government, attempts to drill an exploration well in southern England have been frustrated by large groups of protesters, vehemently opposed to fracking – even though the procedure may not actually be used at the site. The media are having a field day reporting how local people are worried about wildlife, pollution, flaring, spreading industrial sites, water use, escalating atmospheric carbon, oil company profits… the list continues. However, there has been little discussion about the fact that shale gas has much less CO_2 and H_2S than other forms of natural gas, and emits 50% less carbon than coal. Using locally produced shale gas reduces the amount of oil being transported around the world in ships, which burn the 'dirtiest' fuel available. And is it better to use fuel extracted under strict, transparent environmental and safety regulations, or import supplies from countries where less attention is given to these matters?

We cannot deny that there are issues associated with fracking – as there are with any large scale industrial process, particularly one at the cutting edge of technology and concerned with a vital aspect of life, the provision of power. We need constant, intelligent, informed debate, not only over the pros and cons, but about the alternatives – with the possible exception of nuclear energy, no one has yet come up with a viable, long term alternative to fossil fuel.

JANE WHALEY
Editor in Chief

SURINAME

Bright yellow bromeliad epiphytes shine in the morning sun in the rain forest of Suriname: will recent hydrocarbon discoveries in the convergent Atlantic margins of West Africa and South America similarly light up the Surinamese economy?

Inset: Petra is a 'must-see' tourist location for every geologist, not just for its archeology, but also for the rocks which make up the famous monuments.

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New Acreage in Frontier Provinces

In June, 29 companies were awarded frontier acreage in the Norwegian and Barents Seas offshore Norway.

The 1st licensing round on the Norwegian continental shelf (NCS) was concluded in 1965. It took almost 50 years to reach the 22nd round, which includes previously unoffered acreage in the extreme north of the country.

The first round comprised all 278 blocks in the North Sea sector (south of 62°N), with the exception of those closest to the boundary with the Swedish and Danish continental shelves. The Ministry received only 11 applications, covering 208 of the announced blocks. A total of 22 licenses were awarded for 78 blocks, making this the most comprehensive licensing round off Norway to date.

Four years later the first round resulted in Norway's most famous and first commercial oil field: Ekofisk. Contrary to common belief that the find was made the day before Christmas, the drill bit actually hit highly porous and fractured chalk with exceptionally bright, yellow fluorescence on October 25, 1969. "I thought we had hit a gold mine, not an oil reservoir", said Max Melli (*GEO ExPro,* Vol. 8, No. 1), who was well site geologist on well 2/4-2 for Phillips Petroleum that fall. Only two years later, Ekofisk came on stream, based on four wells, and Norway was an oil-producing country.

More than 900 wildcats later, with 88 producing fields (including 12 where production has ceased) and 30 discoveries under development or to be developed, the NCS still attracts minor, major and supermajor oil companies.

Medium-sized Companies Predominate

The 22nd licensing round was announced on June 26, 2012, and comprised 86 blocks in the Barents Sea and Norwegian Sea. By the application deadline on December 4, 2012, a total of 36 companies had applied for production licenses.

Some of the supermajors have already given up on exploring the frontier areas offshore Norway, due to lack of recent success, but ConocoPhillips, Eni, Shell Total and Russian company Lukoil (for the first time) were amongst the 14 companies that were awarded operatorship in the 22nd round. A notable exception is ExxonMobil, which still has reserves of some 500 MMboe elsewhere offshore Norway.

In the newly issued resource report, the Norwegian Petroleum Directorate (NPD) presents analyses showing that the medium-sized companies are strengthening their position on the Norwegian shelf, including four major German gas companies. It looks as if these organizations are about to take over the position that the integrated international oil companies have had on the shelf since the very beginning.

"This confirms that the Norwegian Continental Shelf is a highly interesting petroleum province," said Minister of Petroleum and Energy Ola Borten Moe upon release of the 22nd round results in June.

"There is still a lot of oil and gas to discover in the North Sea, Norwegian Sea and Barents Sea," confirms Sissel Eriksen, director of exploration in NPD, well aware that Lundin Petroleum discovered a giant in the North Sea in 2010 (*GEO ExPro*, Vol. 8, No. 5).

The 22nd round, unlike the 1st round, did not include the North Sea. Acreage made available was either in the Norwegian Sea or in the Barents Sea, as most of the North Sea is considered mature. This acreage is offered on a yearly basis in the APA-rounds (Awards in Predefined Areas).

It was no surprise that the Barents Sea turned out to be more popular than the Norwegian Sea. The reason for this is that deepwater wells in the Norwegian Sea have been largely disappointing, while several recent finds in the Barents Sea, notably Skrugard and Havis, now known as Johan Castberg (*GEO ExPRo,* Vol. 9, No. 2), have upgraded the resource potential and given rise to great optimism.

Service companies specializing in multi-client seismic know all about this. The competition has been fierce, with multiple 2D and 3D programmes, some of them overlapping. ■

HALFDAN CARSTENS

Minister of Petroleum and Energy, Ola Borten Moe, was very pleased with the strong interest in the 22nd round offshore Norway, which resulted in 24 new licenses, 20 in the Barents Sea and four in the Norwegian Sea.

Berit Roald/Scanpix

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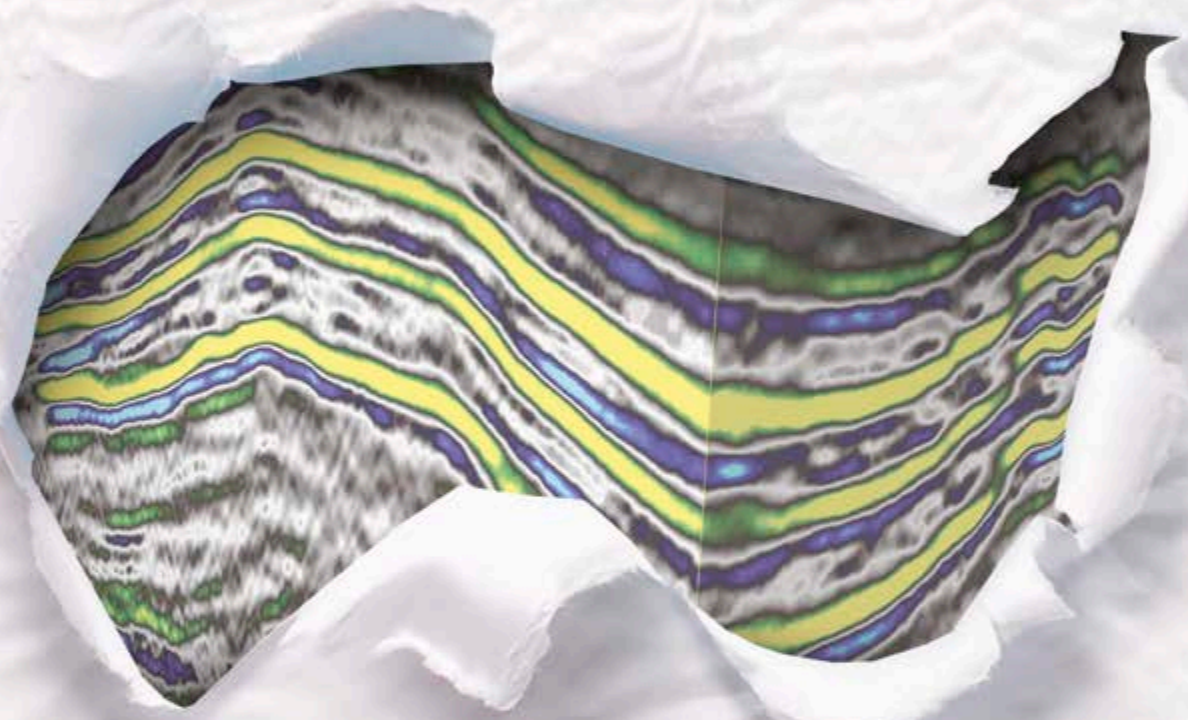

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Conference That's a Cut Above

The Bob F. Perkins Research Conference provides geoscientists with a unique, yearly format to present cutting-edge research papers and share ideas on selected subjects.

For the past 33 years, the Gulf Coast Section of the Society for Sedimentary Geology (GCSSEPM) has held an Annual Research Conference. The first was convened in Houston, Texas, in December 1980 under the leadership of their Past-President, Gene B. Martin and President, Bob F. Perkins. In 1982, the GCSSEPM Foundation took over the responsibility for the conference and the publication of its conference papers. The conference was renamed in 1999 after Bob F. Perkins, the Foundation's first and only Executive Director until his death in 1999.

The GCSSEPM Foundation is a tax-exempt, non-profit, autonomous organization which promotes research and continuing education in the field of stratigraphy and related sciences. It disseminates information for these fields of study through a variety of means including lectures, conferences, publications, and educational courses. The Foundation also provides assistance to public and private schools, colleges and universities in teaching stratigraphy and related studies as well as career guidance.

The primary function of the Foundation is their annual Research Conference. The founder, Bob F. Perkins, set the tone for the future of this organization, and through his efforts of organizing, editing, and publishing, this conference has gained national and international prominence as *the* yearly sedimentary geology research meeting to attend. In addition to his organizational skills, Bob handled all advance registrations as well as conference advertising and publicity.

The Foundation is now in the capable hands of Dr. Norman C. Rosen, the current Executive Director, who took over after the death of Bob Perkins. Norman has been around the editing and geology business since his graduation from Louisiana State University with a PhD in 1968. His first position was as geologist and editor at the Geological Survey of Iran, a United Nations mission. He has since worked in many areas abroad and in the US. He first helped the GCSSEPM as an assistant editor in 1982 and has been very active with the Section serving in various positions until becoming the Executive Director.

2012 Conference

I attended my first Bob F. Perkins Research Conference in 2012 and it proved an excellent experience. The agenda was organized to allow for a great deal of free discussion and plenty of time to meet just about everyone attending. The editors had done their jobs as the talks followed the prescribed topics and all presented new and very thought-provoking information.

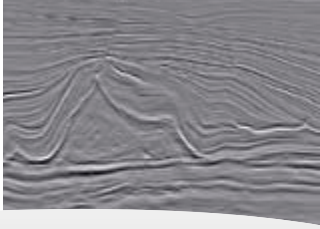
The 2012 conference was attended by more than 160 geoscientists from all over the world. Thirty-seven oral presentations and six posters were presented over the three days under the theme, 'New Understanding of the Petroleum Systems of Continental Margins of the World'. Each afternoon following the presentations, authors were available for discussion and arm-waving sessions. In my opinion, this is the real 'meat-and-potatoes' of this conference – a place where experts studying different areas with new and often different points of view can share ideas.

Put it on your calendar – the 2014 Annual GCSSEPM Foundation Bob F. Perkins Research Conference is set for January 26-28, 2014, again at the Houston, Texas OMNI Westside Hotel. This conference should attract cutting-edge researchers covering the theme of 'Sedimentary Basins: Origin, Depositional Histories, and Petroleum Systems'.

THOMAS SMITH

Executive Director Dr. Norman C. Rosen is always present to see that each Bob F. Perkins Research Conference meets or exceeds all expectations. His excellent work in organizing the conference and editing the papers ensures all the attendees a stimulating and worthwhile experience.



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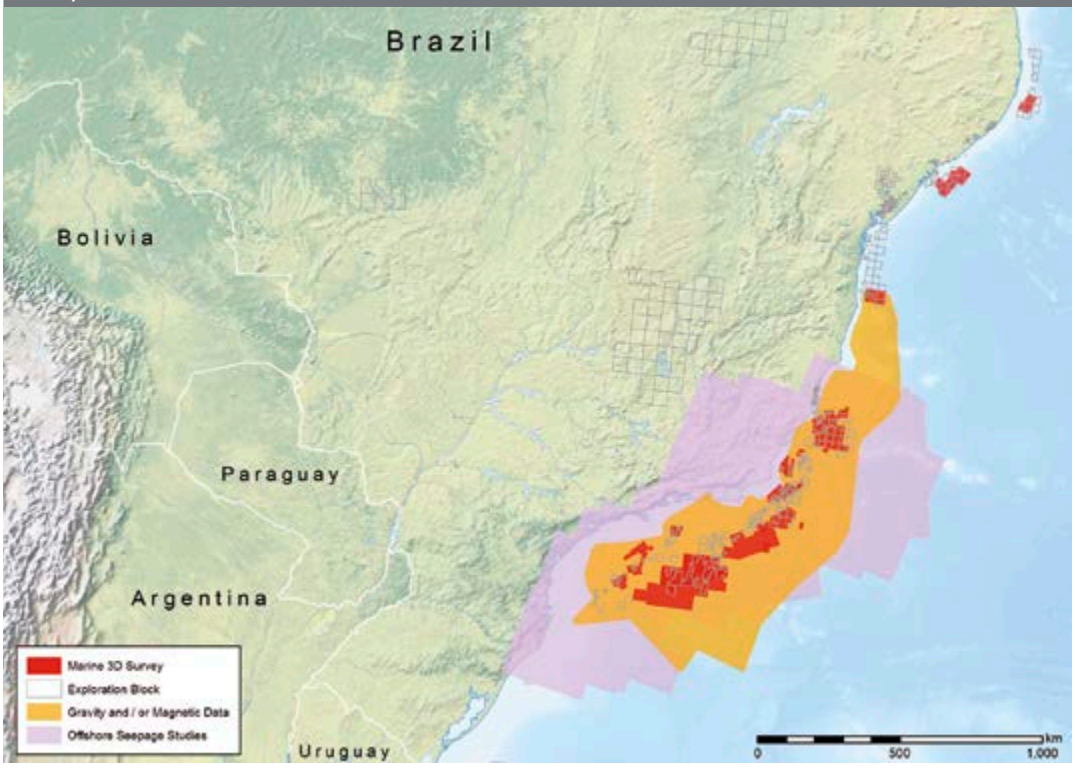

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Elephants are Extinct

The future of the Norwegian Continental Shelf to a large degree depends on the discovery of small fields. The Geological Society of Norway has taken the initiative by organizing a conference dealing with the challenges in defining such prospects.

While the Norwegian Continental Shelf (NCS) is certainly a world class petroleum province, it is also true that the discoveries – with a few important exceptions – are getting smaller within both the mature (APA acreage) and frontier areas.

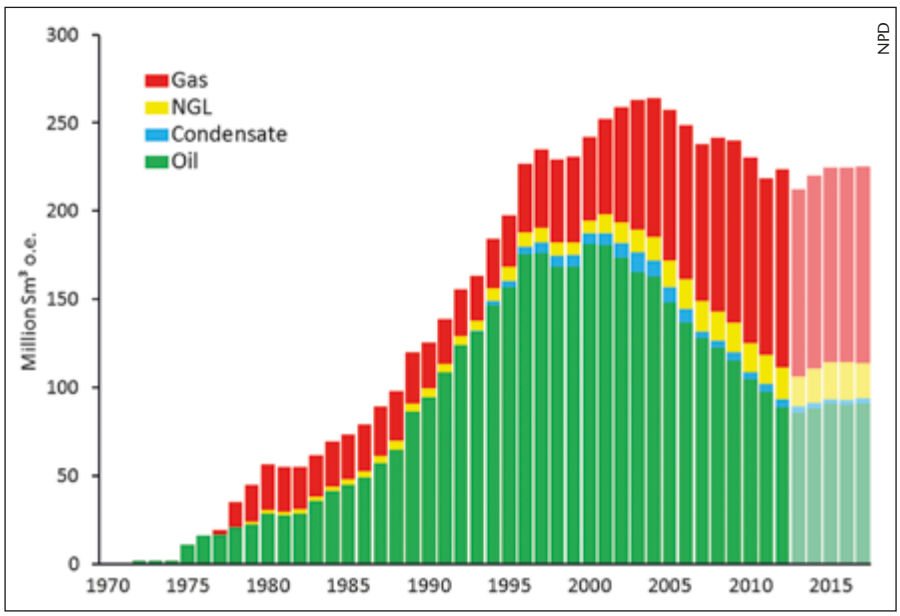
The age of the giants is gone. This is what the players on the NCS are all faced with. This is what they have to base their exploration strategy on – and this is what the future on the NCS is all about. Explorationists will have to deal with increasingly smaller prospects that require sophisticated geophysical and geological analyses to be defined.

This is why the Geological Society of Norway invites explorationists to take part, share their experiences and update their geological insight in a two-day conference which will focus on recent discoveries on the NCS (the last three years), including both technical and commercial discoveries. The main focus of the program will be a systematic review of wells, discoveries and fields (PDO accepted). The idea is for oil finders to tell 'the story behind', including data acquisition, prospect definition, discovery and appraisal wells, source and reservoir rocks, trapping mechanism, particular challenges and reserve estimates.

In parallel with the conference, in a separate poster session, oil companies and service organizations are invited to present prospects on the NCS. These might be prospects in open acreage defined by seismic, or prospects in existing licenses available for farm-ins. This will be the very first prospect fair and exhibition dealing solely with the NCS, and it is expected that players will use this opportunity to attract interest in their exploration ideas. It will take place in Fornebu in Oslo on **May 14–15, 2014**.

The overall idea is that this is the first of a series of biennial conferences and exhibitions covering this subject. In this way, a regular forum will be established for explorationists to discuss results from important wildcats, even if they do not turn into 'goldmines'. Everybody will be winners – not least the Norwegian Continental Shelf. ■

Production on the Norwegian Continental Shelf since Ekofisk was put on stream in 1971. Several giants like Ekofisk, Statfjord, Troll, Snorre and Oseberg all gave significant contributions in the 80s and 90s, but a rapid decline in oil production can be observed since 2000. Future production will therefore largely depend on small and medium-sized fields.



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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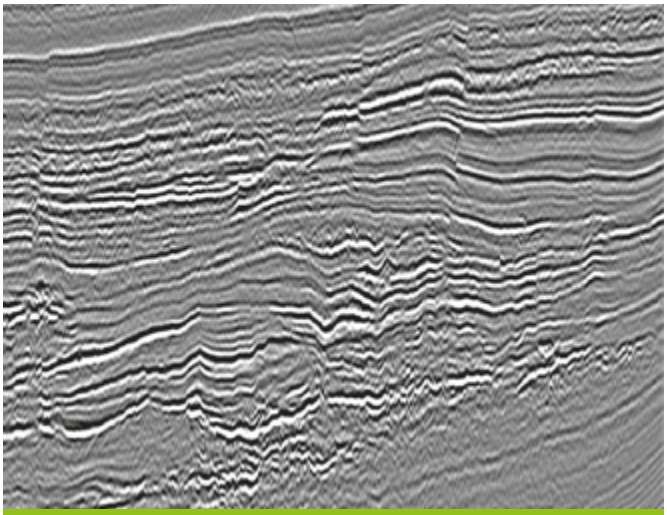
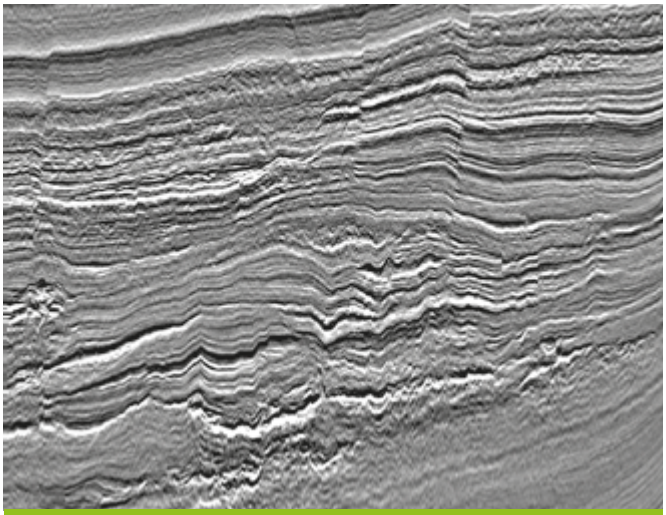


Conventional seismic data



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A UK Shale Gale Coming?

UK Bowland Shale gas in-place resources are estimated at a quadrillion cubic feet

Exploitation of onshore shale gas resources in North America has, in the past few years, reversed a decline in domestic natural gas production and helped reduce gas prices. This has driven a surge in the evaluation of similar resources in other countries such as the UK to determine if the North American success can be replicated.

The most extensive shale gas play in the UK is in the Carboniferous Bowland-Hodder unit that is located, at prospective depths, across northern England in a strip stretching from the Lancashire coast in the west to the Yorkshire coast in the east. In 2010, the UK Department of Energy and Climate Change (DECC) commissioned the British Geological Survey (BGS) to evaluate the potential of the Upper Bowland Shale. The study used simple basin-sized analogies to evaluate the yield at from about 2.1 to 4.7 Tcf gas in-place.

In 2011, the UK company Cuadrilla Resources, a specialist in exploitation of unconventional hydrocarbons, started hydraulic fracturing (fracking) tests at a site near Blackpool on the Lancashire coast. The tests were suspended when they were shown to have induced minor earthquakes and a ban on fracking was imposed. In 2012, DECC/BGS started on a more detailed resource estimate for the Bowland-Hodder unit, using all available data including outcrops, boreholes and seismic data. The results were published in a report issued in July 2013 and available online at *https://www.gov.uk/government/publications/bowland-shale-gas-study*.

The new study has split the Bowland-Hodder into two separate intervals –the upper and lower units. The upper unit is up to a few hundred meters thick and reasonably well constrained in terms of borehole penetrations, core samples and seismic definition. The lower unit is up to thousands of meters thick, but much less explored with few well penetrations and, in general, poor seismic resolution.

Challenges Ahead

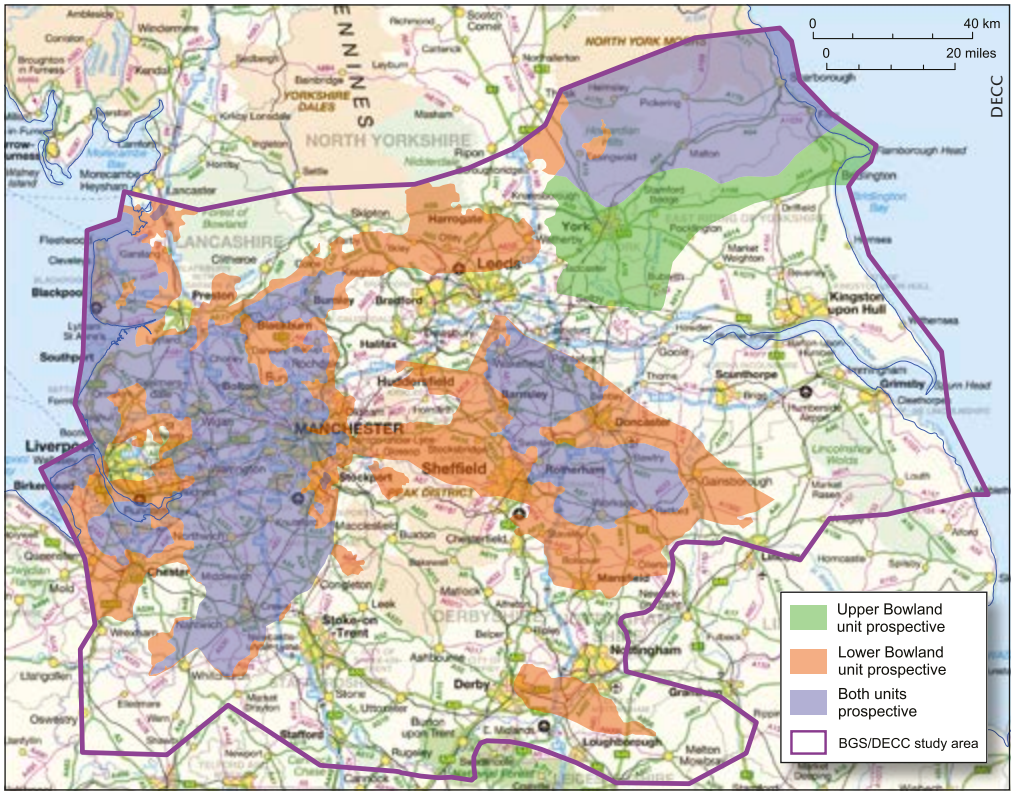
The report states the resource estimate of the upper unit as a P50 (50% probability) of 264 Tcf (7.5 Tcm) and, for the lower unit, a P50 of 1,065 Tcf (30.2 Tcm) total gas in-place (GIP). Because of the uncertainties, in particular for the higher risk and poorly defined deeper unit, there is a wide range in the estimate, with the P90-P50-P10 for the whole of the Bowland-Hodder unit stated as 822-1,329-2,281 Tcf (23.3-37.6-64.6 Tcm).

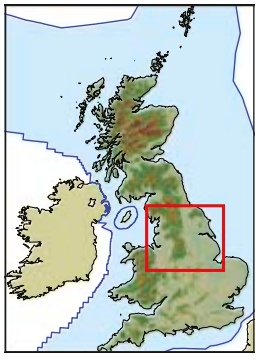
The report notes that this GIP estimate is very large when compared with the Ultimate Recovery (UR) of the total offshore UK gas which currently has a P50 of ca. 100 Tcf. The Bowland-Hodder play is much more complex than US analog s as it is broken up over several basins and troughs and has experienced significant tectonic activity. Because of the geological uncertainties, lack of knowledge about producibility and the significant social and environmental concerns in the UK about shale gas production, the report has not attempted to state an estimate of recoverable volumes.

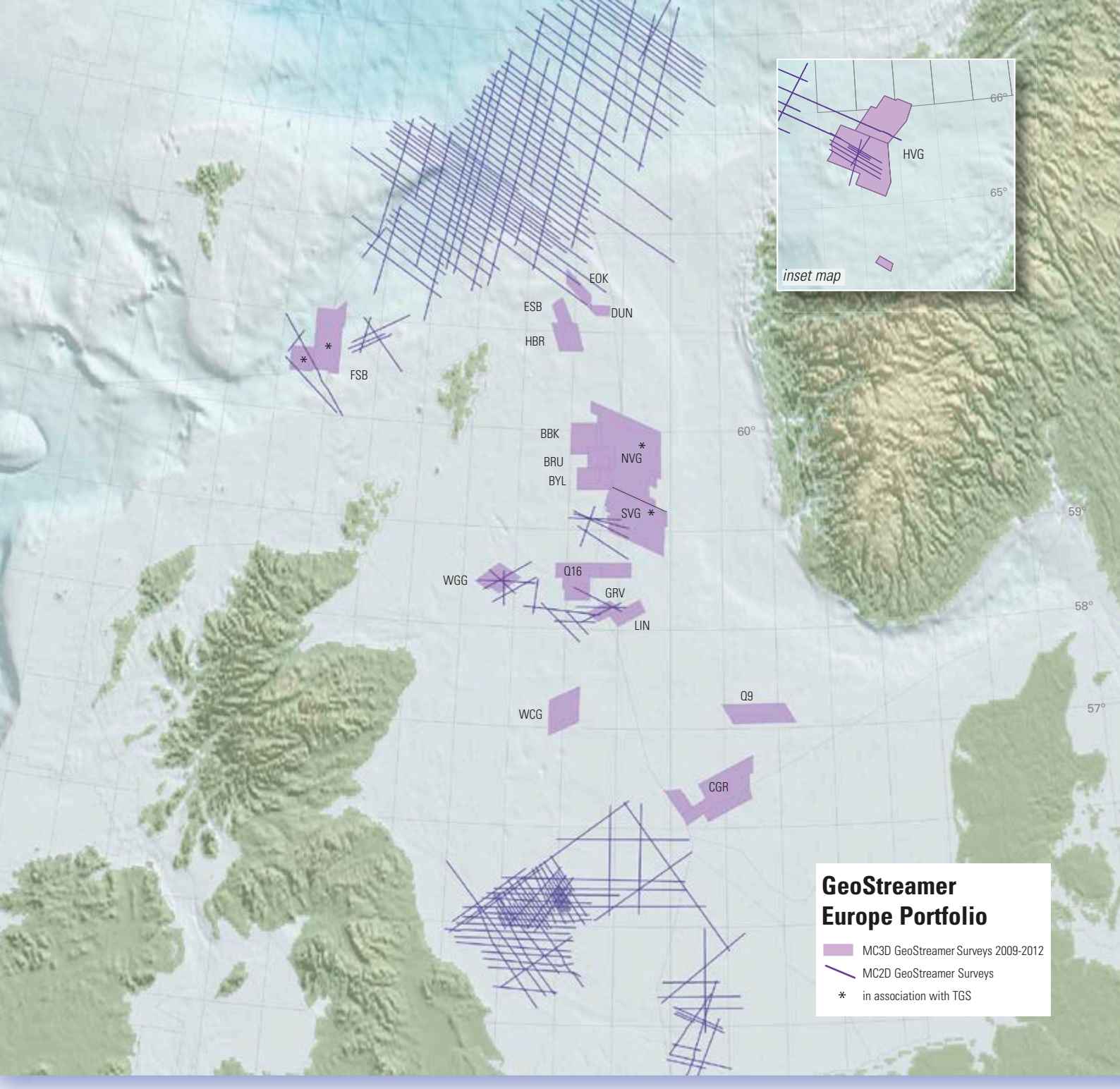
The fracking ban has now been lifted, provided operators can demonstrate that they have the proper controls and seismic monitoring in-place. The UK government also announced, coincident with the DECC report, incentives for communities near boreholes where fracking takes place. Cuadrilla, with partners Centrica, have now announced plans to restart their evaluation of the Bowland-Hodder play. Press reports have appeared that imply that shale gas could provide enough gas for the UK for the next 40 years. But clearly it is too early to make such estimates – very little is known of the play and there are many technical and social challenges ahead.

PAUL WOOD

Summary of areas prospective for gas in the upper and lower parts of the Bowland-Hodder unit in relation to urban areas of central Britain.







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Egypt Déjà Vu

Egyptian unrest sparks fears

THINA MARGARETHE SALTVELT, PH.D

After weeks of grassroots campaigns, mass protests in Egypt erupted in July, culminating in the overthrow of President Morsi in what was effectively a military coup. Two and a half years after the Arab Spring in Egypt resulted in the ousting of President Mubarak, political chaos and bloodshed has returned to the nation. In the oil market, the disruption is sparking concerns about the security of the strategically important Suez Canal, and/or interference with the Suez-Mediterranean (SUMED) pipelines transporting around 2.4 MMbopd to Europe. Fees from the operation of these two transit points are significant sources of revenue for the Egyptian government, so both are strategic targets for strikes or attacks against the regime.

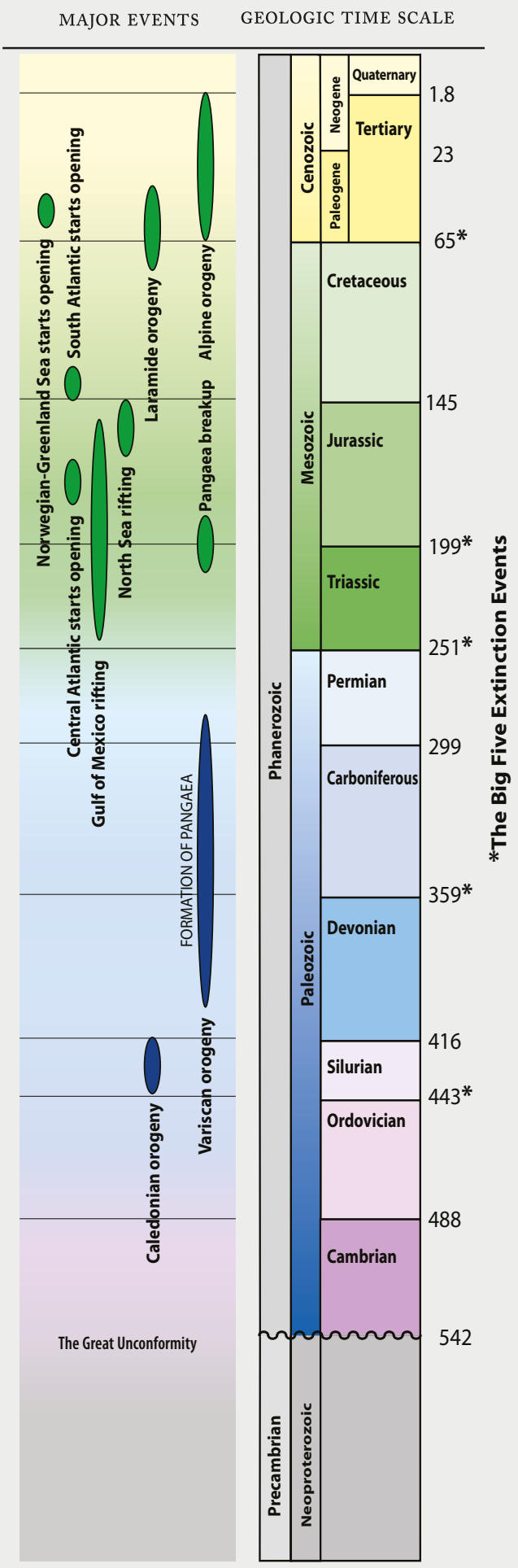
Total oil flows through the Suez Canal reached almost 2.2 MMbopd in 2011, still below the levels seen before the financial crisis and global recession in 2008/09. The decline in transits over the last years also reflects the changing dynamics of international oil flows. Increasing demand from Asian countries, especially China, the shale revolution in the US and falling demand from Europe have redirected oil flows from west to east. Security issues around the Horn of Africa have forced ship owners to take the longer route around South Africa at the expense of routes passing the Suez Canal.

The SUMED pipelines are the only alternative route to transport crude oil to the Mediterranean Sea from the Red Sea. A temporary closure of the Suez Canal and/or these pipelines would add nearly 10,000 km to transit routes and could have a dramatic impact on tanker rates and oil prices. Transit times would increase by around ten days to Europe and 15 to the US, causing a significant build in in-transit inventories and increasing tanker demand. Delayed loads and losses to the oil market and increasing transportation costs will push up the price of crude oil and products, while the longer routes will increase demand for bunker oil to fuel the ships. The fear that Egypt would close down the Suez Canal at the outset of the Arab Spring in 2011 pushed up oil prices by around US$7/barrel.

Home Consumption

Egypt is the largest oil producer on the African continent which is not a member of OPEC, and the second-largest natural gas producer after Algeria. The country's oil exports are limited, only 114,000 bo in 2012, as most of the oil is consumed domestically. It is Africa's third-largest natural gas exporter after Algeria and Nigeria, but volumes have been falling significantly after a two-year moratorium on new gas export contracts in 2008, aimed at increasing electricity consumption at gas-fired power plants.

Thus the crisis in Egypt is primarily a threat to the oil market as an important transport chokepoint and not as a supplier of hydrocarbons to the global markets. A shut-in of the country's oil production would need to be replaced by an increase from other oil suppliers and by reducing OPEC's (the world's) spare capacity buffer. This will put more pressure on the world's supply/demand balance and thus increase the risk premium in oil prices in the short term, as the oil market starts once again to worry about the spill-over effects if the protests spread to the oil-producing regimes of the Persian Gulf. ■



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Tanzania

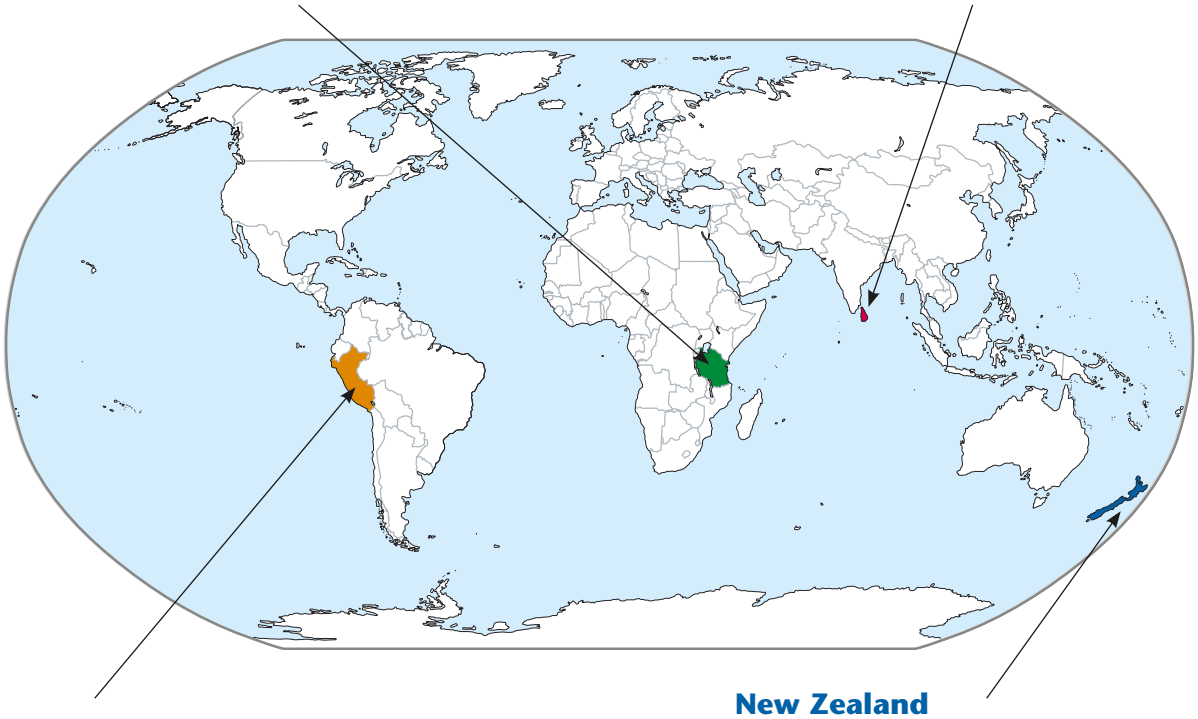
Tanzania plans to launch an oil and gas exploration licensing round on October 25, 2013, offering seven offshore blocks in water depths of between 2,000m and 3,000m, plus one onshore block. The round will close on May 15, 2014. The average size of the blocks is 3,000 km^2, except the North Lake Tanganyika block, which is believed to be about 9,700 km^2. This round was initially announced in April 2012, with an intended closing date of April/May 2013, but it was postponed due to technical reasons and a desire by Tanzania's Ministry of Energy and Minerals to present a new Natural Gas Policy in the October 2012 Parliamentary session. The government is keen to remain competitive with neighboring countries.

When the round was first announced in April 2012, nine blocks were offered, but the delay has allowed the Tanzanian government to reassess the available acreage and, as a result, they have removed two blocks (4/1B and 4/1C) from the auction process, reserving them for Tanzania Petroleum Development Corporation (TPDC). The round is structured by the Petroleum (Exploration & Production) Act of 1980 and the Model Production Sharing Agreement (MPSA 2008) but TPDC has made it known that it will be introducing a competitive fiscal regime for deepwater operation in water depths ranging between 2,000 and 3,500m.

Sri Lanka

The Petroleum Resources Development Secretariat (PRDS) launched the Second Offshore Licensing Round (SL 2013-01) on March 7, 2013, comprising a total of 13 blocks in the Cauvery and Mannar Basins. The blocks in the Mannar Basin range in size from 2,714 km^2 to 8,120 km^2 in the deep to very deep waters of the Gulf of Mannar, while the Cauvery Basin blocks range from 2,403 km^2 in the shallow waters of the Palk Straight, to 4,566 km^2 in the deepwater to the north-east of Sri Lanka. Interested companies are required to submit bids by November 30, 2013 (revised from September 30). Successful companies will secure licenses with an eight-year exploration period divided into three consecutive phases of three, two and three years respectively.

Exploration efforts have generally focused on the onshore and shallow-water Cauvery Basin resulting in the discovery of oil and gas fields. The Mannar Basin is underexplored with only four exploration and three stratigraphic wells, all of which are situated on the north-eastern shallow continental shelf of Sri Lanka. No deepwater drilling has occurred to date. Seeps reported in the basin indicate the presence of an active petroleum system with expected source rocks similar to those found in the Cauvery Basin.



Peru

Perupetro has opened an International Bidding Round for the hydrocarbon exploration and exploitation of nine offshore blocks, which the regulator hopes will generate a minimum investment of US$450 million. The blocks are distributed through the Salaverry-Trujillo, Lima, Lima-Pisco and Mollendo Basins and all are 10 km from the coast. Luis Ortigas, Chairman of the Board of Perupetro, said the offshore basins have good quality seismic information to define the sedimentary sequences, together with regional geochemistry and seismic stratigraphy research data. Petroperu will not participate in the exploration stages in the awarded blocks, but has the option of a 25% back-in in the event of a commercial discovery.

This round constitutes a significant change of plan by the company, which last September issued a statement that before the end of 2012, 36 new concessions would be established, the majority of which would be in the Amazon. The change is a result of the 2011 prior consultation law, which gives a voice to the indigenous tribes on projects affecting the collective rights to their quality of life, cultural identity or physical existence.

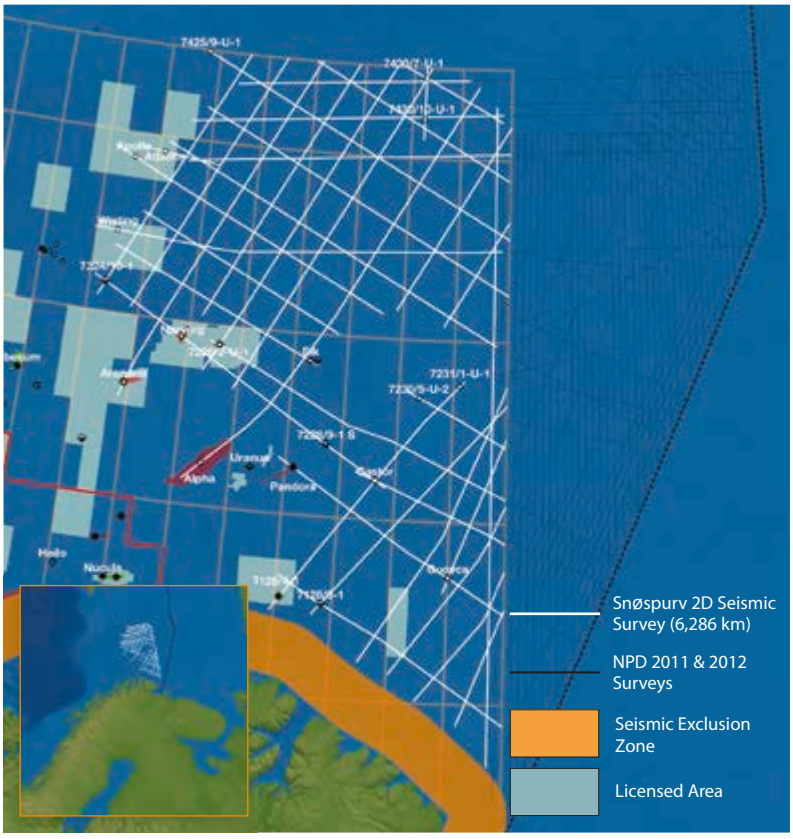
New Zealand

Energy and Resources Minister Simon Bridges has opened the government's Block Offer 2013 comprising 189,000 km^2 offshore and over 1,500 km^2 onshore. These include three defined onshore blocks in Taranaki, and two on the East Coast of the North Island, together with three offshore release areas in the Reinga-Northland, Taranaki and Great South-Canterbury Basins. Permits awarded will be governed by the new Crown Minerals Act regime which came into force on May 24, 2013, which provides for a significantly improved and streamlined two-tier system for permit management. Companies will have until September 26 to submit work program-based bids for their preferred blocks.

Separately, the New Zealand government invites nominations of areas of interest to be included in Block Offer 2014, or any other future offer.

Snøspurv 2D Seismic Survey

6,286 KM - Barents Sea - Norway



The Snøspurv 2D

High Resolution Seismic Survey

- Searcher Seismic and Seabird Exploration have acquired the 6,286 km Snøspurv 2D regional seismic survey covering the Bjarmeland and Finnmark Platforms.
- The survey provides well-ties to 18 planned and completed exploration wells, including Norvarg, Gouvca, Wisting, Atlantis and Apollo and provides the critical link to Barents Sea South East which is now open for exploration.
- The Snøspurv Seismic Survey is designed to enhance the seismic resolution of the prospective Triassic-Jurassic sections of the Bjarmeland and Finnmark Platforms.
- Data will be available from Q4 2013 for participating companies.

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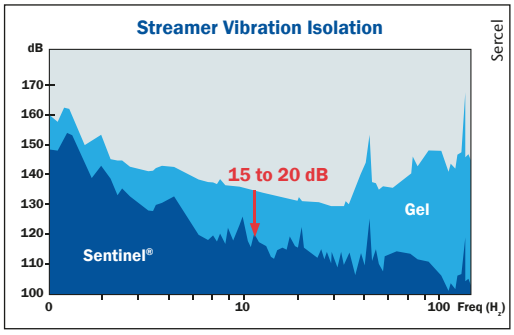
Multi-Sensor Solid Streamer

Leading seismic acquisition company **Sercel** recently announced the launch of a new multi-sensor solid streamer, **Sentinel-MS**, which features two additional acceleration components offering directional measurements for both cross-line and vertical wave fronts, which will deliver multi-sensor data sets for enhanced broadband imaging. By providing wavefield gradient, this new solution enables receiver ghost removal. It is based on the company's very successful Sentinel solid streamer technology, which has proved to provide high quality seismic data and clear seismic imaging with very low signal to noise levels, particularly when compared to gel receivers, whatever the weather conditions and towing depth. A solid streamer is also more robust than a gel one, resulting in better productivity and less downtime. Over 4,000 km of Sentinel streamers are already in use on over 60 vessels worldwide. ■

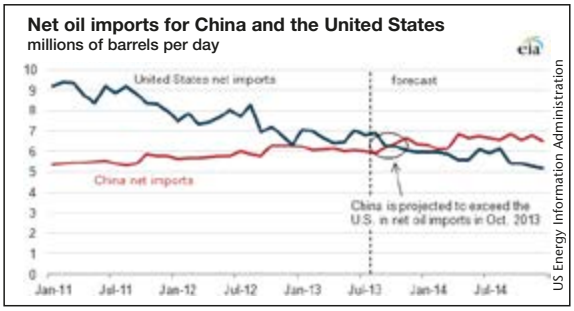


New Gas Collection Device

The **IsoTube AutoLoader** is a gas collection device from **Weatherford** that improves the accuracy of data collected for **isotopic analysis**, particularly in humid climates. The system automatically captures and stores mud-gas stream samples in durable aluminum tubes that are autoloaded into a 'hopper' and reloaded after each sample is taken. Data, including date, time, time zone UTC, tube and device serial number, trigger method, sample depth value, total gas concentration, is recorded onto a radio frequency identification (RFID) tag and mounted directly on the tube, enabling clear and concise sample identification. The system helps to eliminate human error by using digital stamping (vs. handwritten labels) and prevents contamination through the automatic purging tubes of condensation before sample collection. This web-driven device can be programed by the user to take multiple samples and enable or disable the triggers independently. Data files are updated after each sample and can be downloaded in text or Excel formats. ■

Chinese Oil Imports Overtake US

The latest **Short Term Energy Forecasts** from the US Energy Information Administration predict that China's net oil imports will soon exceed those of the US, making it the world's **largest net importer** of the commodity. Net oil imports are calculated as a country's total liquid fluids consumption less its domestic production. Total annual oil production in the US is expected to rise by 28% between 2011 and 2014 to nearly 13 MMbopd, largely due to exploitation of unconventional resources and the Gulf of Mexico deepwater plays, while demand has dropped from a peak of nearly 21 MMbopd in 2005 to 18.7 MMbopd. Meanwhile, production in China is expected to increase at the much lower rate of 6% over this period to about 4.4 MMbopd in 2014, but Chinese liquid fuel use is expected to grow by 13% to 11 MMbopd in the same time. ■

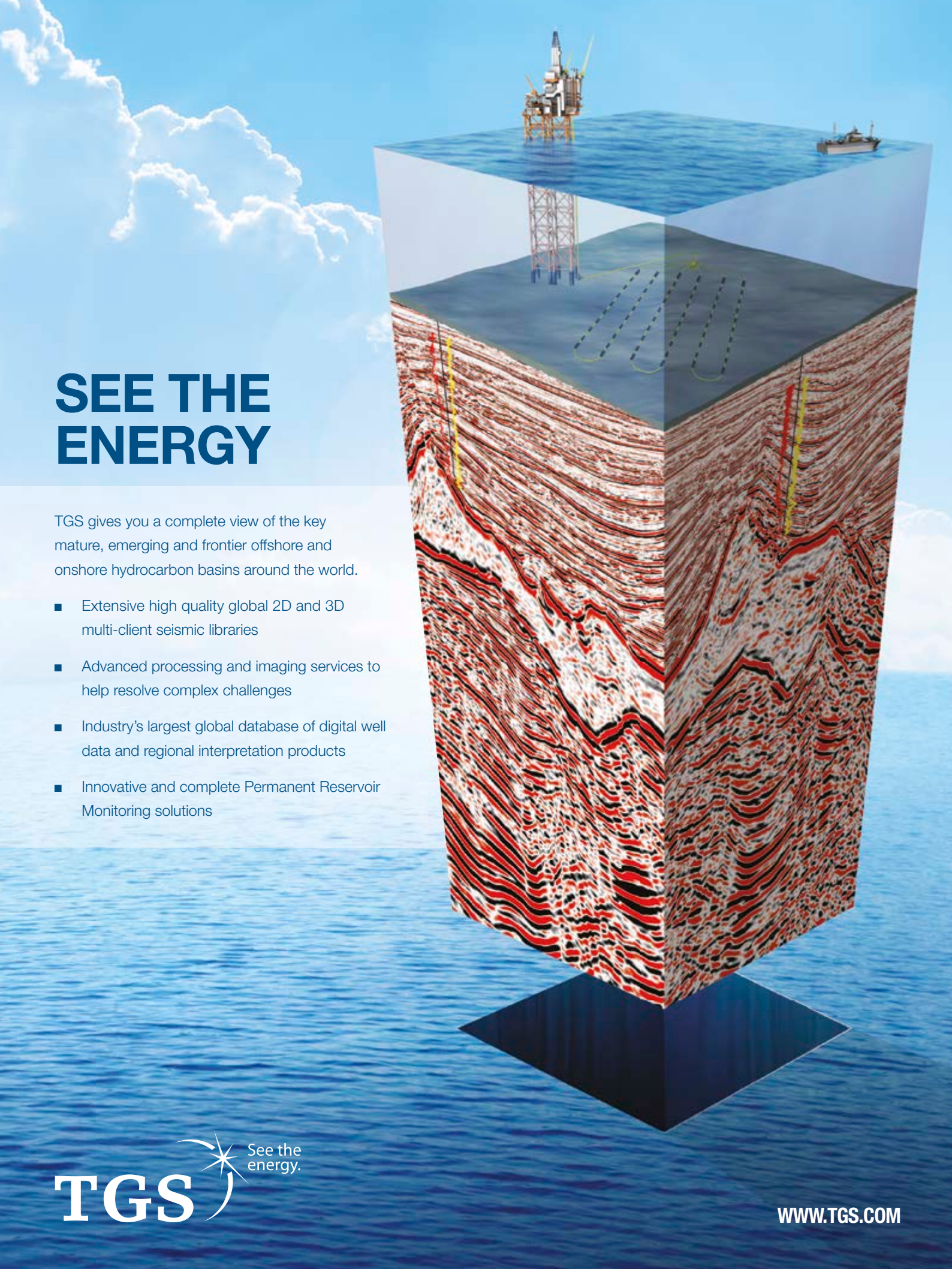


The Father of Fracking

The announcement of the death of **George Mitchell** led to many tributes in national and international media, many hailing him as 'the father of fracking'. But Mitchell, who died in July at the age of 94, was renowned as a successful oil finder and business man, an astronomer, an environmentalist, and a philanthropist, as well as for pioneering the use of horizontal drilling and rock fracturing in the extraction of shale gas.

He was born in Galveston, Texas, to immigrant Greek parents – his father's name was actually Savvas Paraskevopoulos, but he got tired of spelling it and took the simpler name of Mike Mitchell. Having graduated top of his class in petroleum engineering at Texas A&M University and after a short spell with Amoco and in the Army, George set up his own oil company, Mitchell Energy and Development. On previously unproductive land north of Fort Worth, he drilled many successful wells, expanding to hold acreage there of over 1.2 million square kilometers. Mitchell eventually sold the company for US$3.5 billion to Devon Energy in 2002 – but not before he had unlocked the possibilities of shale gas, after many years of doggedly trying to get at the gas locked into the Barnett Shale beneath Texas. Although hydraulic fracking had been used since the 1950s, Mitchell was the first to combine the technique with different fluids and horizontal drilling in the shale gas horizons.

Many obituaries mentioned the '**Mitchell Paradox**' – that the man who pioneered fracking was an environmentalist, who founded 'The Woodlands' outside Houston as a forested, environmentally protected urban development. He supported stronger regulations on fracking and set up a foundation to enable 'innovative, sustainable solutions for human and environmental problems'. ■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Unconventional Resources in Saudi Arabia

Saudi Aramco is broadening its portfolio by venturing into unconventional gas. The company's foray into this arena is promising, with strong indications of substantial shale and tight gas deposits in **Saudi Arabia**. The **Unconventional Gas Initiative** will contribute to the Kingdom's growing domestic energy mix as the economy diversifies and new growth industries are developed.

Saudi Aramco's multidisciplinary unconventional asset teams are deploying the latest technologies across more than 1.2 million square kilometers of frontier basins believed to contain unconventional gas, working with the source rocks and tight reservoirs that are associated with the largest oil and gas fields in the world. The company is currently exploring and appraising several prospects for unconventional gas within the Kingdom, including in the North West, South Ghawar, Jafurah and Rub'al-Khali Basins. ■

Saudi Aramco's Brian Gratto talking about unconventionals within Saudi Arabia during the Unconventional Resources Technology Conference (URTeC) in Denver, Colorado.

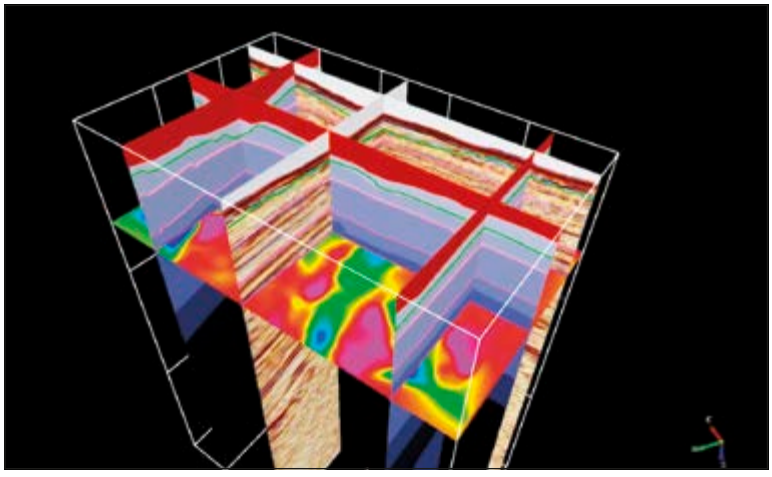
Dr. Joe McCall

GEO ExPro Magazine was saddened to hear of the death of **Dr. Joe McCall**, who featured in our GEO Profile series in 2011 (Vol. 8, No.1). Joe, who died in May at the age of 92, graduated from Imperial College (his time there having been interrupted by war service) and worked as a geologist throughout the world, from East Africa and Iran to Australia and Canada, as well as his native England. He became a renowned expert on carbonatite volcanoes, and also on meteorites and lunar geology, and crossed happily between academic and commercial professions, working at various points in his career with the Geological Survey of Kenya, as a university lecturer in Perth, Australia, and a mining geologist in Quebec and Western Australia. Even after he officially retired, he continued producing papers and editing books and magazines, and was an editor of the Geological Society's magazine *Geoscientist* until shortly before he died.

As Joe himself put it, his was "an extraordinary, unusually diverse, and very rewarding life in geology." ■

ARKeX Launches XFIELD

Gravity and magnetic **potential field data** is rapidly becoming an essential part of the seismic interpreters' tool box. To help with accessing this data, **ARKeX** recently launched a powerful geophysical software modeling tool, **XFIELD**, which allows explorationists to seamlessly integrate and analyze potential field data alongside their seismic data. By using this tool to validate seismic interpretations, geoscientists can easily and efficiently build con strained geological models, which will help reduce exploration uncertainly, risk and cost. They can be created in either time or depth through the integration of all available datasets, including gravity, magnetics, gravity gradiometry, 2D and 3D seismic, well log data, and previous interpretations, in a 3D interpretation workspace. Output is in SEGY fomat. XFIELD is available as a plugin to **dGB's OpendTect** comprehensive seismic interpretation suite. ■



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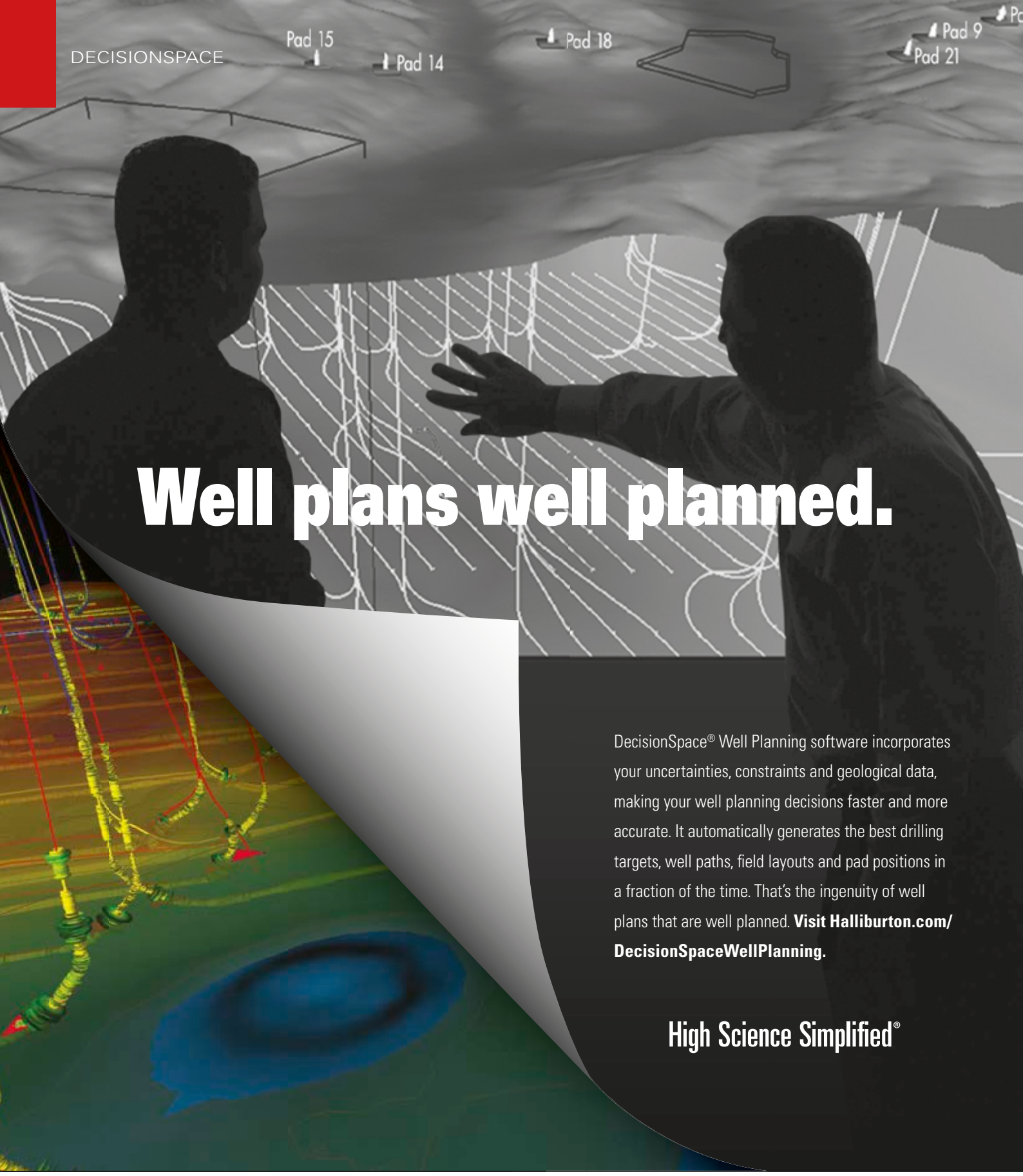

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Petroleum: The New Economic Boost for Suriname

Good proven source rocks and reservoirs, and analogs with the conjugate margin across the Atlantic – could the waters offshore Suriname be harboring great riches?

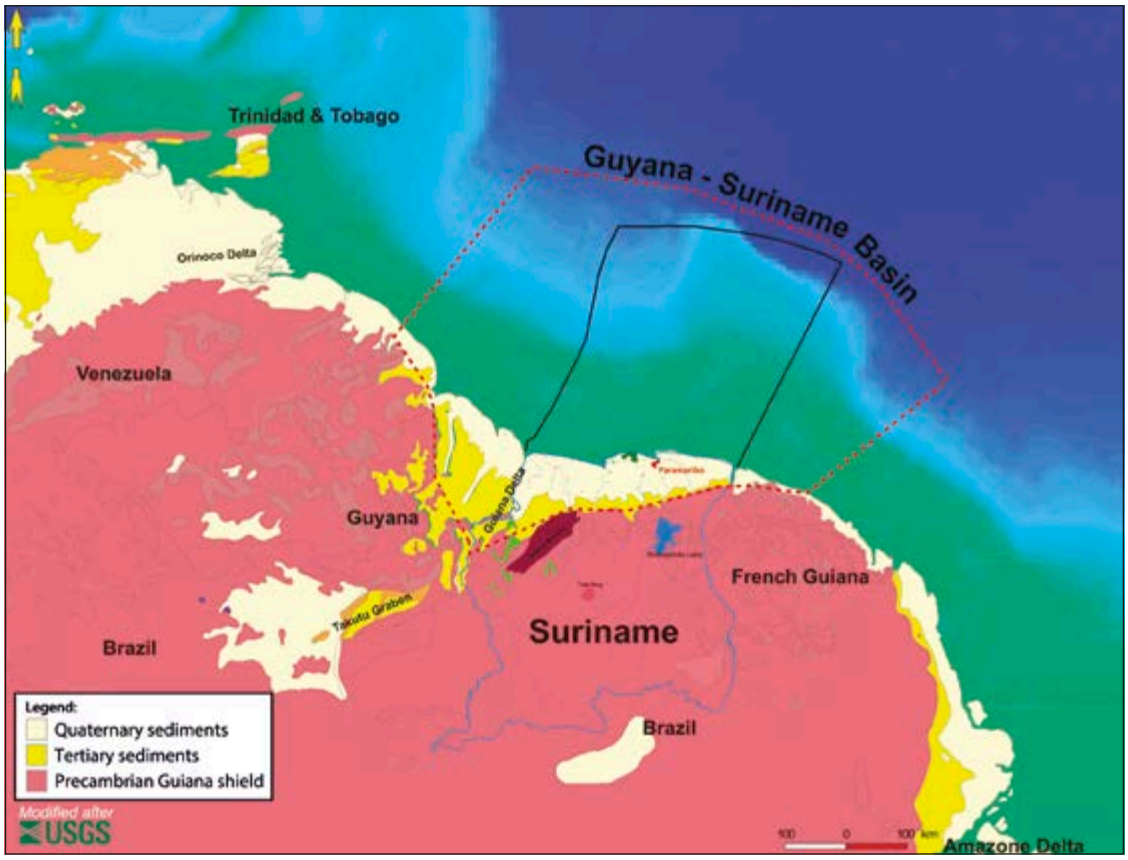
VINITA BIHARIESINGH-RAGHOENATH and CLYDE GRIFFITH, Staatsolie

The Republic of Suriname, with its capital city Paramaribo, is located just north of the Amazon delta on the north-east coast of South America. Since 1980, the petroleum industry has made great progress and has gained a prominent place in the economy of the country. The national oil company, Staatsolie Maatschappij Suriname, is involved in the entire spectrum of petroleum activities: from exploration to refining and marketing. It acts as the petroleum regulator and is responsible for promoting open offshore acreage, negotiating petroleum agreements and monitoring the contracts signed with IOCs. It also manages the data and allows interested companies access to a large open file data set.

The Cretaceous-Tertiary Guyana-Suriname Basin is a classic passive margin basin which came into existence when Africa separated from South America. Prior to this event the area was part of the basin that formed when North America drifted away from North Africa. During this earlier period a thick sequence of Jurassic to Early Cretaceous sediments was deposited. Consequently a thick succession of Jurassic to recent

Roseveld Peak is a 784m granite mountain with breathtaking views over the tropical rainforest

Staatsolie



Outline of the Guyana-Suriname Basin. The north-pointing Demerara rise can be traced back to the Guinea Conakry coast, across the Atlantic in West Africa.

sedimentary section has been built up in environments of deposition ranging from near coastal to deep-marine. Locally carbonates are also found in the basin.

The Suriname part of the Petroleum Province measures 153,000 km^2 and is divided into the onshore, seven near shore blocks and over 20 offshore blocks, with water depths ranging from 50m, about 50 km from the coast, to over 3,000m in the extreme north-west corner of Suriname's territorial waters.

Staatsolie is the sole operator of the onshore blocks with the exception of the Coronie and the Uitkijk blocks, which are operated by its subsidiary Paradise Oil. Operators in the offshore include Apache, Tullow, Teikoku, Murphy Oil, Kosmos and Petronas.

Mixed Exploration Success

Oil was first discovered in Suriname in 1928 in the District of Nickerie on the coastal plain close to the border with Guyana, but systematic exploration both onshore and offshore only started in the early sixties, when a number of IOCs became interested. In 1965, during a potable water drilling campaign by the Geological Mining Department, oil was discovered in the coastal District of Saramacca – in a school yard.

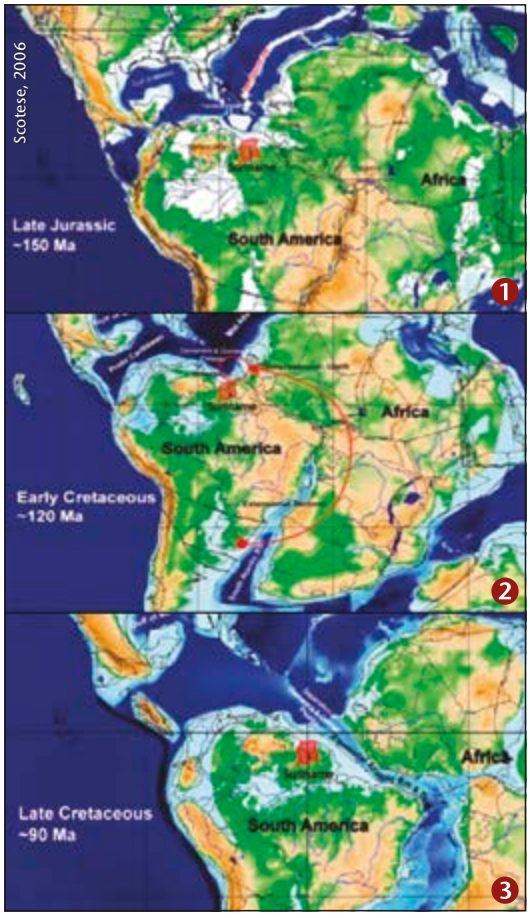
In 1980 Staatsolie was established and the first commercially produced oil came to surface in 1982 from the onshore Tambaredjo Field, near Paramaribo. Crude is produced from Paleocene sands from a depth varying from 260 to 425m and the STOIIP of this field is 700 MMbo. Since 1982, 100 MMb of Saramacca Crude, a heavy sweet oil (16° API) but low on vanadium and sulfur, have been produced. Remaining reserves are estimated at approximately 80 MMbo.

In addition, the nearby Calcutta and the Tambaredjo North West Fields have been on stream since 2003 and 2009 respectively. They are producing from Eocene and Miocene stratigraphic traps, and the total present day production is 16,000 bopd.

Exploration activities in the offshore were less successful. Between 1957 and 1980 four exploration wells were drilled offshore by Colmar and in 1980 the first PSC was signed with Gulf Oil. These efforts did not lead to commercial discoveries nor did the efforts of the Energy World Trade group in 1986. New hope came with the studies executed by Pecten in 1993. Under a PSC signed in 1999 with the Suriname Deep Water Consortium, consisting of Burlington, Shell, TotalFina and Korea National Oil Company, the first regional 2D survey was acquired. However, no wells were drilled.

A study by the USGS (2000) identified the Suriname-Guyana Basin as an under-explored basin with a potential recoverable exploration resource of 15 Bbo, based on the petroleum system associated with the Late Cretaceous-Tertiary Basin. This estimate caught the attention of the industry and triggered Staatsolie to make acreage available through competitive bid rounds. Since 2004 PSCs have been signed with a number of IOCs recognized for their success in frontier exploration. In the last ten years a vast amount of 2D and 3D seismic data was acquired, as well as gravity and magnetic data.

Between 2007 and 2011, four exploration wells were drilled. Repsol's West Tapir well and Murphy's two wildcats did not encounter what they were hoping for, while Teikoku Oil, who drilled the Aitkanti well in Block 31 about 100 km north of Paramaribo, believed



1: Rifting of South Atlantic region;
2: Counter-clockwise rotation of Africa;
3: Drifting of South America

that the purpose of the well was accomplished.

As of July 2013, a total of 65,000 km of 2D seismic has been acquired over the whole basin. In order to de-risk the prospects, approximately 17,000 km^2 3D data, mostly offshore Suriname, has been acquired.

Conjugate Margins

The petroleum geological history of Suriname begins in the Late Jurassic when the North Atlantic rift system, separating North America from North Africa, progressed southward to the Central Atlantic region. The southernmost tip of this rift system terminates in the Takutu Graben, onshore Guyana, where Jurassic lacustrine source rocks resulted in an as yet non-economic light oil accumulation.The stratigraphy of the Jurassic rift basins is poorly known in Suriname, since no well penetrations are available. However, from the Takutu Graben and the conjugate Atlantic margin in Africa, a first estimate of the basin fill can be made. Lacustrine source rocks, alluvial fans and fluviatile deposits, together with volcanoclastics, make up the lower stratigraphy, while salts point to local restricted basins. The salts are overlain by marine clastics and carbonates.

The opening of the South Atlantic Ocean created a counter-clockwise rotation of Africa, causing compression, with inversion of the Jurassic grabens. The uplift and erosion of the Jurassic grabens are clearly seen on seismic over the Demerara Plateau offshore Suriname. This was followed by the rift and drift phase of the South American and African plates and subsequent formation of the present passive margin basin.

A major break-up unconformity occurred, marking the onset of deeper

Stratigraphic column of Suriname. The links between the various source rocks and reservoirs have been confirmed by typing of oils and source rock samples. Facies changes from south (land) to north (basin) from coastal through shallow marine to deeper marine.

marine deposition in response to the still continuing thermal subsidence after the break-up. This break in the stratigraphy is evident throughout the basin. During this period the prolific Cenomanian-Turonian source rock was deposited offshore along the deeper marine margins of South America and West Africa.

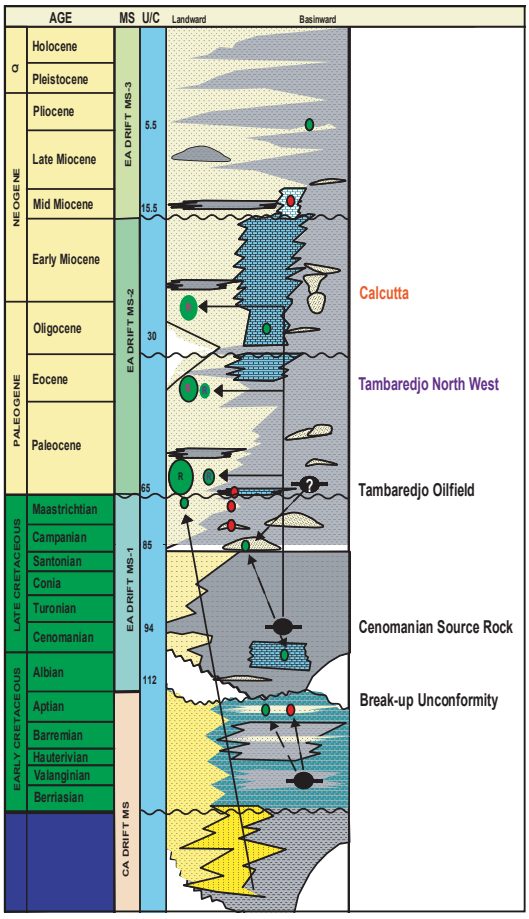
According to Stolte and Darden (2013), the petroleum system of the Guyana-Suriname Basin is believed to be a conjugate of the petroleum system present in West Africa that has revealed several huge discoveries, such as the Jubilee discovery in the Tano Basin offshore Ghana.

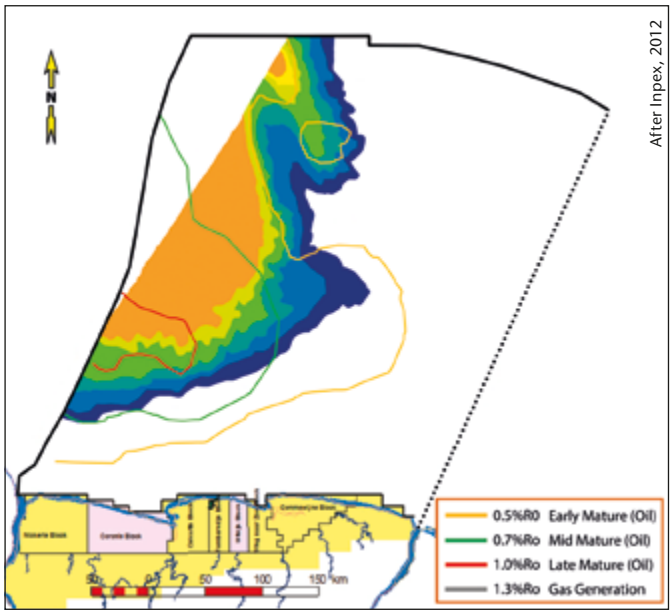
Good Source Rocks

The stratigraphy reflects the tectonic influences since the Jurassic age. About 2,000 onshore and 26 offshore wells provide a solid data set to evaluate the stratigraphy of Suriname.

In Suriname the proven source rock is the Cenomanian–Turonian organic shale. Oil generated from this source rock migrated for approximately 150 km to be trapped onshore in sand reservoirs of the Tambaredjo, Tambaredjo NW and the Calcutta fields. The trapping is stratigraphic (pinch-outs) and the reservoirs are sealed by interlocking high-stand shales. The Cenomanian-Turonian source rock is the time equivalent of the well known La Luna Formation in Venezuela and the Naparima Hill Formation in Trinidad.

Typing of heavy oil shows from onshore wells east of the Tambaredjo field indicates the presence of an additional source of possibly Jurassic age. Lacustrine source rocks occur on both margins of the Central Atlantic (for example Angola and Brazil). Early Cretaceous source intervals have been





Distribution of the Cenomanian-Turonian source rock

encountered in some offshore wells, with TOC ranging from 0.7 to 7.5 %. Similar source rocks and associated oil seeps and slicks have been encountered in the conjugate setting of Guinea Bissau and Guinea Conakry.

Various Play Types

In 2010, hydrocarbons were produced from Tullow Oil's Zaedyus discovery offshore French Guiana, pointing to trapping in Late Cretaceous turbidites charged by the Turonian-Cenomanian source rock. The Zaedyus well hit 72m of net pay in three sands in two turbidite fans offshore French Guiana.

Angus McCoss, Tullow's Exploration Director, commented in September 2011: "The discovery at Zaedyus has proved the extension of the Jubilee play across the Atlantic and made an important new discovery in French Guiana. Tullow has built a commanding and unique acreage position in South America and this result marks the start of a significant and potentially transformational long-term exploration and appraisal campaign in the region."

Various play types have been identified offshore Suriname. In the Jurassic syn-rift setting these include anticlines, fault traps, possible salt traps, sub-crop traps and stratigraphic pinch-outs. The strongly-dipping Late Jurassic sequence depends on closure against syn-rift unconformities. Indications for the prospectivity of this play type are not only from the lacustrine oil discovered in Suriname, but also from the Jurassic to Lower Cretaceous sourced petroleum systems in West African basins and Brazil.

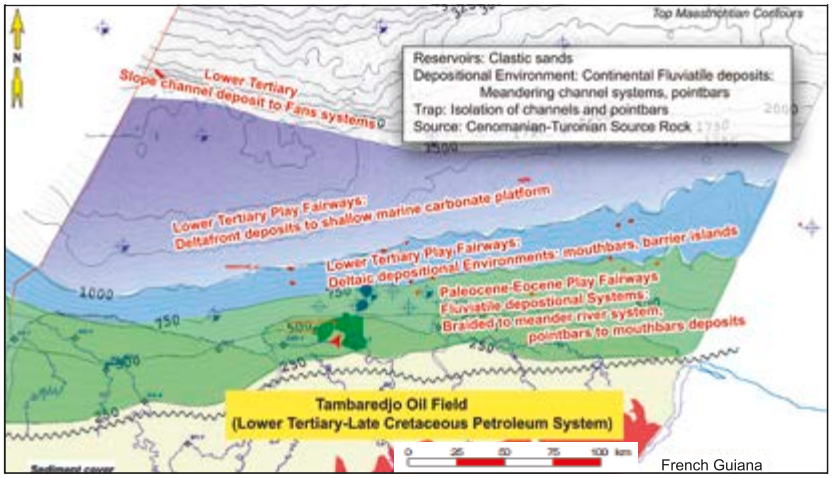
Potential plays in the Cretaceous and Tertiary post-rift cycles include carbonate platforms, channel complexes, anticlines, fault traps, turbidites, pinch-outs, and shelf edge canyon sand basin floor fans.

Potential to be Explored

The coming years will be very critical for the further confirmation of the hydrocarbon potential of the Suriname-Guyana basin. Its success will depend on refinement of the prospect portfolio through detailed studies of the existing data set and through further acquisition of high-tech 3D seismic that can better image, for example, the stratigraphic plays.

If the potential is validated, the region will have to manage the rush of IOCs that will want a piece of the action. For the time being the focus is on the exploration wells that will be drilled by the current operators between 2014 and 2016. ■

Tambaredjo-Calcutta Field analogs. The various environmental belts are plotted on a Base Tertiary/Top Cretaceous contour map. The onlap of the Cretaceous is highlighted by the wavy line. Tambaredjo-Calcutta Field analogs can also be expected in the eastern part offshore area on the continental shelf. Down dip deltaic canyons as well as turbidite systems can be expected. The Paleocene-Eocene fairway is characterized by coastal marine/tidal settings.



A Brief History of Suriname

Suriname, at just less than 165,000 km^2, is one of the smallest countries in northern South America. It is believed to date back as far as 3000 BC when it was inhabited by Native Americans, namely the Arawak and Carib peoples. Other early inhabitants were the Surninen, from whom the country derives its name. Most of Suriname's population of 566,000 now live on the coastal lowlands, whilst the rest of the country is predominantly covered in dense rainforest with an area of savannah along the border with Brazil.

In 1667 Suriname was captured by the Dutch, and plantation colonies were quickly established, relying heavily on African slaves, until slavery was abolished there by the Netherlands in 1863. The country gained its independence from the Netherlands in November 1975, but has been politically unstable since the early 1980s after a series of military coups and localized uprisings.

Suriname's resources were first exploited in 1916 with the mining of the country's newly discovered reserves of bauxite. In 2007, after a long-running maritime dispute between Suriname and Guyana, a United Nations tribunal assisted in settling the situation and redrew the maritime border to give both countries access to an area potentially rich in oil deposits.

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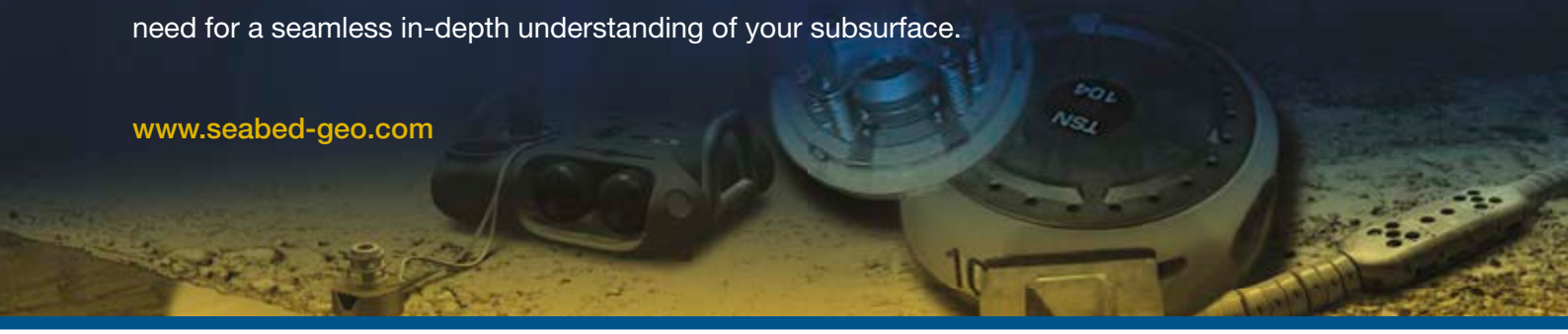

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A Shadow of its Former Self

Nigeria's Petroleum Industry Bill: six years of stop-go progress on oil industry reform has resulted in a bill that falls far short of its original transparency and revenue-generation goals

NIKKI JONES

With an average per capita income of a mere US$2,600 per annum – just below Sudan, Pakistan and Laos – Nigeria epitomizes the problems of the 'resource curse', the paradoxical phenomenon of resource-rich countries becoming poorer. Despite ranking tenth in the world for proven oil reserves and seventh for gas, the country has become renowned for its corruption, violence, poverty, environmental degradation and regional divisions. It is reliant on hydrocarbons for 97% of its export earnings and 78% of government revenue, but despite a ten-year surge in oil prices, in early 2013 Nigeria stood almost alone in its failure to make progress towards the Millennium Development Goals, ranking alongside war-torn Democratic Republic of Congo, while 30 other countries in sub-Saharan Africa were commended for their progress.

However, the Nigerian government has been attempting to reform its finances as well as its transparency and accountability. Key to this has been the Petroleum Industry Bill (PIB), first drafted as policy in 2007. It has been an ambitious attempt to consolidate approximately 16 pieces of former legislation, some more than 50 years old. The Bill's original aims were to tackle the twin problems of inefficiency and corruption in the industry. However, its progress has been tortuous and stop-go, the subject of intensive oil company lobbying, corruption and politicking. In 2013, the abandonment of its guiding principles has led many observes to conclude that the legislation is now in tatters. Whether the PIB will actually become law is still unclear.

An Ambitious Bill

The original Bill had three key aims. First amongst these was the commercialization of the industry and the removal of government from technical decision making. Primarily, this involved a fundamental reform of the Nigerian National Petroleum Corporation (NNPC) which, according to Revenue Watch, has the reputation of being one of the world's most closed companies and a 'slush fund' for government. The original plan was to establish a new national oil company within three months of the Bill being passed that would be independent of government. However, by 2012 the plan had become one of breaking the new NOC into three entities, privatizing only two of them and leaving the third open to political interference. The 2013 revised version appears to be a further compromise from the original Bill, disappointingly thin on details of exactly what assets the new NOC will hold or when it will be sold off,

Pipelines and flare in the Niger Delta

Copyright World Economic Forum. swiss-image.ch/ Remy Steinegger

Nigerian President Goodluck Jonathan believes that the Petroleum Industry Bill (PIB) will be passed and will enable transparent and accountable operations in Nigeria's oil and gas sector.

whilst apparently leaving the old NNPC in existence and able to maintain its current contracts with the oil majors.

The second aim was an increased sustainability of government finance, to be achieved by improving the 'government's take'. Apart from the hope that a new profit-driven NOC would be able to double exports and therefore taxable profits, the PIB also aimed to improve production with new relinquishment provisions that would allow the government to take control of any acreage that companies left idle.

Relinquishment has been strongly opposed by the international oil companies, as have proposals for a new Nigerian Hydrocarbon Tax (NHT) on upstream profits and the extension of the Companies Income Tax, currently only applied in the downstream sector, to production. In order to address the specific problems of the Niger Delta, the Bill also proposed that companies contribute 10% of net upstream profits to a fund specifically aimed at benefitting the people of the region. Although these new fiscal arrangements appear to create a relatively high taxation level, this is largely mitigated by various flexible allowances.

Increased Transparency and Accountability

The third aim was transparency and accountability in all dealings with oil companies. These proposals have been the subject of hard IOC lobbying, and in May 2013 it became clear that many key elements had been dropped, including all requirements for

publication of the amount of oil pumped and the amount paid to government. All transparency regarding signature bonuses, the Companies Income Tax and the Nigerian Hydrocarbon Tax is gone. It is proposed that royalty taxes will be made public.

Given the stated aims of the Bill, the expanded role of the Minister for Petroleum Resources has provoked great controversy and may still prove to be a sticking point. The Bill proposes that the Minister will have relatively unchecked supervisory powers over nine new agencies, each with a paid board and therefore representing an opportunity for patronage. Distribution of the 10% Niger Delta fund will also be at his or her discretion with little transparency; similarly the Minister will have the power to determine many aspects of contracts with very little scrutiny. In fact the latest version of the Bill is reported to explicitly allow the Minister and directors of state institutions to receive 'gifts'.

A Costly Six Years

In November 2012 there was a relatively unusual intervention from Oxford economist Paul Collier, urging the government to stand firm against the IOCs and pass the Bill as it stood. Nigeria has lost a great deal in the six years of deliberations – there have been no licensing rounds, no signature bonuses, a fall in production, and much needed power-generation reforms have been put on hold. To add to the challenges facing the country, demand from its major market, the US, has been shrinking as North America taps into its shale reserves; in 2013 this is reported to have led to a fault-line emerging within OPEC, between the producers relatively untouched by shale production and those that are affected – headed by Nigeria. Advances in LNG infrastructure have brought new competition from Australia and Indonesia. Within the country a state of emergency has been applied to three northern states and in February this year there were strikes within the Onne Oil and Gas Free Trade Zone with workers accusing companies of 'enslavement' and victimization.

The reaction from the majors has been a gradual divestment from onshore and shallow-water production. Some existing licenses have been renewed, but it is unclear whether these are exempt from the PIB. Concerns have been raised that agreements have been made with several newly formed companies who appear to have little technical capability. The International Energy Agency is predicting zero production growth over the next five years.

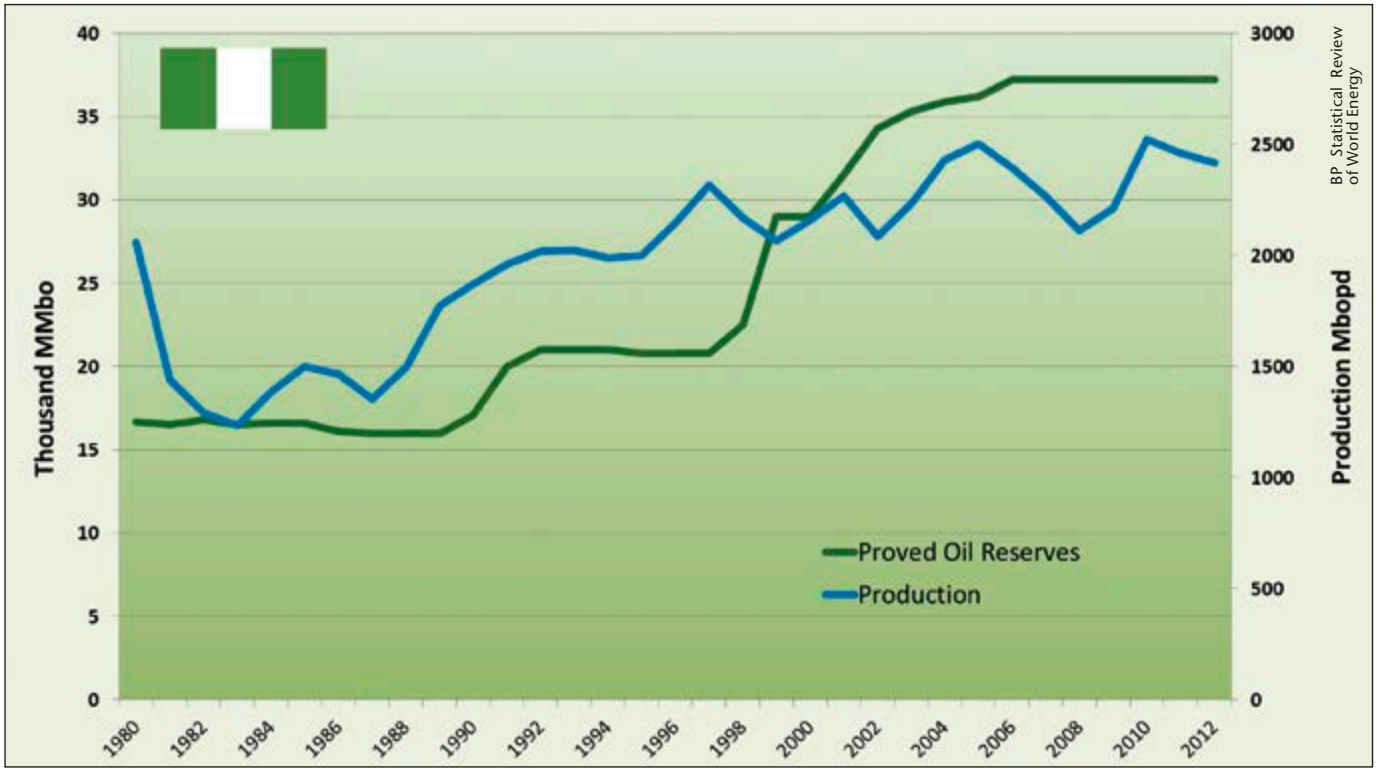
A Nigerian Spring?

Corruption is clearly key to the country's problems: in May this year it was revealed that illicit financial outflows have made West Africa, led by Nigeria, a net creditor to the world, contributing an extraordinary US$494 billion over the last 30 years. As many observers have commented, the IOCs have profited greatly from this environment, clearing an estimated $100 billion in revenues over the last decade.

However, it is just possible that this culture of opacity and toleration may be coming to an end, with some commentators pointing to a 'Nigerian Spring'. Ordinary people have become more vocal in their condemnation of corruption and openly angry with their government, fueled further by last year's revelations of a nearly $7 billion fuel subsidy fraud.

Whether this public anger will translate into a new public culture remains to be seen. It appears unlikely that it will be sufficient to bring about a meaningful Petroleum Industry Bill. Possibly one day the full account of how the Bill was killed will be written. Its failure will have lasting repercussions on the country's population of almost 170 million, Nigeria's role as a regional power and as the holder of world-class reserves. This lost opportunity will leave Nigeria and the world at large with much to regret. ■

Nigeria is the largest oil producer in Africa, production disruptions mean that it is producing well below capacity, while proved reserves have not been increasing.



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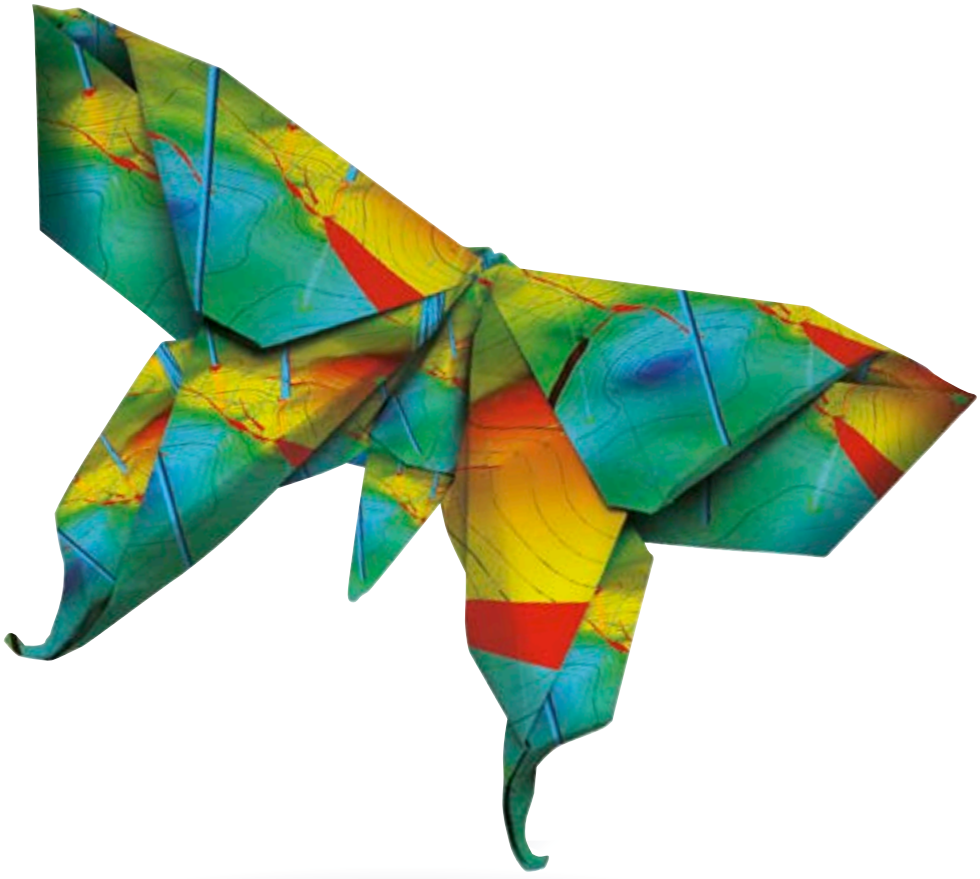

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A Challenging Job!

A move from geophysical R&D into marketing, sparked partly by his proficiency in English, was an unusual career path for BGP geophysicist **Liu Juxiang**, but it has taken him all around the world in a job he loves.

JANE WHALEY

"This is a challenging job, but very satisfying. I love it!" says Mr. Liu Juxiang, Marketing Vice President, Business Development of BGP International, China National Petroleum Corporation.

Although he has been involved in Marketing for BGP now for a number of years, Mr. Liu is a geophysicist by training. "I come from northern China and was born in a rural area, so I was not really aware of geophysics in my early years," he explains. "However, my school education showed that I was very good at mathematics, as well as science, so geophysics seemed to be an obvious and interesting career path for me. I studied the subject for three years at the Geophysical School under BGP.

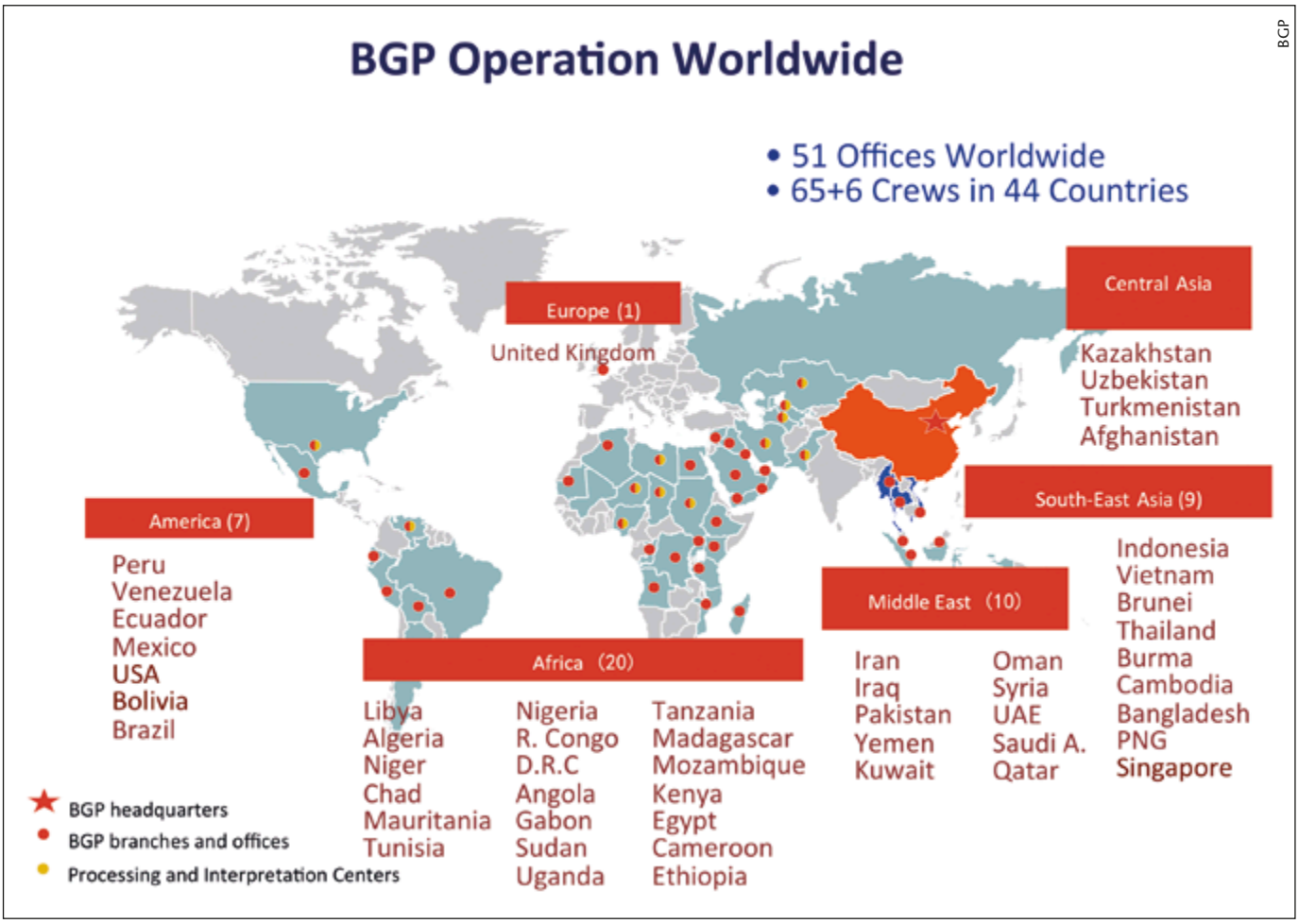
"After my study I joined BGP in 1981 as a seismic processing specialist at the BGP Geophysical Research Institute in Zhuo Zhou," Mr. Liu continues. "At the time I didn't know very much about the industry, but I learnt a lot in my fifteen years at the Institute, where I concentrated on seismic processing, geophysical research and software development for BGP. I was also lucky enough to get a lot of additional training from a number of our western collaborators in China, such as Western Geophysical, CGG and GSI. In addition I finished my university study in 1991 and got a degree in Geophysics by correspondence."

Move into Marketing

One of Mr. Liu's tasks while working for the BGP Geophysical Research Institute was to open the company's first seismic processing center outside China, in Houston. "I was BGP Representative in the United States from 1995 to 1996, where as well as starting and developing the processing center, I was able to improve my English."

This proved to have been a useful additional skill, as a couple of years after

Mr. Liu, seen here at the Cape of Good Hope in South Africa, enjoys the travel which is a vital part of his job.



he returned to China from Houston, Mr. Liu was asked if he was interested in moving into marketing in the fledgling international branch of BGP, where the ability to speak English would be a major asset. "At first I almost refused the offer, as I wanted to stay in the technical side, which I loved, but I realized that there were many interesting opportunities for both career development and travel in marketing, so I accepted. In 1999 I became Marketing Manager of BGP International, initially based in our head office in Zhuo Zhou, about 50 km south of Beijing.

"In 2000 I moved to Dubai as Deputy General Manager responsible for marketing. At the time we had no business in the Middle East, but within four years we were working in Saudi Arabia, Oman, the United Arab Emirates and Syria. We had also set up BGP's first regional division with the Middle East office, based in Dubai."

Mr. Liu admits that while he enjoyed living and working in Dubai, there was one big disadvantage – his family could not move there with him, so he had to travel back to China every few months to see them.

In May 2004, he moved back to the head office, having been promoted to Vice President, Business Development of BGP International, responsible for marketing, the post he still holds.

Keeping Up to Date

"I have been nine years in this job now and the company has developed amazingly fast in that time," Mr. Liu says. "In 2003 our total annual revenue was less than US$300 million. It is now over US$1.36 billion, and most of that growth is a result of our move into the international arena, so that has been very satisfying. So far, BGP's footprint of international operations covers more than 60 countries and BGP has provided its services to more than 200 oil and gas companies.

"I enjoy the job very much," he adds. "I travel a huge amount – I think I have been to more than 70 countries now, promoting the company and talking to clients. Sometimes I manage to see our operations in the field as well, which is always very interesting. I'm not so keen on the jet lag, though!"

He admits that the demands of the job mean that he finds he has little free time, but enjoys reading to relax – but he also loves sight-seeing during his travels.

To what does Mr. Liu attribute his success in marketing, a field which is not the obvious career choice for a geophysicist who enjoys technical research? Actually, it is that very technical background which he thinks makes him good at his job. "I think it is very important that you understand what you are talking about when you are marketing a company like BGP," he explains. "You have to have a strong technical knowledge to understand what makes the company special and to ensure that you are at the forefront of the business. You need to know the industry from all sides and understand what is

going on. I like to keep up to date with new developments in technology, operations and equipment, which is crucial to help develop and market the company.

"It is also important in my job to understand commercial and business issues, as well as health and safety and cultural matters. I undertook a Masters in International Trade in 2010 and that has been very useful and helped me understand more about international business."

An Exciting Time

Mr. Liu thinks that this is a very exciting time to be involved in the hydrocarbon industry in China, with demand growing very fast and the government trying to decrease the country's reliance on gas.

"As we all know, China is a vast country, so the potential is correspondingly huge," he explains. "As well as local companies like BGP, a number of international companies, such as Chevron, Total and Shell, are exploring for oil and gas in the country. The demand is there, and that is why they are coming to China.

"Many of the foreign companies, as well as home-grown ones, are actively looking for unconventional resources, and we know that our country has huge reserves of these. However, the exploitation of these is going to be much more complicated than it has in the US, because the geological setting is so different. It is going to be technologically challenging, so we have set up a special R&D branch in BGP to study the new technologies which we know will be required for the successful exploration for unconventionals. That is one of the great things about BGP – it is a learning company, continually moving on."

Unique Culture

"Something else that makes BGP special is the way it manages to mix western and Chinese culture," he adds. "It has deep roots in China, but now more than 70% of our clients are from outside the country. We have to meet, understand and assimilate Western, Arabic and other cultures. We learn from them and take this understanding back into the company. Even 30 years ago the senior leadership were open to ideas from outside China and knew how to develop the business."

There are many other things that Mr. Liu likes about working for BGP. "I think it has a very special culture," he says. "The majority of the employees, like me, have worked for the company for all of their working lives. We are like a big family – a community which works together and also lives together. Sharing our lives, we build good lifetime friendships and we know each other's families, so we trust each other. As a result, everyone is very loyal to the company.

"This loyalty is shown by how long people stay with BGP. Like me, over 90% of the older generation have only ever worked for this company. But even in the younger generation, although there is some movement, more than 70% of those who started their career with BGP have not changed to a different company. These young people have a much wider knowledge and education than many of their predecessors, not just in technical subjects like geophysics and processing, but in business and languages. These are the assets which are essential for their careers, and which BGP needs to help the company progress.

"I have been with BGP for 33 years now," Mr. Liu continues. "During that time I have watched the company's steady growth, which I am sure will continue, which means that employees will also be able to benefit and share in its success. Many young people want to work for this company, so I hope it will continue to grow so that the younger generation will have the opportunities which I have had."

Mr. Liu smiles. "Do you know what is the best thing about this job?" he says. "Simply winning a contract and having a satisfied client. When the client is happy, I am happy!" ■

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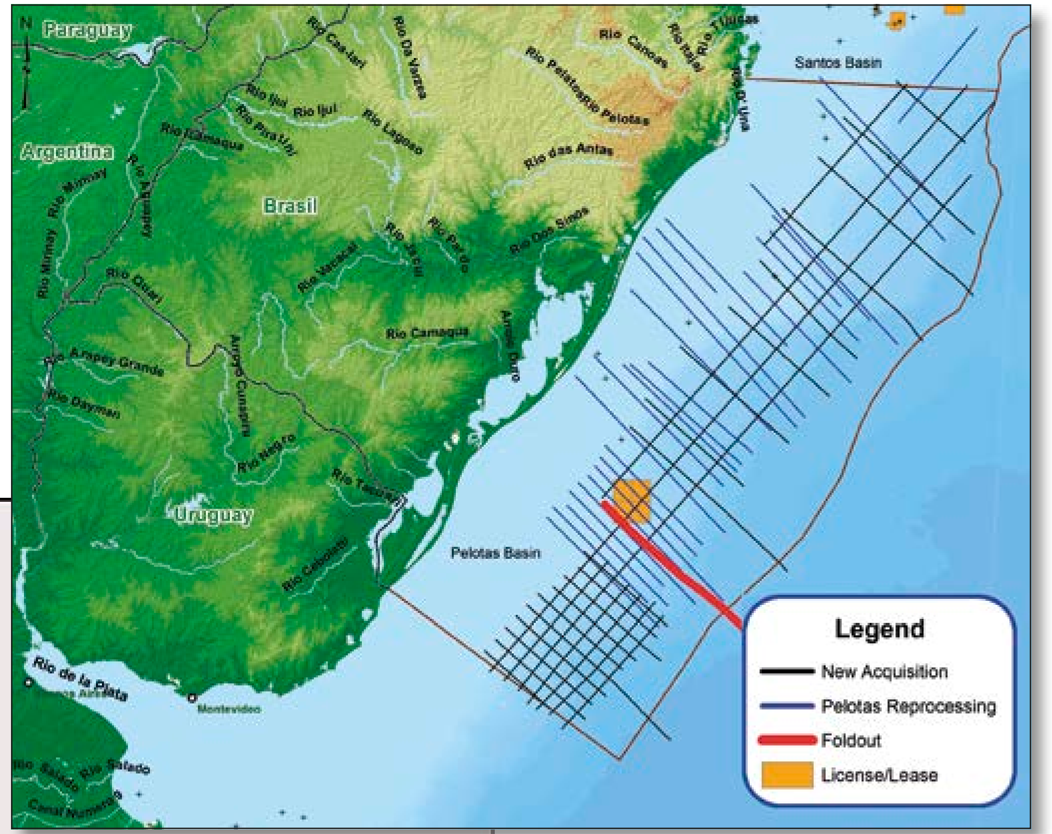
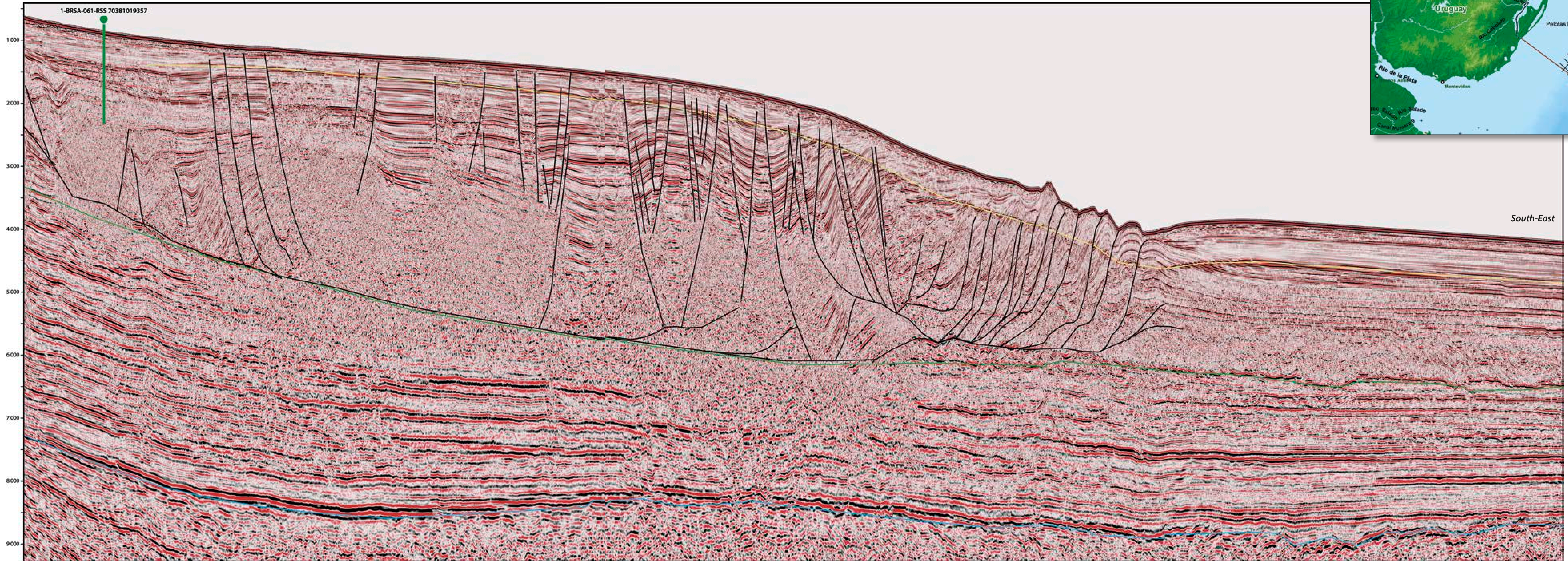
The Pelotas Basin Oil Province Revealed

Whilst the white heat of sub-salt exploration in the Santos and Campos Basins of Brazil's Atlantic Margin has yielded extraordinary success, its southern sister, the Pelotas Basin, has seen little attention for over ten years, despite displaying clear direct hydrocarbon indicators. However, a new 2D seismic program acquired in 2013 is revealing new evidence for sand-rich systems and oil plays, making the deepwater Pelotas Basin an excellent choice for blocks to be nominated in Brazil's upcoming Bid Round 13.

Map showing the location of Spectrum 2D Seismic Data in the Pelotas Basin (7,500 km new acquisition and 6,000 km re-processing). The 200 km long line of section in the foldout below is indicated in red.



North-West



Yellow = Bottom Simulating Reflector
Green = Paleocene
Blue = Barremian

In 2013 Spectrum acquired 7,500 km of 2D seismic data with a 12 km cable and a 13-second record length, and is currently re-processing 10,000 km of legacy 2D data across the Pelotas Basin. Modern pre-stack time and depth processing has imaged structural and stratigraphic features within both the clastic section and volcanic-rich extensional basement.

Spectrum

An Untapped Hydrocarbon Province

Potential for large oil plays is refocusing the attention of E&P companies in the Pelotas Basin.

MIKE SAUNDERS – Spectrum,
SCOTT BOWMAN – Petrodynamics,
LAURIE GEIGER – Spectrum

The Pelotas Basin is an untapped hydrocarbon province comprising a 280,000 km^2 passive margin located on the south-east coast of Brazil, bordering Uruguay to the south. Up to 7,000m thickness of Cretaceous and Tertiary post-rift clastics have been deposited in the basin, including both Paleocene and Albian source rocks. These source rocks are actively generating hydrocarbons today and there are seismic indications of an active, working petroleum system similar in character to those found in the Niger Delta in West Africa. Recent high quality 2D seismic data has imaged multiple potential reservoirs, traps, source rocks and direct hydrocarbon indicators in the basin.

Evidence for Hydrocarbons

The new seismic data show that since the inception of rifting between South America and Africa (at 125 Ma), the mouths of paleo tributaries of the Rio de la Plata moved along the margin several times. The most recent depocenter comprises a four kilometer thick Tertiary clastic sequence which displays a world-class direct hydrocarbon indicator in the form of a 40,000 km^2 sheet of Bottom Simulating Reflectors (BSR), which are confined inside the 3,000m Tertiary isopach. The Tertiary delta has prograded over, and matured, a Paleocene source rock, and gas and condensate from this source rock subsequently migrated up through the prism via abundant gas chimneys and plumes, to be trapped by the gas-water crystal phase change creating the BSR.

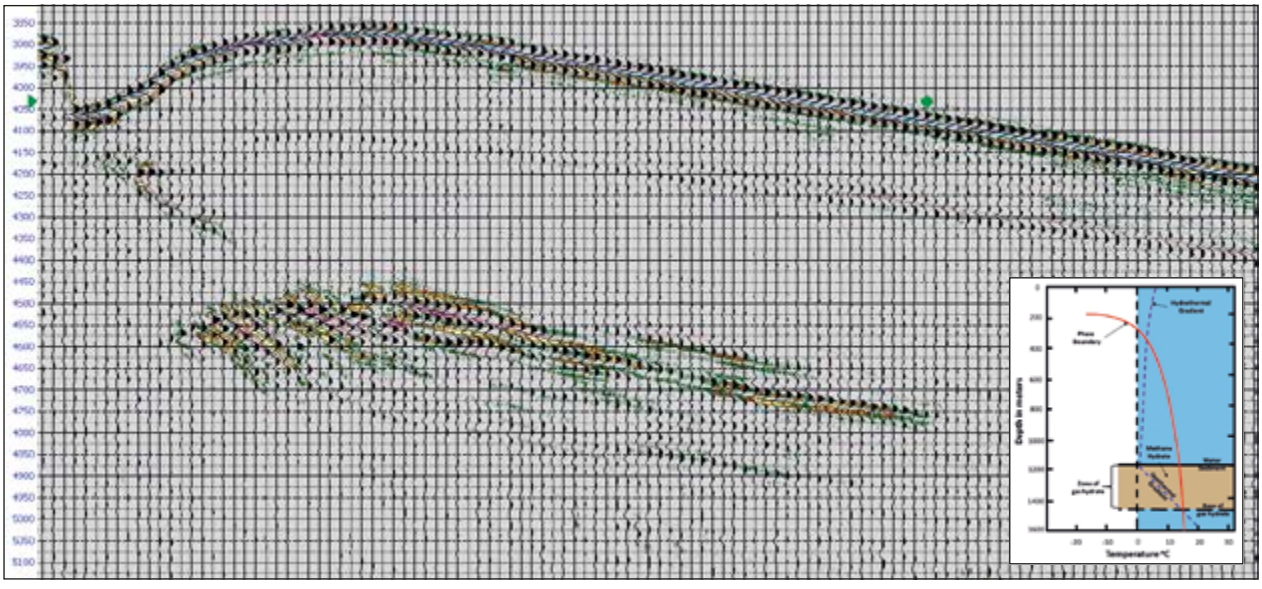
Additionally, numerous oil seeps detected by Synthetic Aperture Radar and standard satellite imagery in the southern Pelotas Basin appear to define a linear feature, approximately coincident with the 500–800m isobaths. This suggests that oil, generated at depth below the Tertiary prism, is migrating up to the impermeable solid base of the hydrate until it reaches the up-dip extent of the BSR (ca. the 500–800m isobath). This oil is also trapped by stratigraphy or structure below the BSR, creating a shallow oil play within the Tertiary prism itself. Preliminary AVO analysis indicates large accumulations of free hydrocarbons are trapped in porous intervals below the solid hydrate layer. Despite the abundant gas in these sequences it is the potential for large oil plays which is refocusing the attention of E&P companies in the Pelotas Basin.

The BSR represents the base of a solid layer of gas hydrates, comprising water molecules that form cages containing methane (CH_4), ethane (C_2H_6) and propane (C_3H_8) molecules trapped by high pressure. The pressure and temperature conditions necessary for the formation of hydrate crystals require an environment with water depths greater than 300m. The associated gas hydrates exist from approximately 100m beneath the sea floor to as deep as 450m beneath the sea floor.

Petroleum System

The conjugate margin rift basins of West Africa and Brazil

Enhanced Gradient AVO section with gas hydrate phase diagram

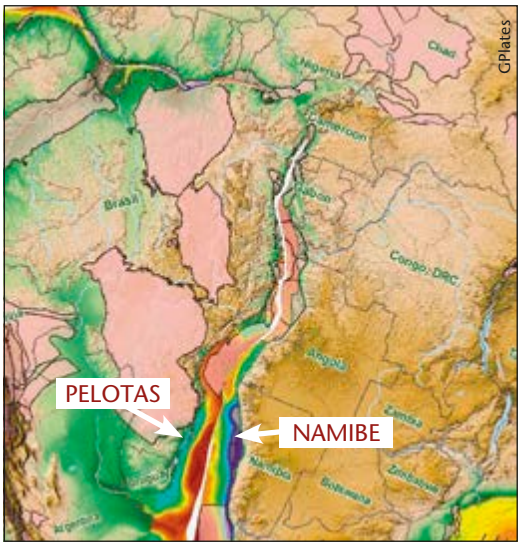


initially formed by east-west extension initiated during the early Cretaceous, as the South American plate began to separate and rotate clockwise from Africa. When the margins are reconstructed to their respective positions in the Albian it is informative to compare the respective margins for differences and similarities. A reconstruction with today's sediment thickness, joined where they may have been 125 Ma, shows the asymmetry from the Pelotas Basin to the conjugate Namibe Basin.

This occurs because of large differences in the elevation of the terrains supplying a sediment source to each basin, and it is possible to correlate an Apto-Albian sequence from Namibia to Pelotas. In mini-basins directly above the break-up unconformity, planar-bedded high amplitude Apto-Albian marine shales are correlated with units in the Namibe conjugate basin. In Namibia these shales are considered the primary deepwater oil source for the light oil recovered from Wingat-1. Additional source intervals in the Pelotas Basin include syn-rift Cretaceous lacustrine shales (Kudu, Orange River Basin analog), post-rift Apto-Albian, Cenomanian-Turonian and Paleocene marine shales.

Both the Pelotas and Namibian Basins are underlain by thickened high-density volcanic crust with an abundance of seaward dipping reflectors. Basin subsidence is controlled both by long-term post-rift thermal contraction and differential sediment loading and accommodation. The new seismic data in the area illustrates the Pelotas Basin received substantially more sediment than the Namibe Basin and consequently the basement is deeper.

In Pelotas, the prograding Tertiary wedge over the Paleocene source rock triggered a glide-plane detachment within the source rock, similar to the Niger Delta. Structural traps are developed within this gravity-driven structural complex along listric normal faults up-dip, and toe-thrust structures down-dip. The Orange River Basin in Namibia exhibits a similar, though older, feature with a deeper detachment on the Cenomanian-Turonian source rock.



Paleo-reconstruction with sediment thickness 125 Ma, showing the original proximity of the Pelotas and Namibe Basins.

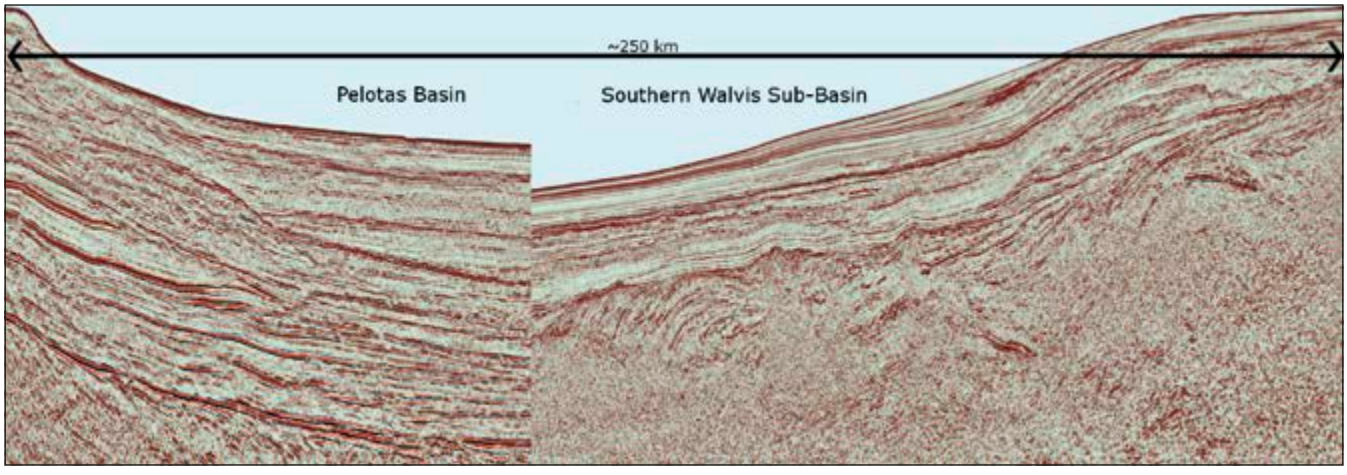
Although few wells have penetrated the deepwater section of either margin, the interpretation of the new seismic data suggests deltaic processes generated numerous potential plays. The supply of sediments via shelf and delta to the post-rift thermally subsiding margin was subject to both global sea level change and locally controlled delta lobe switching. The new seismic data in the area indicates much of the potential reservoir was deposited by mechanisms common to many passive margin mixed-source deltaic systems. Thin highstand sands are interpreted from prograding clastic wedges, in addition to aggradational shelf edge sequences and lowstand slope fan sands. In the Early Cretaceous, however, it appears the pro-delta slope was too steep for deposition of slope fans as these appear to have bypassed the slope and accumulated as thick ponded turbidites on the basin floor, creating a very exciting play above Albian source rock. Additionally through the Upper Cretaceous and Tertiary, overbuilt prograding units appear to have suffered shelf collapse and slope failure in the northern parts of the basin, depositing thick stacked slump sequences on the basin slope and floor.

Exploration Opportunities

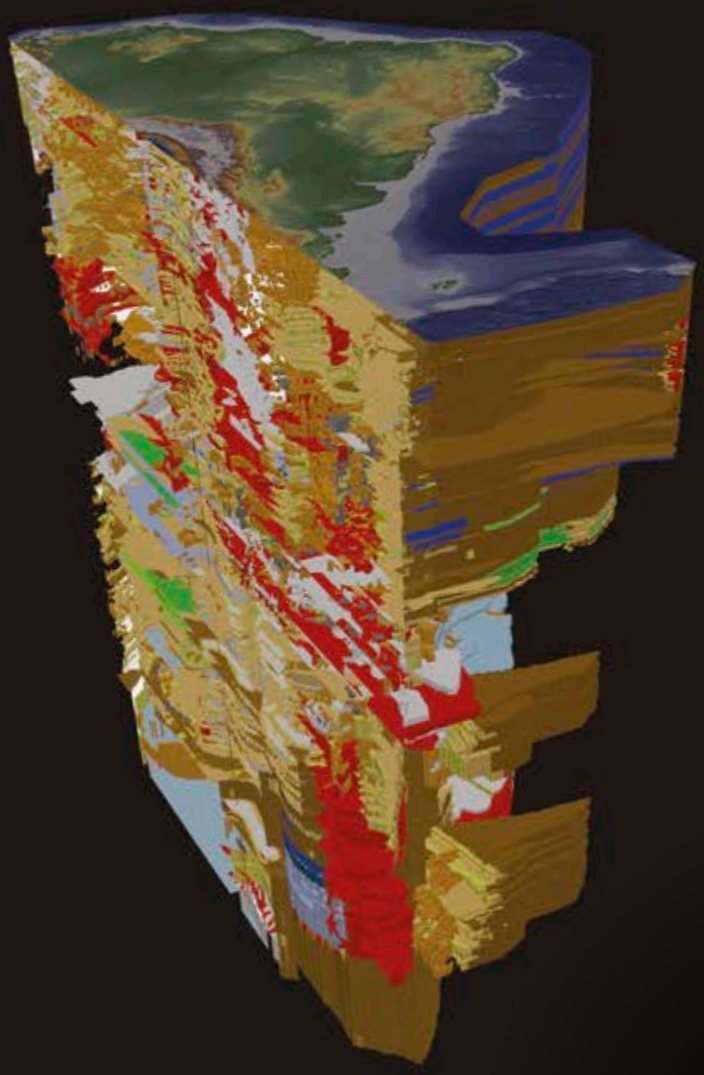
Of the twelve wells drilled in the offshore Pelotas Basin to date, three were effectively stratigraphic probes, seven were drilled on the shelf and two wells tested Tertiary prospects in deeper water, all of which were dry with oil shows. A more detailed examination of the seismic data indicates the deepwater Pelotas Basin contains substantially more prospective targets than the shelf.

There is considerable evidence of a working petroleum system with a Paleocene source rock presently within the oil window, and correlation with the conjugate margin provides evidence of source rock in the Albian section which opens up a second deepwater oil play. There are many good reasons to believe that the deepwater Pelotas Basin would make an excellent choice for blocks to be nominated in Brazil's upcoming Bid Round 13. ■

Comparison sections at equal scale of the Pelotas and Namibia Margins.



New dimensions in exploration



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Broadband Seismic Technology and Beyond

PART IV: PGS'S GEOSTREAMER – MISSION IMPOSSIBLE

In 2007, PGS took the industry by surprise with the launch of the GeoStreamer, the dual-sensor towed streamer that kick-started the broadband revolution. But how did they solve the riddle of combining the hydrophones and geophones into broadband measurements? For most geophysicists, it was seen as 'a mission impossible'. It turned out to be so simple, so elegant, and so brilliant. It was a fantastic journey, of course with setbacks, but with persistence, a culture of innovation, and outstanding geophysical work, they won. Their achievement represents maybe the largest single step in the technological development of the marine seismic streamer.

"For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled"

Richard P. Feynman, Nobel Prize in Physics, 1965

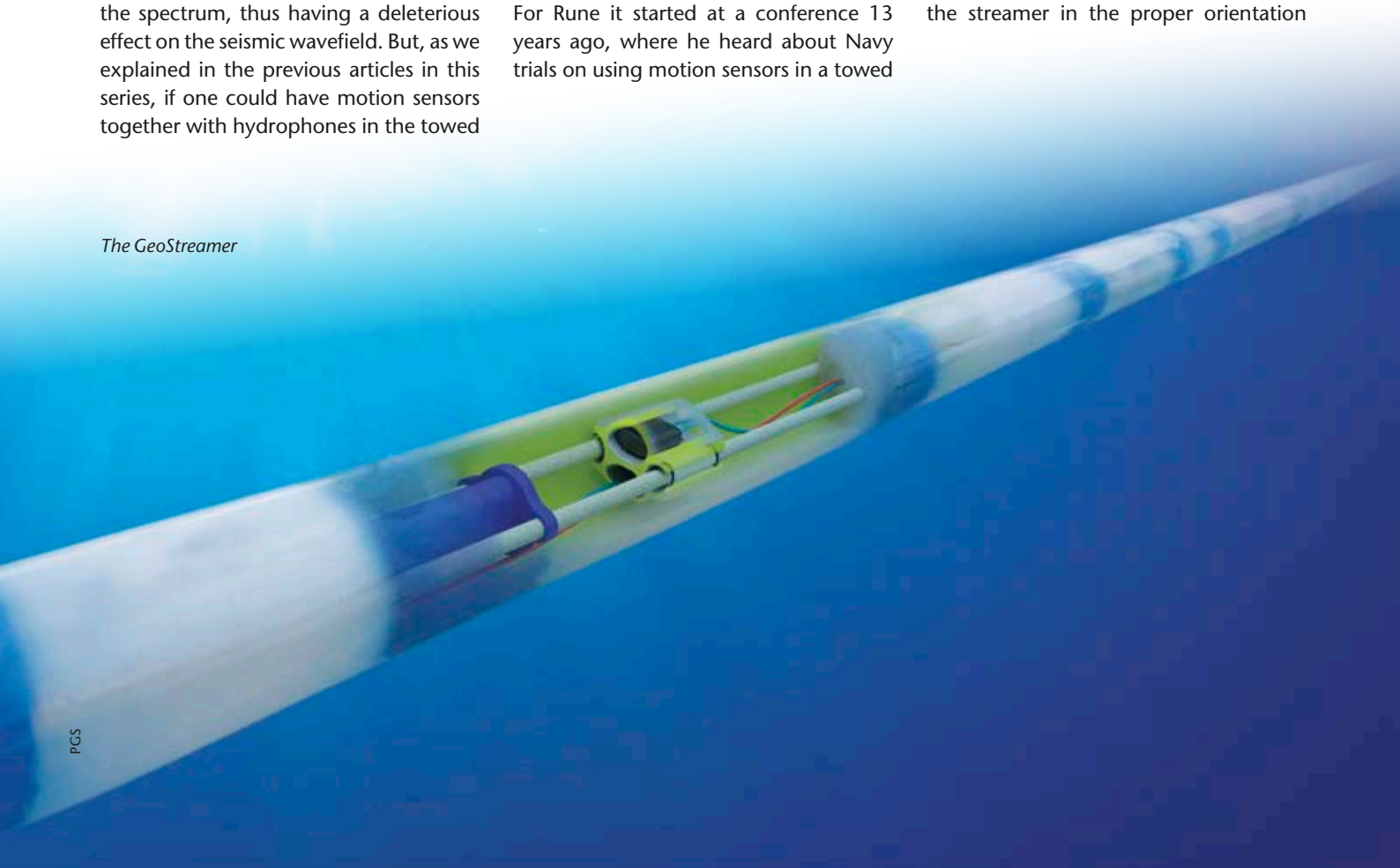
LASSE AMUNDSEN, Statoil and
MARTIN LANDRØ, NTNU Trondheim

In many ways, finding a cure for the marine seismic ghost has been the holy grail for geophysical researchers. Ghost elimination has been a problem that everyone has known about and wanted to solve. The ghost kills most of the low frequencies and provides notches in the spectrum, thus having a deleterious effect on the seismic wavefield. But, as we explained in the previous articles in this series, if one could have motion sensors together with hydrophones in the towed streamer, one can exorcize the ghosts.

Rune Tenghamn and Svein Vaage from PGS, assisted by their colleagues Audun Sødal, Claes Borresen and Andre Stenzel, took on the challenge in the early 2000s.

Curious – and Optimistic

For Rune it started at a conference 13 years ago, where he heard about Navy trials on using motion sensors in a towed array. When he came back to the office, he discussed it with his colleagues and suggested they should try it out. No one really believed it was possible. Several challenges were seen. Firstly, it would not be easy to maintain the many thousands of particle motion sensors in the streamer in the proper orientation



The GeoStreamer

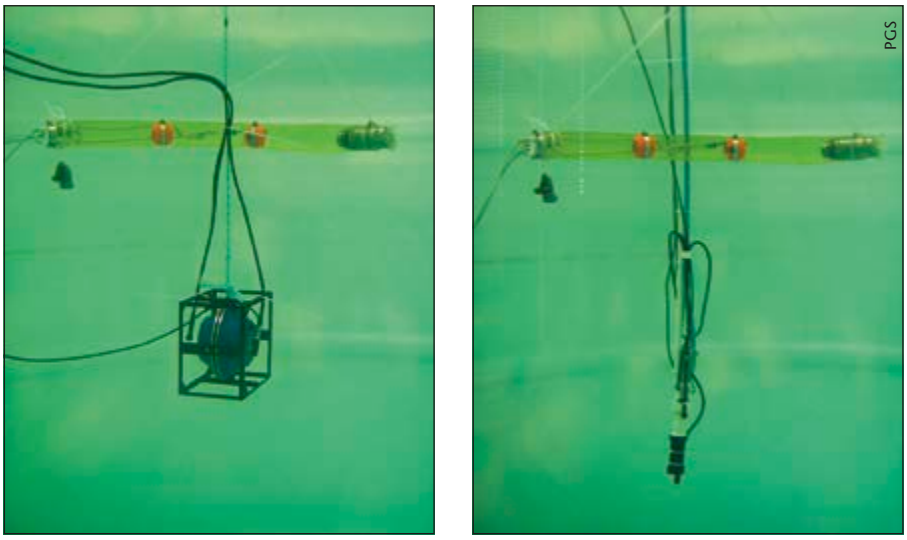
PGS

to detect vertical motion. Secondly, due to the noise level in the streamer cables, motion sensors in streamers were regarded as having limited utility. In particular, the mechanical vibrations in the cable were known to produce high noise levels in geophone signals at low frequencies.

Rune was nevertheless curious and optimistic, and saw different pieces coming together. In the past, PGS had worked a lot with ocean bottom sensor systems which contained hydrophones that could sense pressure alongside geophones that detected particle motion. These stationary systems succeeded in the tranquility of the ocean bed where there were no vibrations. Developing a towed streamer system to work in the dynamic environment near the sea surface was a very different and difficult mission.

The first test was with a short streamer section in a test tank at PGS' research lab in Houston. Using a small source, they studied how the system worked but did not get very good results, although the experiment showed promise. Early 2001, they did a second test in the Gulf of Mexico outside Galveston. Due to high currents, the data were disappointingly noisy; it did not look like a breakthrough. But spending a weekend to analyze the frequency spectra of the data, Rune saw that the data for the higher frequencies of the recordings were fantastic. Encouraged by the results, a patent was filed in August 2002 (US 2004/0042341). The patent also discussed, we note, the possibility of using three component geophones to sense motion in both vertical, inline and crossline directions. That would enable the direction of the incoming signal to be detected, and enable the identification of strumming and other mechanical behavior to the cable.

Inspired by the Galveston test, PGS decided to continue the work. More challenges lay ahead.



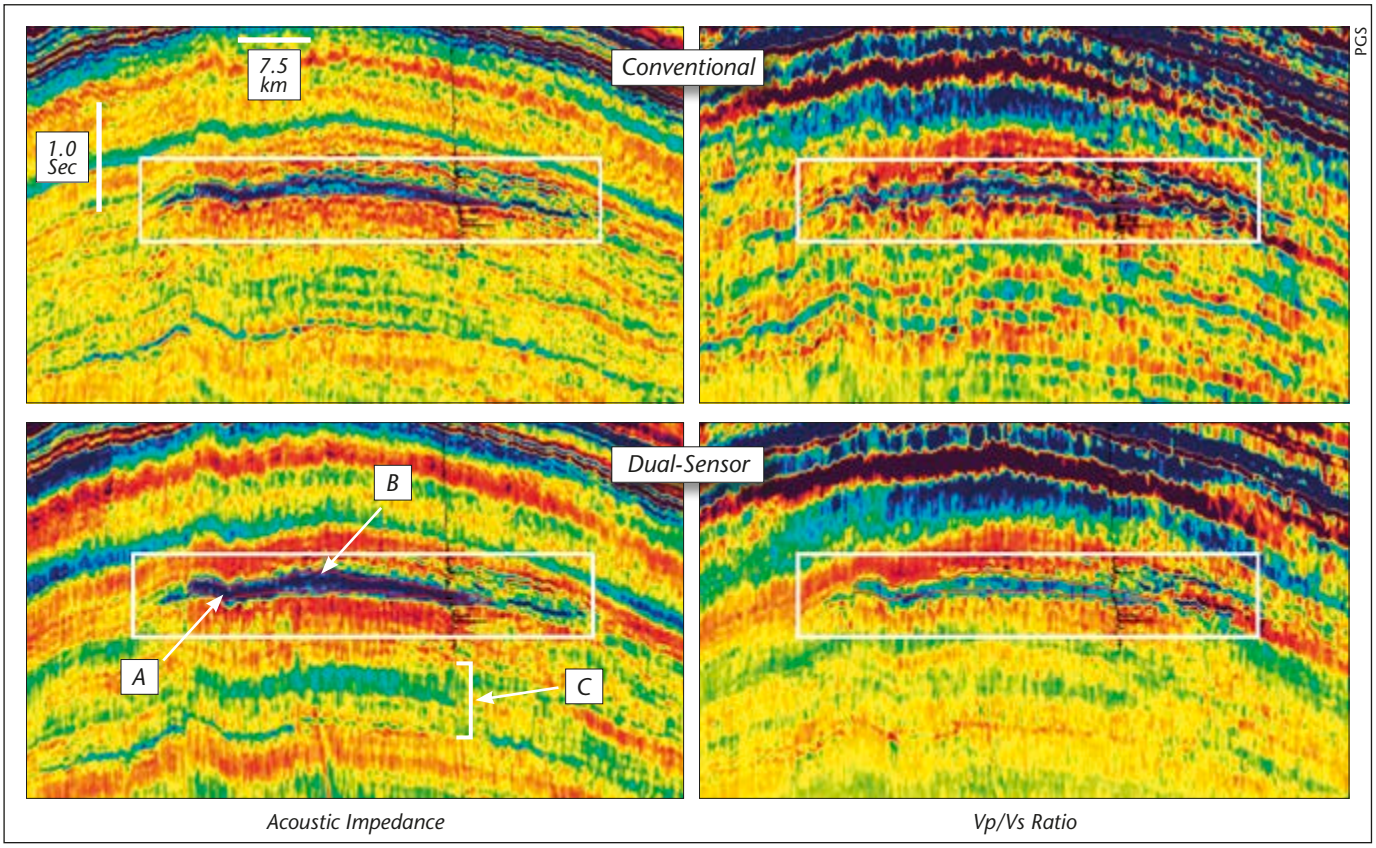
In 2000, PGS was ready to take the step from idea and theory to practical testing in a water tank. These photos are from one of the first experiments at the PGS test facility in Houston. The PGS team used a piezo-electrical source and tested various devices designed to measure pressure, velocity and acceleration. Recordings were also made using a small air gun (only 1 cubic inch in volume) source. None of these early experiments were successful. However, the research team made modifications to the concept, and the first sign of progress was actually observed during a small field test in Galveston, early 2001.

A Clever Solution

For the very low frequencies, noise induced by vibrations in the streamer was significantly present. Svein entered the scene, and soon came up with an elegant solution. He suggested simply estimating from the hydrophone signal what the ideal geophone recording should be for the low frequency part of the signal. This principle, which is described in *GEO ExPro,* Vol. 10, No.2, is a deghosting-ghosting solution which has been proven to work astonishingly well. The hydrophone recording for the low frequency part of the signal is first effectively deghosted, a process which is not very sensitive to the state of the sea surface and/or possible moderate errors in measured receiver depth. Secondly, the deghosted pressure is multiplied by the geophone ghost. The resulting calculated low-frequency geophone response is then merged with the non-noisy measured geophone recording for the higher frequencies. Finally, the two broad bandwidth signals of pressure and particle motion can be combined into deghosting. This method was filed as a patent in March 2004 (US 2005/0195686). It was a really clever cure to the holy grail problem that no one had ever thought of before, even though the necessary elements of theory were in place (see Amundsen, 1995, and references therein).

Next, special sections containing sensors for velocity measurements were

The 'staging' of a GeoStreamer prototype in 2005 used in field tests.



The two images on the left represent the acoustic impedance and the two on the right represent the Vp/Vs-ratio from the conventional seismic and the dual-sensor streamer acquisition. The acoustic impedance and Vp/Vs-ratio have been estimated in a pre-stack inversion process. For arrows A-C see text. White box denotes area used for cross-plot analysis.

installed in conventional streamers. In the period 2001-2004 the tests showed encouraging results, and in 2004 PGS built the first GeoStreamer, 2,500m long. Prior to the commercial launch of the new streamer concept, two other prototype streamers of 6,000m length were built and tested. In 2007, the PGS development team concluded that they had reached their overall goal: to develop a streamer that measured both pressure and particle velocity with an acceptable noise level.

The journey from the early test experiments in Houston in 2000 ended in 2007 with the successful commercial introduction of the new system. Taking the GeoStreamer from idea and prototype to a robust, reliable, seaworthy commercialized product was a dream come true.

Today, practically all vessels operated by PGS are equipped with GeoStreamers. In the six years since the GeoStreamer solution was launched, service company competitors have launched a diverse family of broadband solutions. More recently, industry attention is also turning to broadband source solutions so that the source ghost can be attacked.

Rock 'n' Fluid

The ability to predict reservoir properties from seismic data is crucial in reservoir characterization. The accuracy of the reservoir property prediction is improved by having more low frequency seismic information and less *a priori* (well) information included in the process.

With extended seismic low frequency content, the dependency on any well information will become increasingly less important. Increased high frequencies provide better vertical seismic resolution throughout the available depth range and more importantly at the reservoir level, allowing reservoir geoscientists to see as much detail as possible.

As an example, we have data which were acquired in the North West Australian Shelf of the Carnarvon Basin with both conventional and dual-sensor streamer technology. This area is a world-class gas province with minor oily sweet spots in the Permo-Triassic sediments, overlain by Jurassic to Cenozoic syn and post rift successions.

The figures and caption above, taken from *PGS TechLink*, March 2011, present the result of a relative acoustic inversion study using both conventional and dual-sensor streamer data. A relative inversion (inversion without any low frequency or *a priori* model) was chosen to avoid any bias from well information, so the inversion results represent only the seismic contribution. The dual-sensor streamer provides a clearer acoustic impedance image (left) observed in the following aspects: definition of the flat-spot is greatly improved (arrow A), the top and base of the reservoir is more clearly defined (arrow B) and improved delineation of the geo-bodies (arrow C). From a seismic inversion point of view, one should expect to retrieve the layering of the earth (removal of the wavelet effect) and this is better achieved with the dual-sensor streamer technology as opposed to the conventional streamer which looks more like the seismic. It is always a challenge to estimate the Vp/Vs-ratio directly from streamer data, shown to the right in the figure. Also for

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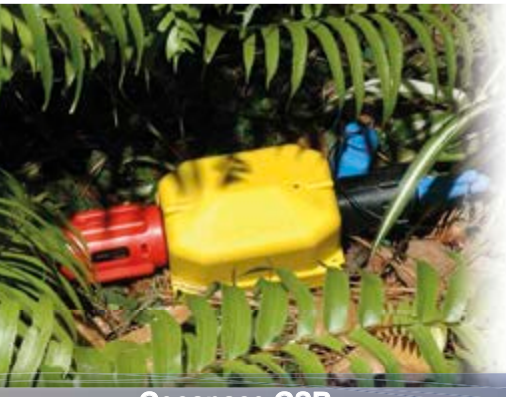

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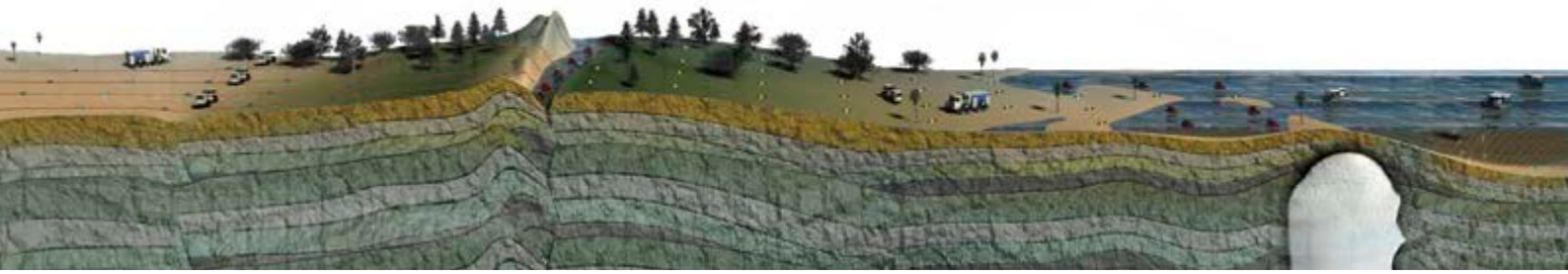

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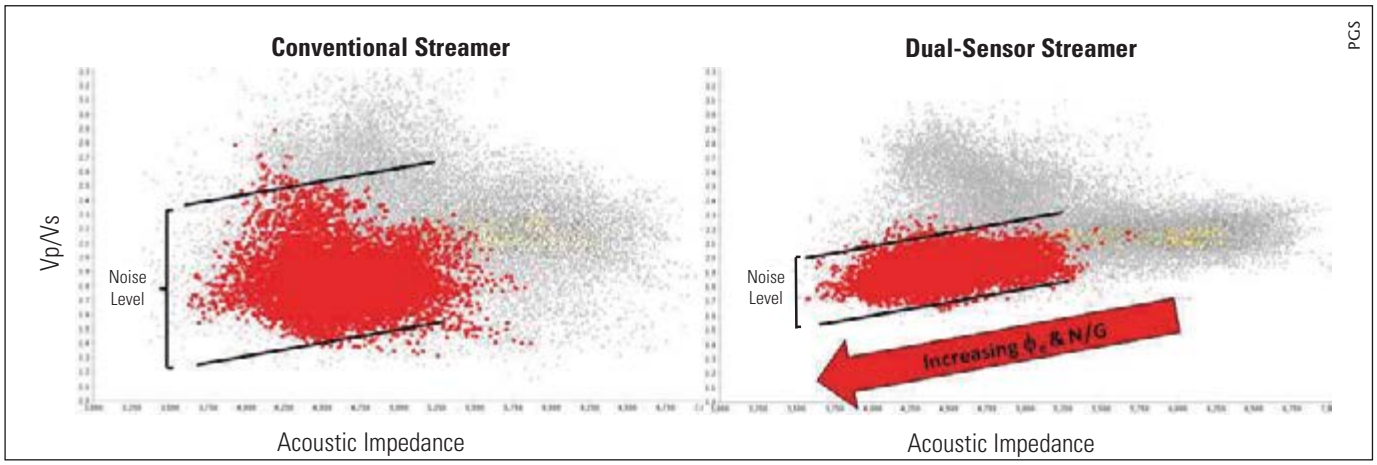

Cross-plot comparisons, based on seismic data only. Red points are within the reservoir zone. The uncertainty in relative acoustic impedance is only marginally better in the dual-sensor data, whereas the Vp/Vs-ratio has much lower noise in the dual-sensor data. The slope of the cluster is consistent with variations in porosity and net-to-gross (N/G).

the Vp/Vs inversion results we observe a clearer and more precise definition of the reservoir sand as well as of the overlaying shale layer.

Both simultaneous inversions were carried out using exactly the same parameters except for the wavelet (narrower frequency bandwidth for the conventional seismic and broader wavelet for the GeoStreamer dataset), same low frequency model and inversion parameters. Therefore the only differences between the two datasets are simply due to the type of towed streamer. The dual-sensor seismic inversion results exhibit a clearer definition of the individual geological layers and the fluid contact.

To further extend the analysis between the two datasets, a cross-plot was done over the area enclosed in white in the figure on p44. This area includes the gas reservoir and should therefore have an unambiguous elastic attribute response, with the gas having both lower acoustic impedance and lower Vp/Vs-ratio as seen in the figure above. The cross-plot demonstrates clearly the better stability and lower noise in the pre-stack domain of the elastic reservoir properties, especially in the Vp/Vs-ratio using the dual-sensor streamer acquisition system compared to the conventional data.

The extended bandwidth, especially at the low frequency end of the spectrum, thus represents a key improvement in lithology-fluid prediction and also in seismic reservoir property estimation. The need for a priori information is considerably reduced by relying more on the data and less on a low frequency background model compared with a conventional seismic streamer. ■

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Tenghamn R., S. Vaage and C. Borresen, 2007. A dual-sensor towed marine streamer: Its viable implementation and initial results: SEG Expanded Abstracts 989–993.

PGS TechLink March 2011

Today, almost all vessels operated by PGS are equipped with GeoStreamers, including their Ramform fleet

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Magnetics and Fractures in Coal and Shale

IRENA KIVIOR, FRANCIS VAUGHAN, STEPHEN MARKHAM
Archimedes Consulting Pty

Magnetic surveys can provide an economic alternative to seismic in the search for coal seam and shale gas, and do not impinge on the environment

Coal seam and shale gas exploitation has presented vast new opportunities, but has also brought with it some new and unusual challenges, not all of them technical in nature. Accurate characterization of the geological properties of the coal units or shale beds is a pre-requisite for efficient and cost-effective fracking. Whereas 3D seismic surveys are the most common method of extending knowledge found from drilling samples, there are many times where such acquisition is not realistic. In addition to the high cost, issues of access, either because of environmental concerns, existing well developed agriculture, or simple political opposition, may make seismic unappealing. Magnetic surveys are able to provide a viable alternative, providing a much more economical survey, and one which does not impinge upon environmental issues over the surveyed area.

Horizon Mapping

The methods used to analyze magnetic data are twofold. The first analysis, in frequency space, allows determination of depths of geological horizons. The second is a spatial analysis that identifies individual causative bodies, and through this allows interpretation of the geological structure.

Energy Spectral Analysis (ESA) is a method used in mapping geological horizons from gridded magnetic data, and is equally applicable to gravity data. The technique relies upon magnetic susceptibility or density variations between geological horizons. The application of ESA involves using a moving window (ESA-MW) and a Multi-Window Technique (ESA-MWT) to detect and map horizons such as basement, shales, coals, carbonates, salt and basalts. ESA applied to magnetic or gravity data allows calculation

A vineyard in South Australia: magnetic surveys are ideal for use where environmental concerns make seismic operations difficult.

of an average depth to ensembles of causative bodies. Plotting the logarithm of the radially averaged energy spectrum versus the radial frequency from potential field data shows the decay of the spectrum function, and depths are calculated from the slope of linear segments of the function. These depths are not dependent on assumed or measured susceptibilities or densities. The areal extent of the window analyzed limits the maximum depth being investigated, thus there is an optimal window size that detects a given horizon. To determine an optimal window size, the window size is incremented slightly, spectra are computed and depths interpreted. Around the optimal window size, the depths determined from increasing window sizes are stable, forming depth-plateaus. Depth-plateaus correspond to the geological interfaces where significant magnetic susceptibility or density contrasts exist. Analysis may find two or more plateaus at the same location, implying multiple geological interfaces.

Lateral correlation of depth plateaus is used to build horizons. This unique approach to interpretation of magnetic data distinguishes the new methods from conventional modeling techniques.

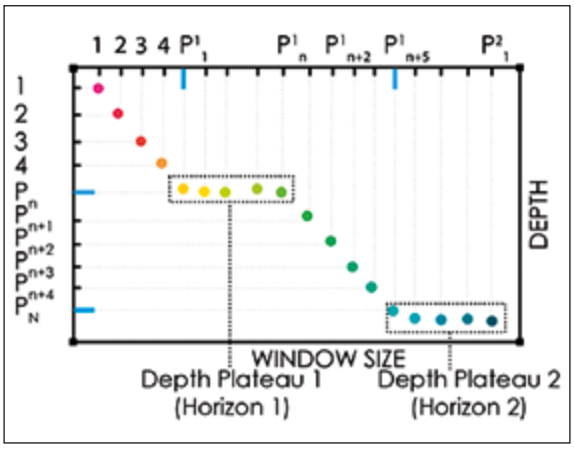
Fracture Detection

Automatic curve matching (ACM) is applied to the magnetic data. By identifying a magnetic anomaly on a profile, comparing the functions derived from the observed anomaly with a theoretical model, and varying the model's parameters, the depth, geometry, and magnetic susceptibility can be computed.

Fault interpretation is undertaken by interpreting the output of ACM processing to find linear features and offsets. Identification of faults is aided by several factors, including changes in magnetic susceptibility along a fault plane, and contrasts in magnetic susceptibility between adjacent rocks. These make identification of both non-mineralized and mineralized faults possible. ACM lineaments detected at different depths can be correlated, and thus fault faces delineated in 3D. This approach to the interpretation of high resolution aeromagnetic data allows the detection of faults, associated structures, fracture patterns within different sedimentary formations, as well as underlying basement. These techniques deliver a detailed interpretation to aid in further exploration and development.

Red Hill Case Study

Archimedes recently completed a study in the Red Hill region of Moranbah, in the Northern Bowen Basin, Australia. The targeted units were the Fort Cooper and Moranbah, coal measures from the Blackwater Group of Late Permian age. The techniques successfully mapped the top of the Fair Hill Formation and the base of the Goonyella Middle Seam, which is a regional primary target within the Moranbah Coal Measures. These Permian coals were deposited under dominantly fluvial flood plain environments.



ESA is used to detect horizons by identifying the plateau effect: when the window is large enough to detect bodies at the depth they lie, the detected depth stabilizes and a plateau of depths becomes evident.

Tectonic activity during the Early Permian included extension, subsidence and transgression in a marine environment. Between the Early to Mid-Permian, the tectonic stress field shifted from extensional to compressional. This change in stress field was also accompanied by regression in sea level, leading to lacustrine and fluvial environments of deposition. The Blackwater coal measures formed during this period. During the Late Permian to Early Triassic, increased compression created thrust faults and caused uplift and erosion, ending sedimentation in the area.

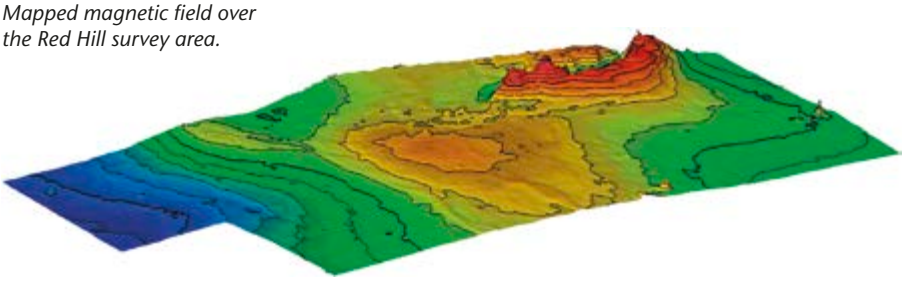
Magnetic Minerals

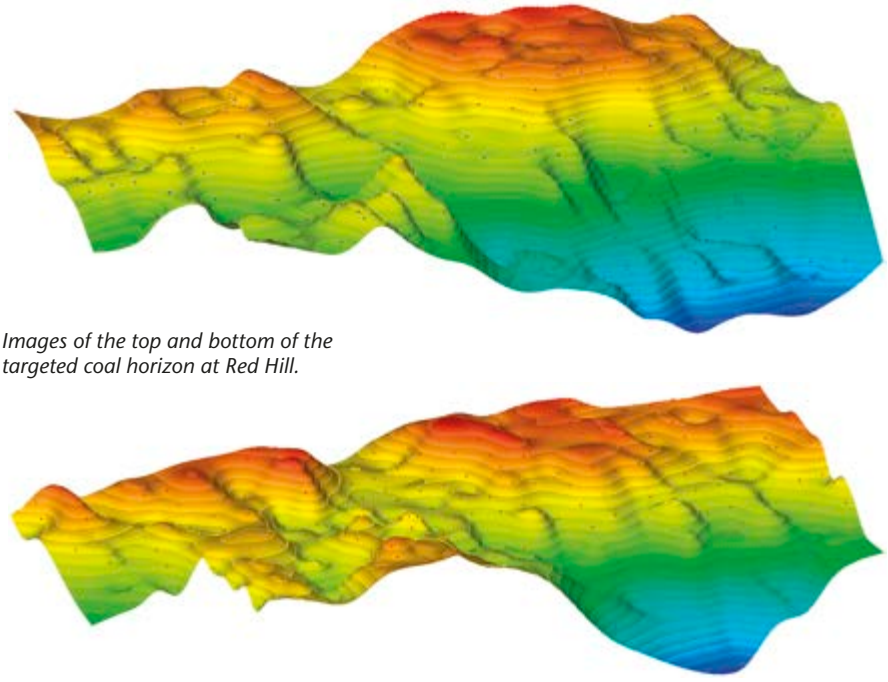
The magnetic response of sediments depends on the amount of magnetic minerals present at their formation, as well as the amount that has formed over geological time since then. There are a number of iron-rich clays that are very common in sedimentary environments such as the swamps that are typically the source of coal beds. These clays are initially usually only very weakly magnetic. Other sources of iron include eroded haematite and siderite which are transported to swampy environments from their source.

As the subsurface oxygen is depleted, geochemical conditions become more favorable for the formation of magnetic minerals. This process can occur where sulfur has been released into the anaerobic groundwater by decomposition of the plant material, where it comes into contact with the iron-rich clays or other iron sources. Insoluble iron sulfides can form around the contacts between coal beds and claystone/mudstone layers. Some of these iron sulfides will be magnetic. Magnetite can form in these environments when some of the iron atoms in weakly magnetic haematite lose an electron to more reactive ions, changing the crystal structure and increasing the overall magnetic moment.

In addition, a variety of anaerobic bacteria that live in these environments derive food by using sulfur or iron from minerals to break down hydrocarbons, making these elements available. Some

Mapped magnetic field over the Red Hill survey area.





Images of the top and bottom of the targeted coal horizon at Red Hill.

microbes simply deplete the oxygen from the groundwater, aiding the creation of a reducing environment.

Faults and fractures are saturated with groundwater, which transports dissolved iron or sulfur to locations where the geochemical conditions change to a reducing environment, thus leading to the precipitation of insoluble iron sulfides and, sometimes, magnetite. The compressional and extensional forces applied to coal or shale beds and adjacent formations determine which faults and fractures are open to the migration of groundwater and this, in turn, will determine where the geochemical conditions are favorable for the formation of magnetic minerals.

By establishing the dominant direction of linear magnetic features in and around the coal or shale beds, it is therefore possible to determine the direction of the main compressional and extensional forces acting in an area.

Red Hill Horizons and Fractures

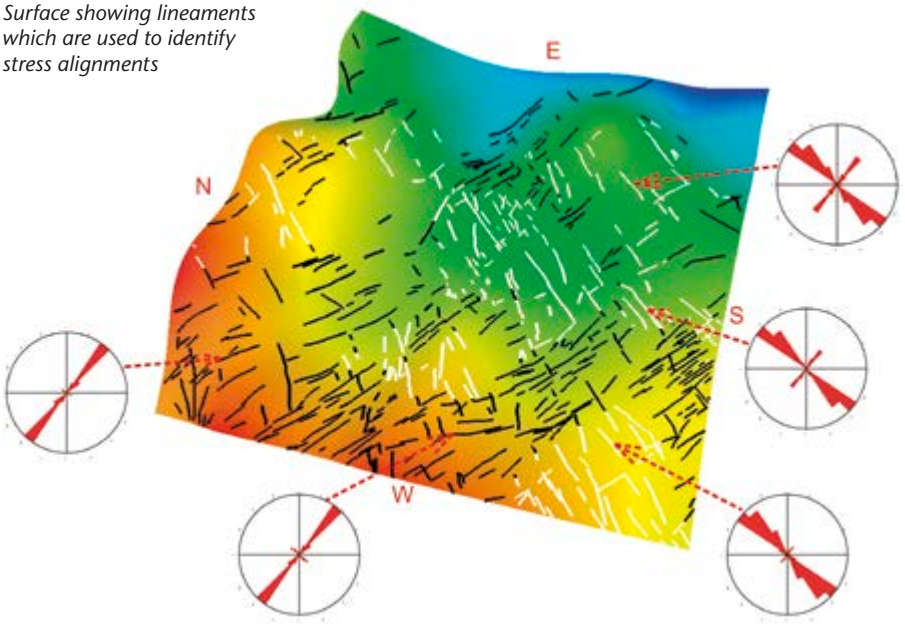
Horizon mapping was undertaken to produce a surface of the Top and the Base of the targeted coal measure. The surfaces were mapped using the methods described above for ESA-MWT and ESA-MW. The technique relies on magnetic (and density) contrasts to map laterally continuous horizons. For this reason the Fair Hill Formation and the Moranbah Middle Seam, both of which have highly magnetic tuff bands from volcanics, were chosen. The two horizons were mapped over an area of 35,000m^2 with the Top of Coal showing depth variations of -50 to -650m and the Base of Coal, -150 to -900m below MSL. Both horizons show a similar east-dipping trend with the highest point in the west of the study area.

Stress orientation was interpreted by analyzing the magnetic data using the ACM process to detect the depth to magnetic sources and their susceptibility. This analysis was used in conjunction with the results of the horizon mapping techniques (finding Top of Coal and Base of Coal). Using the Top of Coal surface, a band of magnetic sources between 10m above the coal to 100m below the coal surface was analyzed. In some cases, lineaments were determined by assessing the alignment of solutions, such as mineralized faults, while other lineaments were defined from the offset of magnetic markers. Swarms of short extended magnetic features correspond to fracture patterns within the coal measures interpreted. The trends were then grouped into dominant orientations for easier analysis. These are displayed along with their rosette diagrams in the figure below.

Range of Applications

Archimedes' unique technologies, expertise and experience are vital tools for exploration and production when looking for a wide range of hydrocarbons. The techniques used in the Red Hill Case Study are equally applicable in other coal seam and shale gas regions. Knowing the fracture pattern or stress field orientation within the target area is of critical importance for exploration and production. The use of the Archimedes techniques makes exploration more economical, particularly in areas where seismic acquisition is not possible. ■

For further information about these techniques, see GEO ExPro app for iPad, Edition 4



Surface showing lineaments which are used to identify stress alignments

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Yet Another Final Frontier? Honduras

Following on from his article about the prospectivity of Jamaica in *GEO ExPro*, Vol. 7, No. 6, Chris Matchette-Downes moves westward to take a look at the eastern part of the Central American country of Honduras. He argues that the petroleum geology, particularly potential source rocks, has important similarities – but exploiting any hydrocarbons is not going to be easy

CHRIS MATCHETTE-DOWNES, CaribX

Exploring in Honduras is not easy and often best done on horseback, as Chris and his colleague seen here, CaribX country manager Dr Valerio Gutierrez, discovered.

Chris Matchette-Downes

Leaving the emerald green island of Jamaica and travelling nearly due west for some 720 km, one arrives in the semi-autonomous Mosquitia region of eastern Honduras, a coastal swampy area occupying the plain formed by the Coco River as it drains from the crystalline basement interior into the Caribbean Sea. It is not an easy place to reach as there are no direct flights and the capital, Tegucigalpa, boasts one of the world's most dangerous airports, nestled between several densely populated hillsides and with a very short runway complete with a vertical 30m drop at the end. The second city's airport is marginally better but then there is a terrifying mountainous drive to Tegucigalpa.

I first came to Honduras in 2009 to meet with government officials and seek exploration rights, some 35 years after my father visited the country while trying to protect a patent infringement. I am now unable to compare stories with him but clearly remember his visit was not plain sailing.

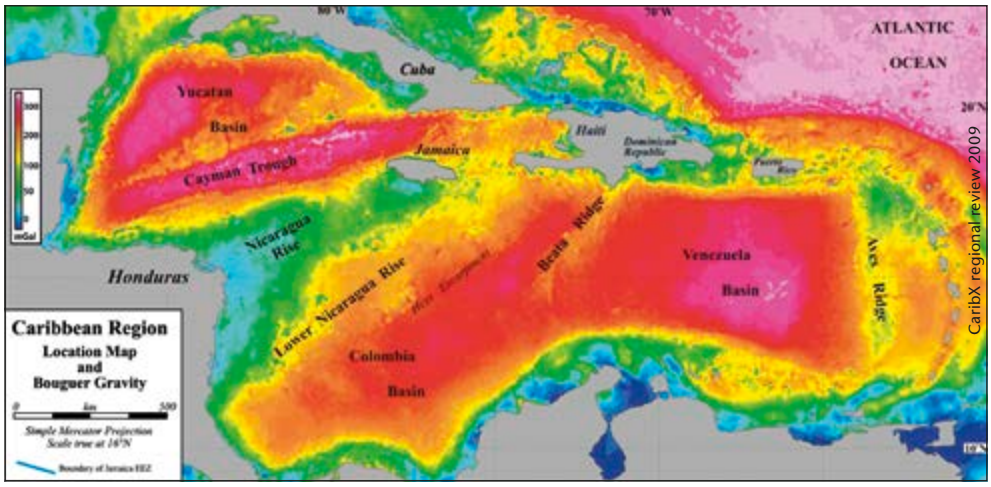
Tectonic Similarities

As in Jamaica, my interest in Honduras was steered by plate tectonics, which has guided the search for new hydrocarbons in that country as it now readies itself for new oil and gas rounds and the next wave of oil company investment and interest.

The two countries both lie on the Chortis Block, a partially submerged continental fragment which stretches from Honduras and Nicaragua in the west to Jamaica in the east. It originates from further west and is still

moving in an eastward direction, having caused the uplift of the Blue Mountains in Jamaica. Chortis is characterized by strike/slip movement which has created a series of basins such as the Forimgas, Seagull, Blossom and Walton Basins, becoming more defined as we move westwards towards the Honduran/Nicaraguan Mosquitia Basin.

The Upper Nicaraguan Rise broadens with increasing distance from Jamaica. To the north of the Rise are the abyssal plains and new oceanic spreading ridge of the Cayman Trough and to the south the Lower Nicaraguan Rise (Suina) with its more attenuated crustal geology. As with Jamaica, it is the Upper Mesozoic and Cainozoic that hold the most interest for the petroleum geologist, though an understanding of the deeper geology is needed to build a picture of the regional fabric and tectonics.



Regional Gravity map: The Nicaragua Rise, represented by blue and green colors, is located between the ultra-deep Cayman Trench to the North and Columbia Basin to the south. The Mosquitia and Walton Basins appear blue. Well data confirm that these are deep basins. Higher resolution data reveals the presence of multiple basins

Same Prolific Source Rocks

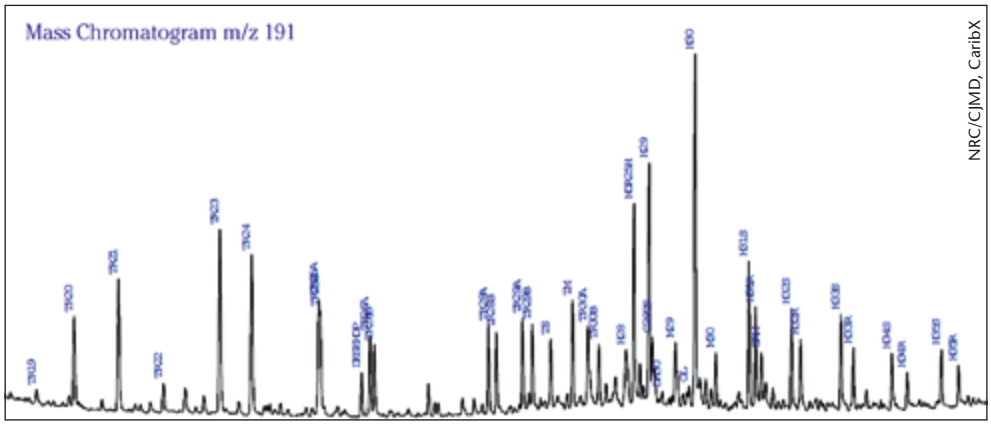
The CaribX approach to exploration is to determine source presence, quality, maturity and distribution. The early wells often contain considerable source information which can be overlooked if the well is labelled dry or non-commercial. Data from derived oil shows is particularly useful and often clues such as high S1 or S0 Rock Eval data, fluorescence observations and other optical petrological information can point to zones of hydrocarbon ingress. Once successfully extracted, these shows can then allow the precursor source system to be examined in terms of maturity and paleoenvironment of deposition by recourse to biomarker, stable isotope ratio determination and elemental analysis (nickel, vanadium and sulfur in particular). In the western Caribbean, the prolific and robust Punta Gorda and Touche source units have an Eocene equivalent seen in both outcrop and in well bores which further east is called the Chapleton Formation. In Jamaica's Content #1 well the Chapleton Formation includes some 600m of elevated TOC and HI shales. The oil geochemistry from samples collected from Honduran wells not only supports the presence of a Tertiary source as in Jamaica, but also shows clear evidence for an older Middle to Upper Cretaceous source system as well.

The main Tertiary source unit in Honduras is thought to be the Punta Gorda Formation, which as explained above is equivalent to the terrestrial Chapleton Formation, except as we move westwards the depositional environment becomes more transitional. The Punta Gorda is encountered in boreholes and is responsible for the oil shows containing significant levels of the higher plant biomarker oleanane.

In outcrop a possible candidate for the Cretaceous source is exploited in Honduras for paving material. The Guare Limestone is bituminous and is mined in shallow pits where surface weathering has resulted in the accumulation of loosely cleaved slabs which are easily separable. This is similar to the (although non-bituminous) Stonesfield Slate in the east Cotswolds area of the UK, which when mined and left out on a frosty night will cleave along the sandy bedding planes to make the rough tiling material characteristic of the area.

Another feature of the Guare Limestone is the preservation of some spectacular fossil fish. The fish evidence suggests that the limestone was deposited in some kind of restricted shallow environment perhaps alternating from brackish to near shallow marine conditions, as restriction (stress) is often associated with source rock development.

A study of Honduran offshore well Main Cape-1, analyzed by Geochemical Solutions International for CaribX, suggests that the precursor source rock has at least reached the early part of the peak zone of oil generation. To refine this observation it is necessary to review other biomarker assemblages such as the steranes, but biodegradation has removed these diagnostic biomarkers. When reviewing the aromatic component separated from this oil it is possible to see evidence for greater maturities and perhaps for mixing. Other indicators such as Ni/V ratio and elevated sulfur content all indicate a restricted marine environment such as found within the robust, regionally extensive and prolific Tertiary Punta Gorda/Touche source successions.



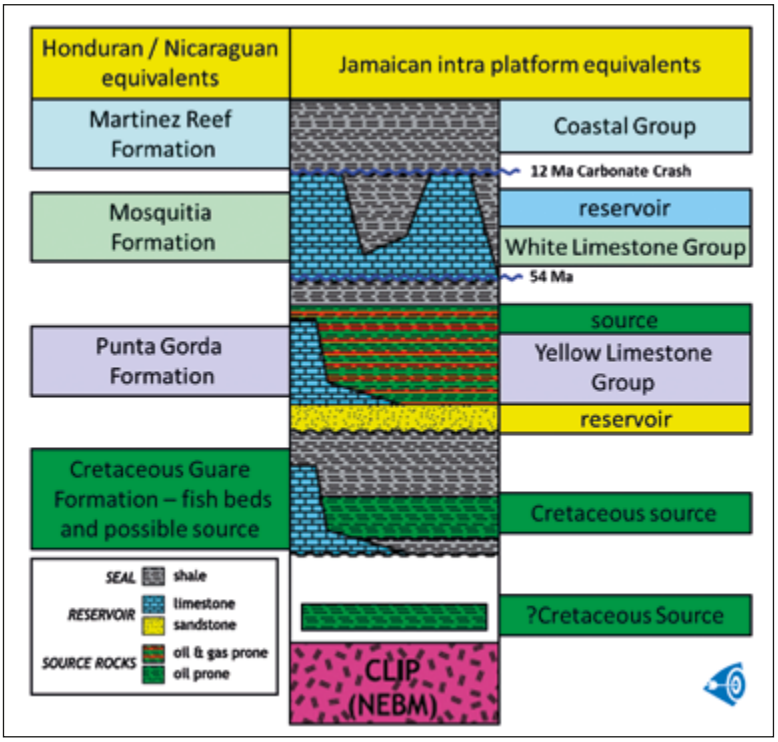
Reservoir structures include large structural closures, carbonate reefal build-ups and clastics derived from the Paleo Coco river.

Underexplored Area

Political turmoil throughout the eighties and nineties prevented any serious interest in the region. However, there are maps with three seep localities in eastern Honduras, and previous wells recorded plenty of shows, with two of them, the offshore Main Cape #1 (1973, Union Oil) and onshore Lempira #1 (1956, Unocal) both flowing oil to the surface. The latter is reputed to have flowed at 2,000 bopd but this is unsubstantiated at the moment.

The last well to be drilled before political turmoil switched off international investment was Castilla, drilled by Texaco in 1980, which proved dry. There followed a long period of inactivity with some minor indigenous activity. With only 31 wells drilled in the whole country, the first being in 1920, the area remained relatively underexplored until CaribX began its two year-long review in 2009 and coincidently PGS acquired a new regional, widely spaced 2D seismic grid in the same year.

In 2010 CaribX opened an office in Tegucigalpa and submitted its application to explore the Sang Sang graben, which had been newly identified through satellite and airborne imagery in the very deep onshore of the Mosquitia Basin in eastern Honduras. At the time of writing this was under consideration, as are eight similar CaribX applications in the greater region. Progress can be slow; one unfortunate company's application has been lodged for nearly 20 years. On a brighter note, at the end of July 2013, BG International were awarded the 35,000 km^2 Main Cape offshore block.



The Nicaragua/Honduras source (Nicaraguan Rise) is within the Punta Gorda to Touche section (earliest Eocene to Oligocene), while the Chapleton Formation source is in the lower part of the Yellow Limestone Group (early Eocene).

As with all new areas, field trips are necessary, and I was lucky enough to explore part of the Caribbean coast following a conference ('Honduras is Open for Business') in Honduras' second city, San Pedro Sula. In the western Omoa region outcrops of the Cretaceous fish beds had been reported, along with seeps and shows, so we set off to collect what we could. We found several well heads and the fish beds, but regrettably

The bituminous Guare Limestone cleaves when weathered, exposing spectacular fossils. This is a potential Cretaceous source rock.

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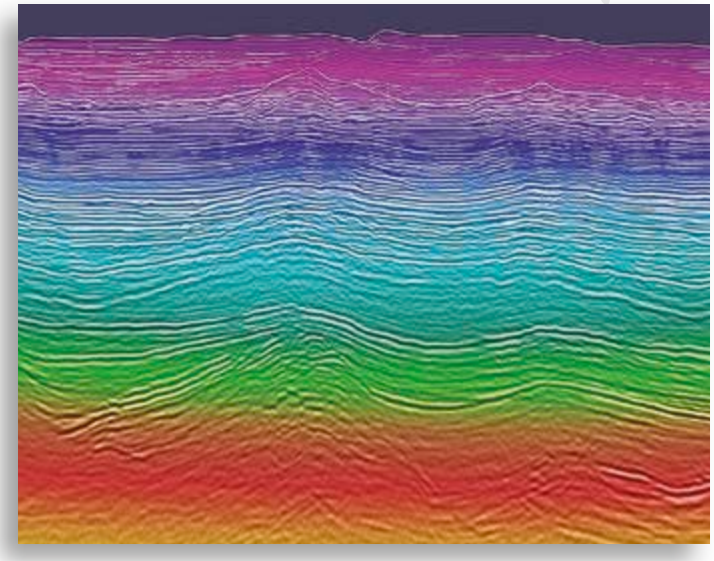
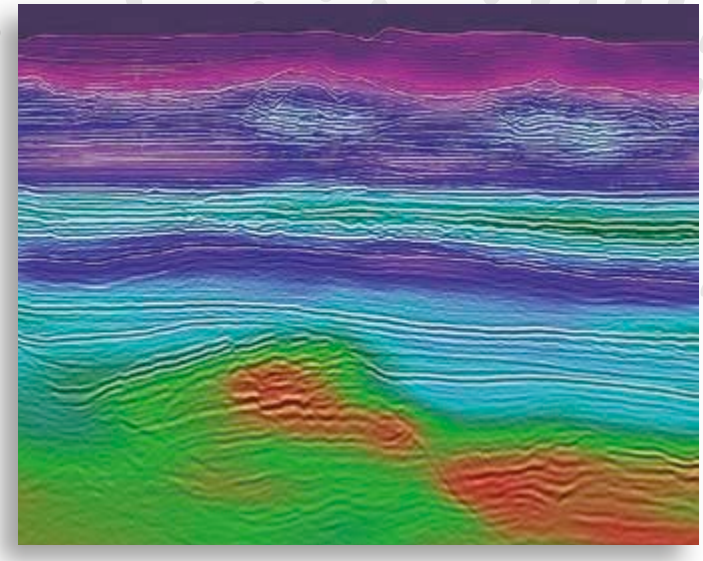


Velocity model before application of general moveout tomography.



Application of GX Technology's high resolution tomography using accurate general moveout picks resolves small-scale velocity heterogeneities.

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no evidence of seepage. On the coast our efforts were frustrated by a recent earthquake which had caused the coast to sink some 1.5m and the sea had encroached, the water table rising so much that the paths and roads had become elongated lakes. We had to resort to securing horses from a local farmer and wade through water sometimes up to the animals' nostrils to navigate the sunken lanes and tracks.

While in CaribX's area of interest there is also a lot of farmland, plus the ongoing development of Porto Lempira, it lies outside any of the national parks, which would have added extra challenges.

Problems to Overcome

The geology is encouraging with all the ingredients being in place: two robust sources, with both carbonate and clastic reservoirs, as well as structure and seal, and with oil flowing to the surface.

However, the main block to success in the unexplored frontier Caribbean and Latin American regions is not actually the geology. It is instead the overly complex and outdated hydrocarbon laws, coupled with the loss of expertise since the last wave of exploration, which came to an end just about the time I joined the business in 1981, as well as unrealistic expectations of what may be present due to optimistic comparison with producing nations and little understanding of risk. The latter is however is not the exclusive domain of this region, it is perhaps the hall mark of governments generally.

These are hard problems to overcome and can be quite draining. The idea that a small company can come in and open up the region, start to de-risk and that larger companies will then follow is not understood, despite the success of this approach in the mining sector. However, occasionally one gets an opportunity that with perseverance, patience and suitable backing becomes a possibility, and it is hoped that CaribX will be able to announce a successful award in the region in the near future. ■

La Mosquitia: 'Central America's Little Amazon'

La Mosquitia has the largest wilderness area in Central America, made up of rainforest, coastal lagoons, mangroves, patches of pine savannah, grasslands, and undisturbed white, sandy beaches. Spanning the north-eastern lowlands of Honduras and into adjacent Nicaragua, La Mosquitia is a vast and virtually roadless area. It contains the Río Plátano Biosphere Reserve which covers an area over 5,200 km^2, and in 1982 was declared a UN World Heritage Site.

The region has been inhabited for around 3,000 years, and is home to the most diverse range of indigenous people in Central America, including the Garifauna, Miskito, Paya, and Sumu Indians. Most of the inhabitants of La Mosquitia live along the coast and major rivers, these waterways acting as transport highways.

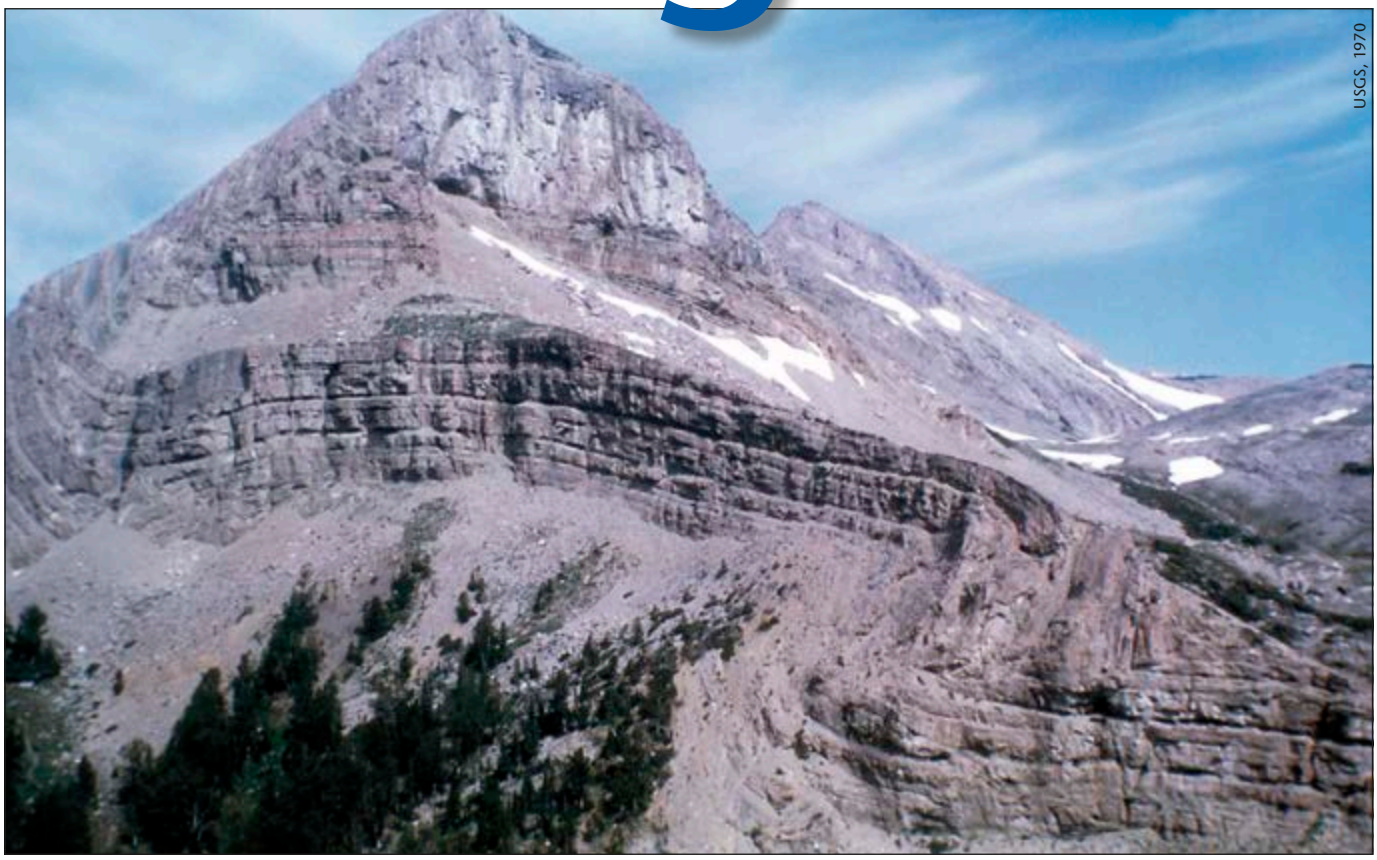
The Miskito name, which is not related to the word 'mosquito', possibly comes from the word musket, a rifle which was introduced by the British and was trading in this region.

In spring of 2012 an airborne LiDAR survey over previously uncharted areas within La Mosquitia revealed the presence of two ancient cities, one of which could explain the local legend of the lost city of Ciudad Blanca, which stems from reports made by explorer Hernan Cortes, who visited the region in 1526.

Folds and Folding Part II

RASOUL SORKHABI, Ph.D.

The Alps, the Himalayas and other similar high mountains on Earth owe their existence to a series of giant rock folds. But how do stiff, solid rocks fold?



Spectacular folding of Paleozoic carbonate strata in Scapegoat Mountain, Montana

In the nineteenth century, the predominant theory was that since its hot, molten formation, the Earth has been slowly cooling and thus shrinking and collapsing, like the skin of a drying apple, which produces mountain-building structures such as faults and folds. This theory has been refuted and is outdated. With the advent of the plate tectonic theory and structural geologic research grounded in field mapping, mathematical analysis, analog experiments and numerical simulations, we now have sophisticated and detailed explanations for rock folds. In Part I of this article (*GEO ExPro,* Vol. 10, No. 3), we looked at the geometry and shape of folds. Part II discusses folding processes in relation to their form and development.

Fold Dimensions

Rock folds come in various sizes, from micro-structure scale features observable on a thin-section of a rock sample to mountain-size folds. Nevertheless, folds in geology are what waves are in physics. Therefore, certain geometric measures can characterize rock folds, and these can be used to analyze them .

The size of a single fold is measured by its **height** (distance between crest and trough), **width** (distance between the inflection points bounding a fold), and **amplitude** (distance from crest to width, measured parallel to the axial plane). Another measure to note is **wavelength** or distance between two consecutive crests or troughs. The **aspect ratio** of a fold is the ratio of its amplitude to its width. Robert Twiss of University of California at Davis (*Journal of Structural Geology*, 1988, Vol. 10,) has suggested the following terms to describe a fold's aspect ratio: Wide (0.1 to <0.25); broad (0.25 to <0.63); equant (0.5 to 2.0); short (1.50 to <4); and tall (4 to <10).

Tightness of a fold is measured by its **interlimb angle** (the angle between the two limbs of a fold). In a classic paper

published in 1964 (*Proceedings of the Geologists' Association*, Vol. 75) Michael Fleuty of Imperial College in London outlined several categories for fold tightness. The following is modified from his paper: Gentle (interlimb angle <180° to 170°), broad (170° to 120°), open (120 to 70°), closed (70° or 30), tight (<30° to 10°), and isoclinal (<10° and the limbs have the same dip).

In a stack of sedimentary layers, each individual layer may deform independently due to its own or surrounding rock properties. Therefore, changes in fold wavelength and amplitude among layers result in **disharmonic folds**. In a sedimentary stack where folds keep the same shape across the layers they are called **harmonic folds**.

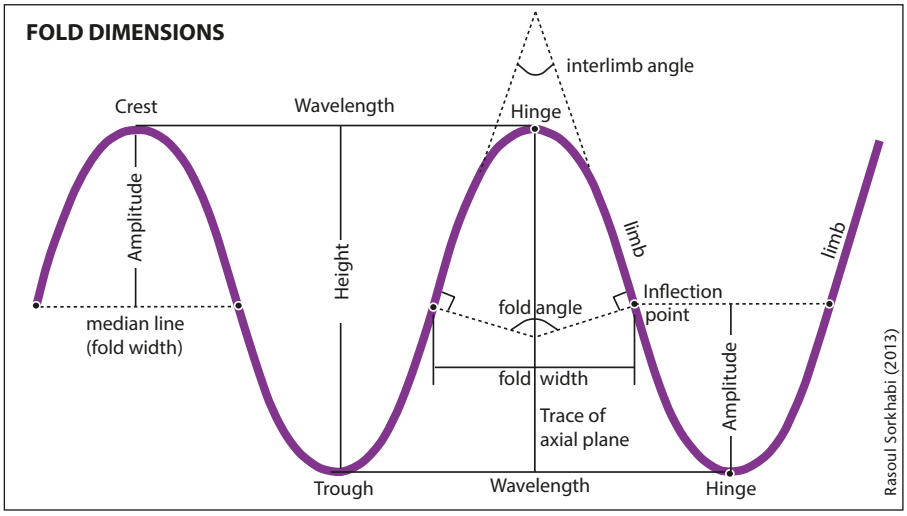
Fold is a kind of strain in the rock, and knowledge of the attitude and dimensions of folds helps us understand the direction and degree of stresses that has deformed the rock.

Bends, Buckles and Flows

Fred Donath and Ronald Parker in 1964 (*GSA Bulletin*, Vol. 75) presented a totally different classification of folds based on the mechanism of their formation, for which they considered the 'mean ductility' and 'ductility contrast' in the folded strata. On this basis, folds are categorized into **flexural folding** in which layering and mechanical anisotropy between the layers play the dominant role (in other words, mean ductility is low to moderate); **passive folding** in which interlayer anisotropy is ineffective (mean ductility is high); and **quasi-flexural folding** in which the geometry of the fold appears to be flexural but the overall behavior of the folded sequence is passive (mean ductility is very high). The last category largely corresponds to disharmonic folding. The first two categories, flexural and passive, can be further subdivided into slip (between layers) and flow (within layers).

The Donath and Parker classification directs us to the genetic mechanisms of folding and the tectonic environments in which folds form. Three distinct mechanisms have been identified for the folding of rocks: bending, buckling, and passive folding.

Bending of rocks occurs when the deforming force is applied across (at high angle to) rock layers. For example, basement uplift along a fault, magma intrusion or salt diapirs all produce bends (folds) in the overlying sedimentary rocks. Bending often produces gentle or broad folds, especially in continental interiors (cratons) situated far from plate boundaries but subjected to some vertical stresses.



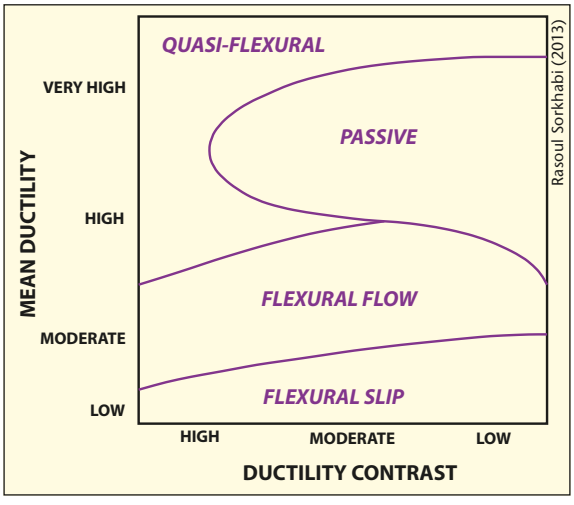
Fold geometry and various lines and angles used to measure fold dimensions

Buckling occurs when the deforming force is applied parallel to rock layers. This is usually caused by horizontal compressional tectonic forces and results in layer-parallel shortening of rocks and thickening (relief) of the rock body perpendicular to stress direction. Geologists have worked out mathematical relationships between wavelength of a buckle fold and thickness of the stiff layer embedded in a ductile rock mass. As a general rule, in a given stress field and ductility contrast between the layers, thicker stiff beds will have longer fold wavelengths and thinner stiff beds will have shorter wavelengths.

Bending and buckling may also be described as two modes of **active folding** in which rock layers with their inherent mechanical properties (notably stiffness or ductility) take part in the deformation process and control the fold shape. In contrast, in **passive folding**, rock layering itself does not play an active role in folding, and instead the rock mass as a whole is subjected to folding and is usually marked by penetrative **cleavage** developed in a direction nearly parallel to the axial surface of fold. Rock cleavage is a set of planar discontinues that develop as secondary features in the rock fabric; it also refers to the ability of a rock to split (cleave) along those planes. Well-developed (continuous, spaced) cleavage occurs at temperatures of 200–350°C, corresponding to burial depths of 7–12 km.

Passive folding takes place in a mechanically isotropic rock mass and on a grain scale rather than a layer scale. Passive folds may be subdivided into passive-slip folds and passive-flow folds. In **passive-slip folds** there is minor but discrete displacement across (perpendicular to) rock layers and more conveniently along cleavage planes; they are also called **shear folds**. In **passive-**

Fields of folding related to mean ductility and inter-layer ductility contrast of folded rocks (from F.A. Donath and R.B. Parker, 1964, Geological Society of America Bulletin, 75: 45-62)



flow folds, there is across-layering material flow in a ductile environment and in the direction of folding.

Passive folding produces **similar folds** in which the fold shape is preserved throughout the layered sequence because of the lack of mechanical differences between layers. Examples of passive folding include folding of rocks in ductile shear zones and drag folds along brittle faults.

Flexural Slip and Flexural Flow

Bending and buckling produce **flexural folds** in which (as stated before) viscosity contrast between competent (stiff) and incompetent (ductile) rock layers plays an important role in the folding process. In flexural folds, competent layers do not change their thicknesses and incompetent layers are marked by cleavage sets nearly parallel to fold axial surface. Flexural folds are the most common folds in sedimentary basins.

Flexural folds are subdivided into flexural-slip folds and flexural-flow folds. In **flexural-slip folds**, there are displacements along bedding surfaces, much like the bending of a telephone directory book. These slips are greatest along the fold limbs and approach zero along the fold hinge. Flexural slip typically produces parallel or concentric folds in which the attitude and thickness of layers remain the same throughout the folded sequence. (For illustrations of similar, **parallel**, and **concentric folds**, see Fold and Folding I, *GEO ExPro*, Vol. 10, No. 3.)

In **flexural-flow folds**, rock material in incompetent layers flows from fold limbs toward fold hinges, and therefore appreciable thickness changes occur in the rock layer. Obviously, flexural-flow requires more ductility contrast between layers than flexural slip. Flexural flow produces **similar folds** in the weak layers.

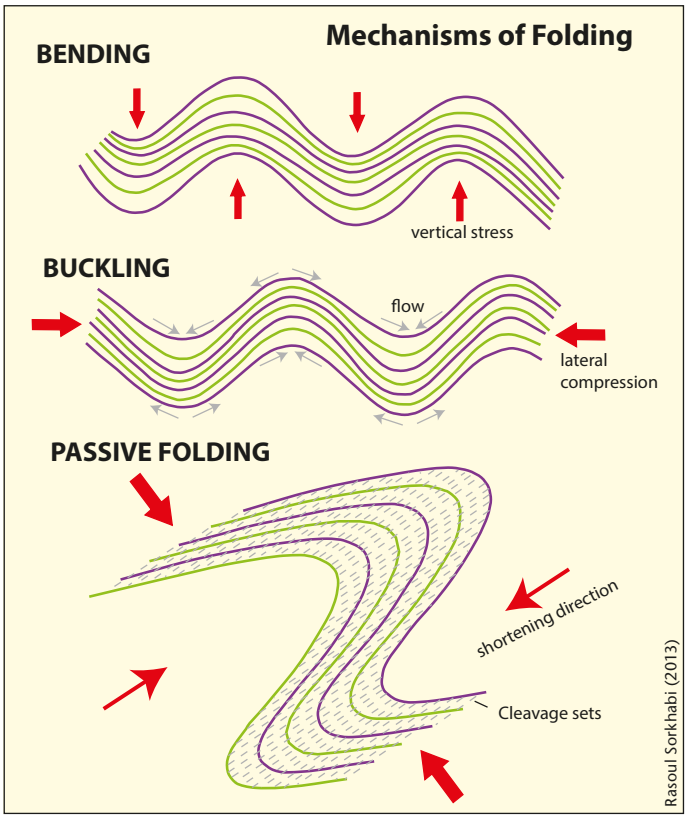
Free and Forced Folding

In **free folding**, rock layers are free to exert their mechanical properties on the development and shape of the folded stack and thus layer-parallel strain dominantly takes place. Buckling discussed above typically produces free folds.

In **forced folding**, the shape and geometric features of the folded stack are 'forced on' the layers usually by a fault that is the primary structure. In this case, to quote American geologist George Davis in his textbook *Structural Geology* (1996), the rock layers "just go along for a ride." Notable examples of forced folding include **drape fold** (folding of sediments overlying a high-angle basement fault), **fault-bend fold** (bending and slip of an anticlinal fold as a thrust block overrides the footwall block along a ramp), and **fault-propagation fold** (asymmetric bending of rock strata along a thrust ramp). In these examples, folding depends on faults, and bending is the main process of folding.

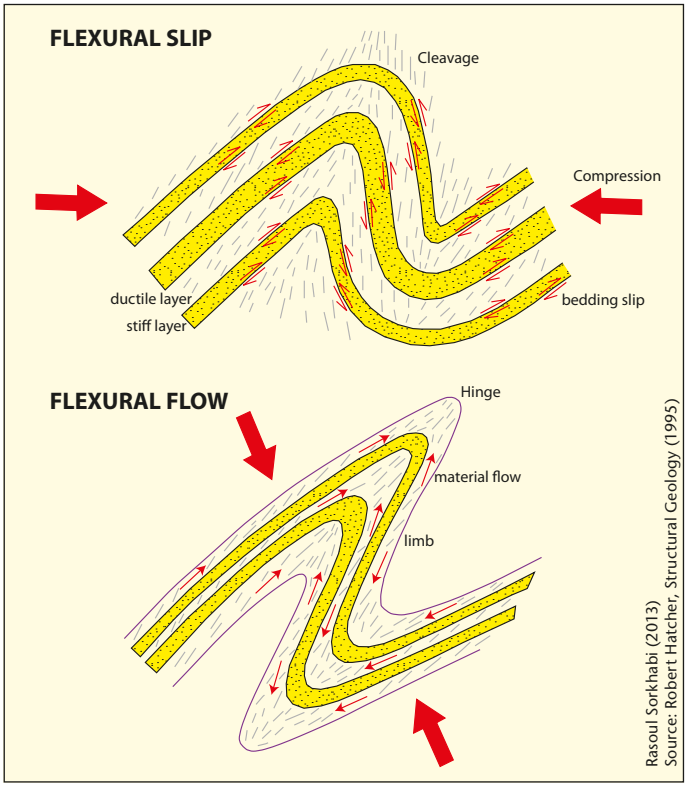
Folds and Petroleum Fields

In summary, various forces produce rock folds. **Horizontal compression** resulting from the motion of tectonic plates is the most dominant force which produces series of regional and basin-scale folds. But other forces can also create localized or even widely distributed fold structures. These include **vertical stresses** (such as magma intrusion or basement upwarping); **slope instability** (such as rollover anticlines on



Three main mechanisms of rock folding: bending, buckling and passive folding. Note changes in thicknesses of rock layers related to bending and buckling. (Bending and bucking figures modified from Hans Ramberg, 1963, AAPG Bulletin, 47: 484-505. Passive folding figure from Robert Hatcher, Structural Geology, 1995.)

Two modes of flexural folding: layer-parallel flexural slip of sedimentary rocks in a parallel fold at relatively lower temperatures and pressures; and flexural flow of weak layers in a simple fold. (Modified from Robert Hatcher, Structural Geology, 1995.)



UK Southern North Sea Gas Basin

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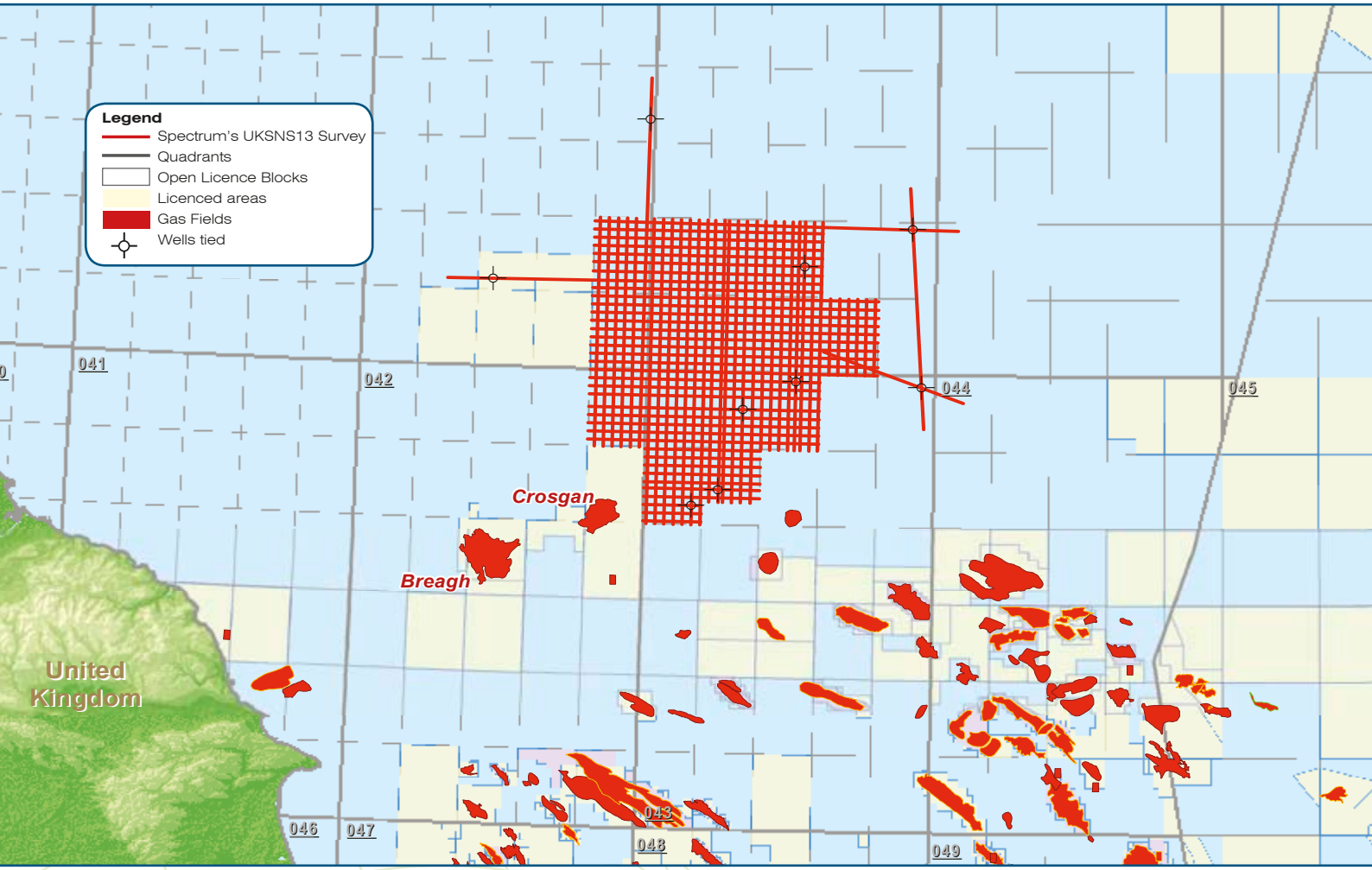

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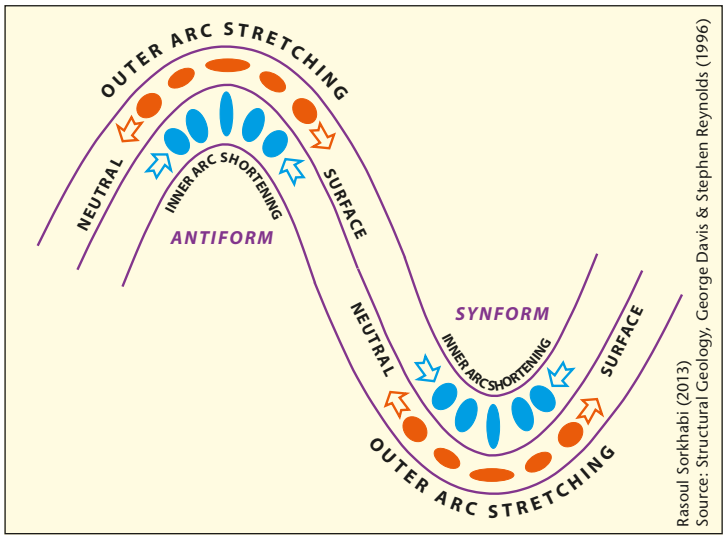
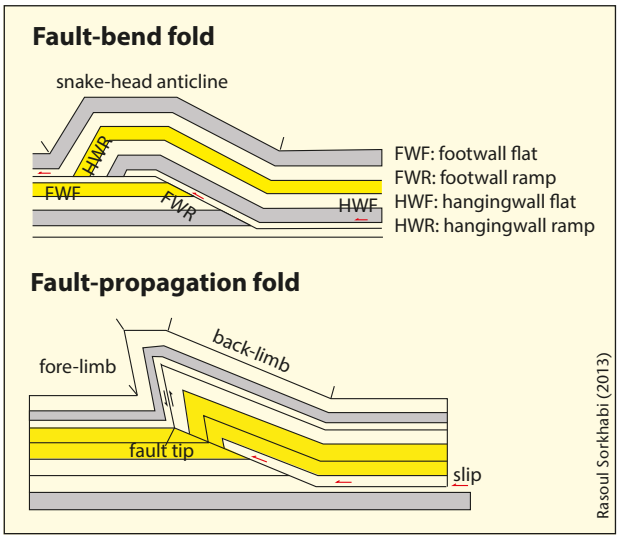


Individual buckle folds show internal deformation in two contrasting styles: layer-parallel stretching (marked by extensional fractures, minor normal faults or boudins) in the outer arc of the fold, and layer-parallel shortening and thickening (marked by minor folds or reverse-faults) in the inner arc of the fold. These internal strains decrease toward the middle of the fold layer called the neutral surface of no strain. (Modified from George Davis & Stephen Reynolds, Structural Geology, 1996.)



Fault-bend fold and fault-propagation fold are two important styles of 'forced folding' in which the fold shape is controlled by thrust fault. (After John Suppe, Principles of Structural Geology, 1985.)

normal-fault surfaces and toe-thrust folds on continental slopes); and **density instability** (for example, salt diapirs below denser sediments).

Folds are important structures to study in petroleum fields for a variety of reasons. Large folds provide important petroleum traps, such as anticlines or fold-bend folds in foreland basins, rollover anticlines in extensional basins, and deepwater toe-thrust folds. In these kinds of traps, three-dimensional mapping of fold structures are thus necessary for reserve estimates. In addition folding creates natural fractures which provide crucial permeability for oil and gas production in tight reservoirs, which is why **curvature analysis** of rock strata is sometimes made on seismic images to gain an understanding of the distribution and relative population of fractures. ■

An anticline in the Miocene Barstow Formation exposed in the parking lot at Calico Ghost Town County Park in the Mojave Desert of Southern California

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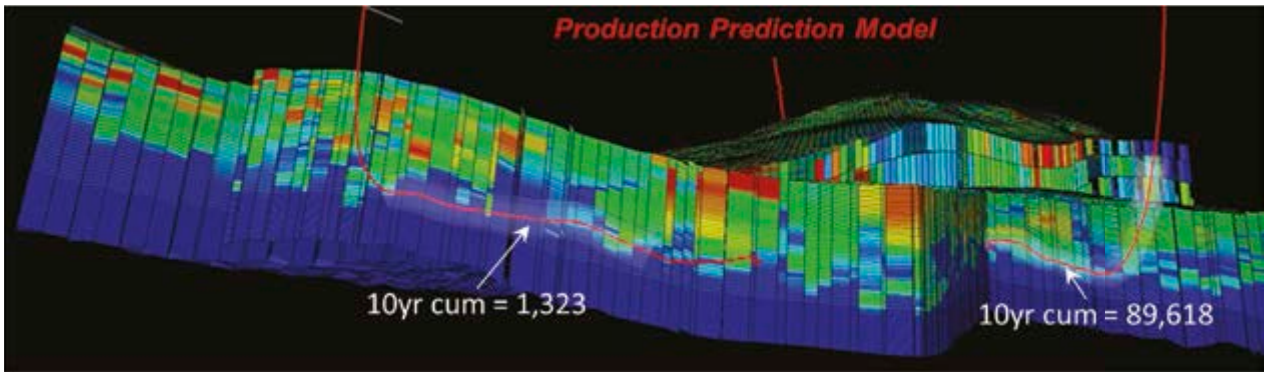

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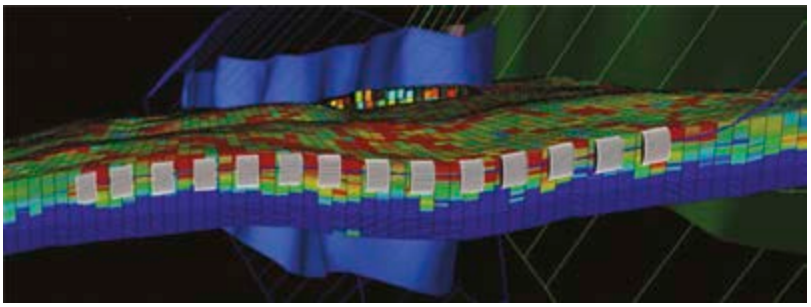

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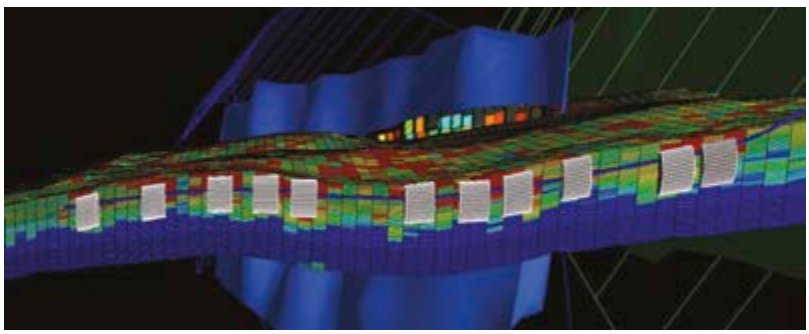

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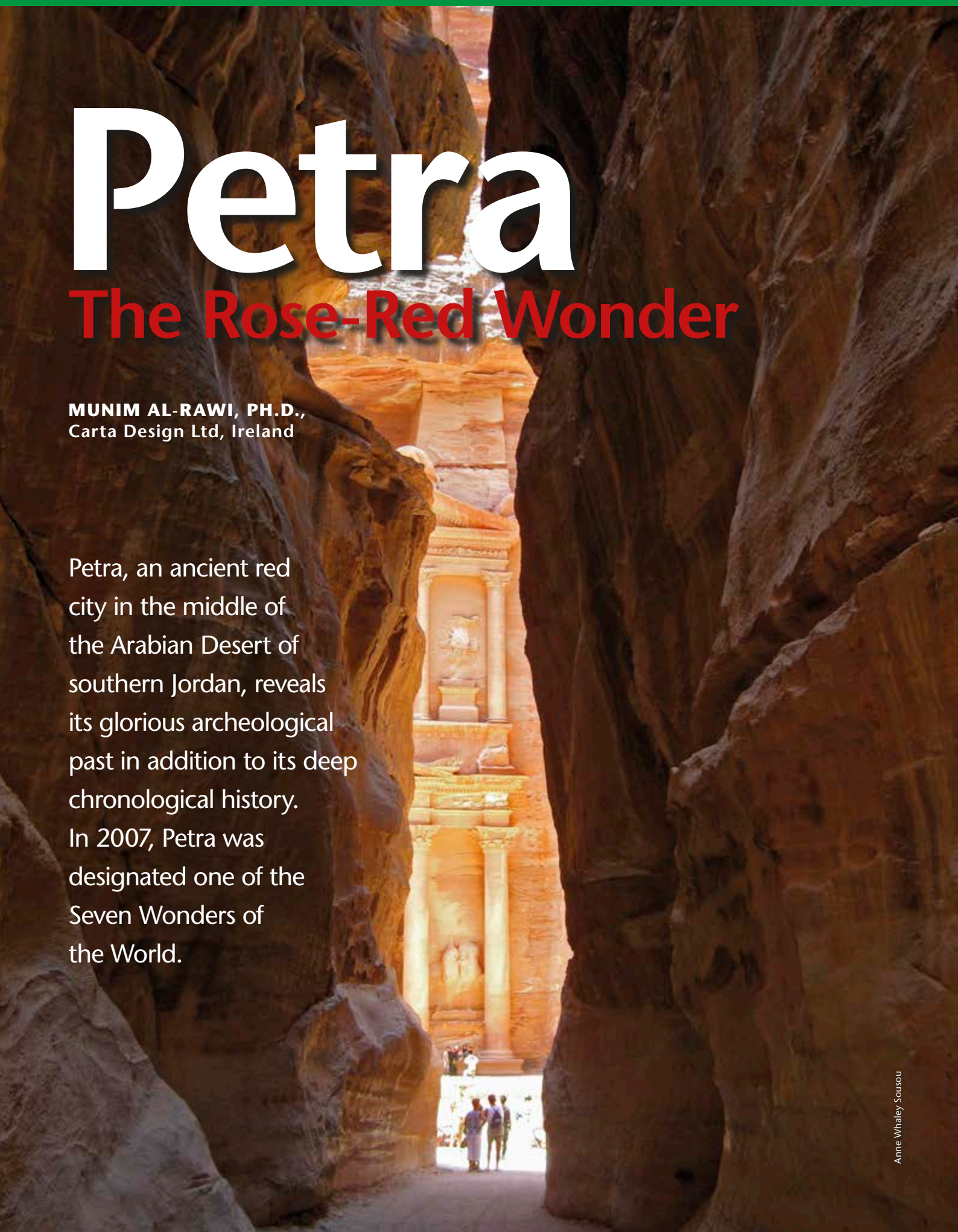
Petra

The Rose-Red Wonder

MUNIM AL-RAWI, PH.D.,
Carta Design Ltd, Ireland

Petra, an ancient red city in the middle of the Arabian Desert of southern Jordan, reveals its glorious archeological past in addition to its deep chronological history. In 2007, Petra was designated one of the Seven Wonders of the World.

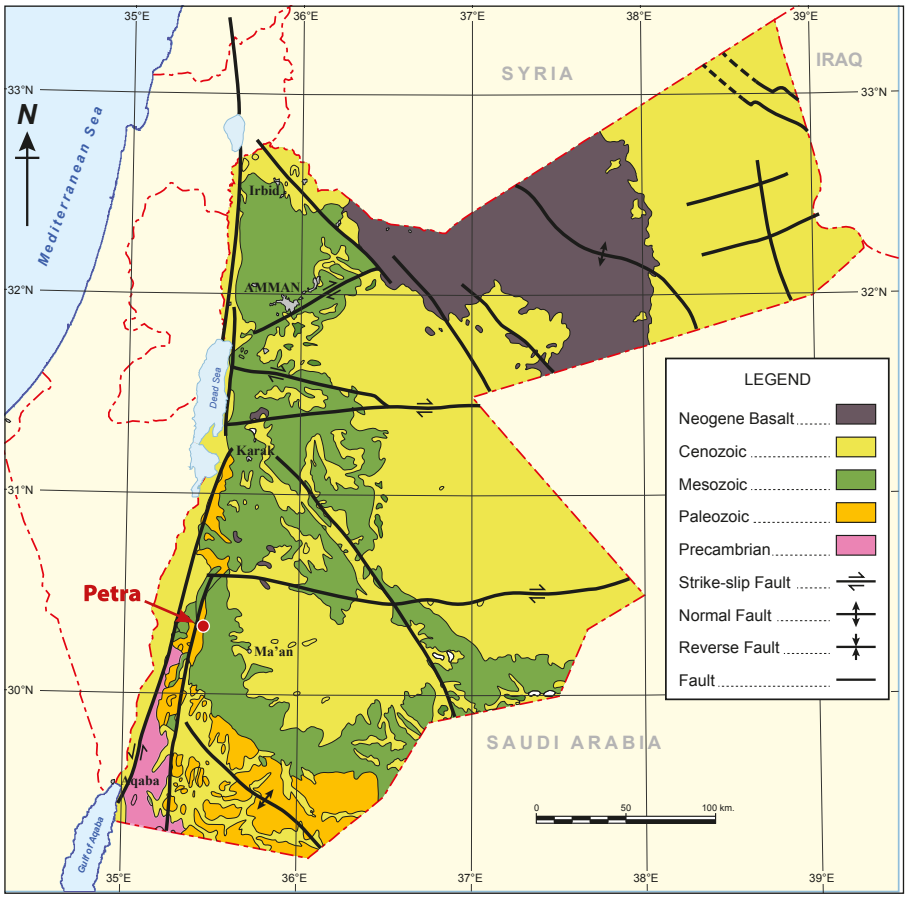


Anne Whaley Sousou

The present site of Petra was originally built by the Nabataean Arabs during the 4th century BC, and was known in Arabic as Sila'a سلع, and Ar Rakeem الرقيم, or biblically as 'Rqm', which all mean 'cut in rock'. The site was conquered by the Romans in AD 106, and was renamed in Greek as Petra, or in Arabic Al Betra البتراء, which also means cut in rock. It is believed that Petra was destroyed by several earthquakes, ending in complete destruction and eventual evacuation during the 6th century AD.

Petra is located in the heart of the mountainous desert of southern Jordan, half way between the Red Sea and the Dead Sea, but importantly, was adjacent to an ancient route down from the high plateau eastwards to Wadi Araba. The site can also be reached from the city of Ma'an to the east. The town surrounding the site of Petra is called Abu Mousa, as well as the valley (wadi) leading to Petra. In detail the site occupies an open valley (occupied by the town itself) surrounded by mountains, which were used for religious ceremonies, tomb building and water collection in cisterns. Routes through the mountains follow deep gorges or 'siqs'. Although the formal entrance was through the main Siq in the south, general access is also possible from the north.

Although Petra is now a major archeological tourist destination, receiving nearly one million visitors each year, in this article we will highlight the geological perspective of Petra.



Simplified geological map of Jordan (modified after NRA, 2006, in Naylor et al, 2013)

Petra's Geology

The mountains to the south of Petra are composed of Precambrian igneous rocks of the Aqaba Granite Complex, cut through by a series of intrusive dikes. These are unconformably overlain by the massive quartzose sandstones of Middle Cambrian to Lower Ordovician age which make up the rocks and monuments of Petra. The properties of the rock itself may have persuaded the Nabataeans to site their city here, as it was evidently suitable for rock carving and excavating, and also pleasing to look at. After 2,000 years, however, much of the worked and excavated stone is showing signs of decay, not least through the footsteps of many tourists.

The impressive gorges were formed when the force of desert flash floods over many thousands of years exploited lines of weakness in the rocks such as faults, joints and fractures, a process which is still continuing today.

Simplified stratigraphy of the rocks in the Petra area

Mesozoic	Upper Cretaceous		**Upper Cretaceous Limestones**: above Wadi Mousa
	Lower Cretaceous		**Kurnub Sandstone:** soft sandstones occupying the valley in the centre of Petra; also visible behind Wadi Mousa
Paleozoic	Lower Ordovician		**Disi Sandstone**: white domes near Wadi Mousa and behind the Visitor Center
	Upper Cambrian		**Umm Ishrine Sandstone**: pale white to reddish and hard sandstone, most of the monuments are carved in the middle part of this unit; Liesegang banding is abundant.
	Lower – Mid Cambrian		**Salib Sandstone**: thin unit resting on the unconformity
Precambrian			**Basement Complex**: only visible beyond the Monastery

A Walk Through Petra

Following the archeological route in Petra, there are five sectors with important geological features. These are from the Visitor Center outside Petra to the entrance of the Siq; the Siq itself; the Khazneh or Treasury and the Street of Façades; the Roman Theater; and the museums and surrounding mountains. We will look at each of these individually.

1. From the Visitor Center to the Siq

The hills surrounding the Visitor Center and Wadi Mousa are covered by whitish-colored Lower Cretaceous Kurnub Sandstone. This formation lies unconformably on the pale white sandstones of the Lower Ordovician Disi Formation. The Disi in this area is characterized by tabular cross-bedded sandstones and several tombs have been cut in this sandstone.

Planner cross-bedding in the Disi Sandstone, Petra

2. The Siq

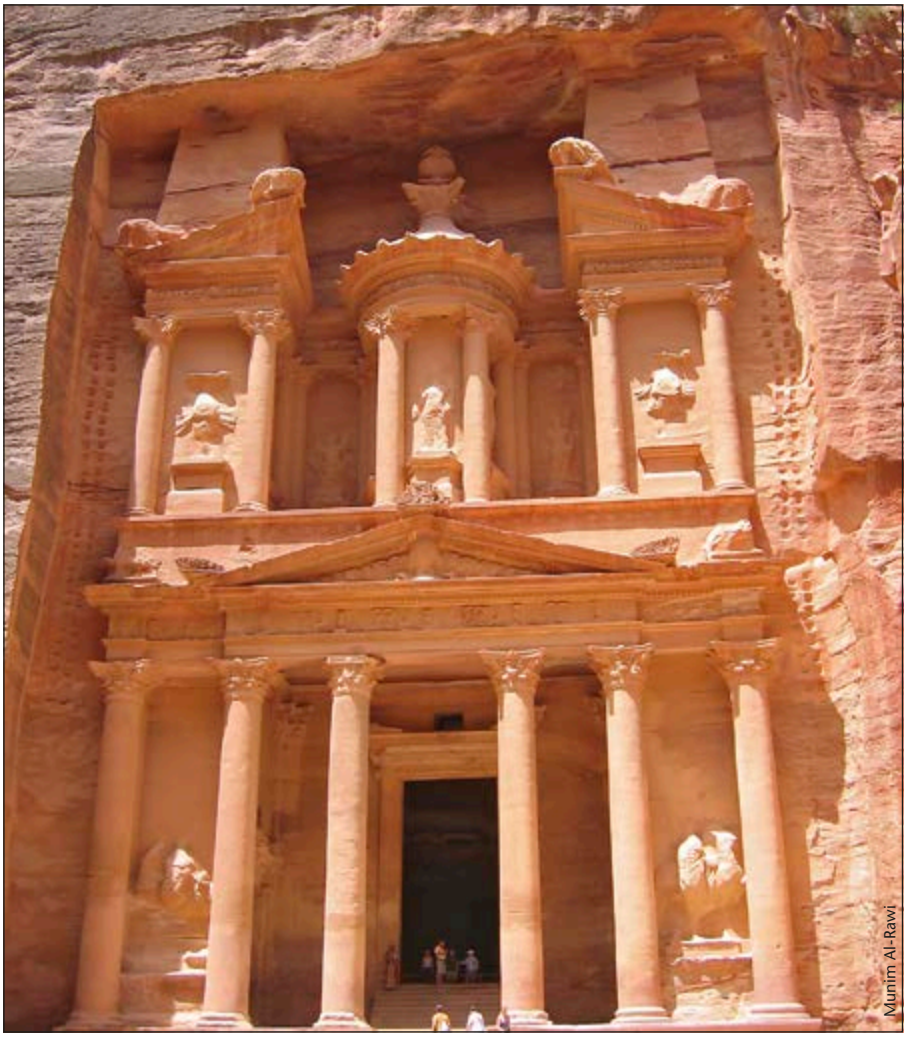
The Siq, a narrow winding cleft in the rock made by water cutting of the fracture system, is basically the road to the ancient city of Petra. At the top of the cliffs is the white sandstone of the Lower Ordovician Disi Formation. It is underlain by red mudstone, and following downward in sequence there is the thick, cross-bedded, very hard sandstone of the Upper Cambrian Umm Ishrine Formation, pale white to reddish in color, with vertical fractures and joints. This is the formation which represents all the famous rose colored sandstone in Petra.

The Siq is about 1,000m long, over 80m high and in some places only three meters wide. In addition to numerous archeological writings, there are several sedimentary features to be seen on its high walls. These include sets and cycles of cross-bedding, where secondary iron oxides can be seen filling joints and

View of the entrance of the Siq at Petra. The remnant of the archeological arch or gate can be seen on the cliff sides and the horizontal line running at a height of about a meter along the left wall is the site of a cistern bringing water into the city.

View of the Umm Ishrine Formation in the Siq at Petra. The cross-bedded sets are separated by mud layers.

View of the Khazneh Façade, the main archeological chamber at Petra, showing thick cross-bedded Umm Ishrine Sandstone



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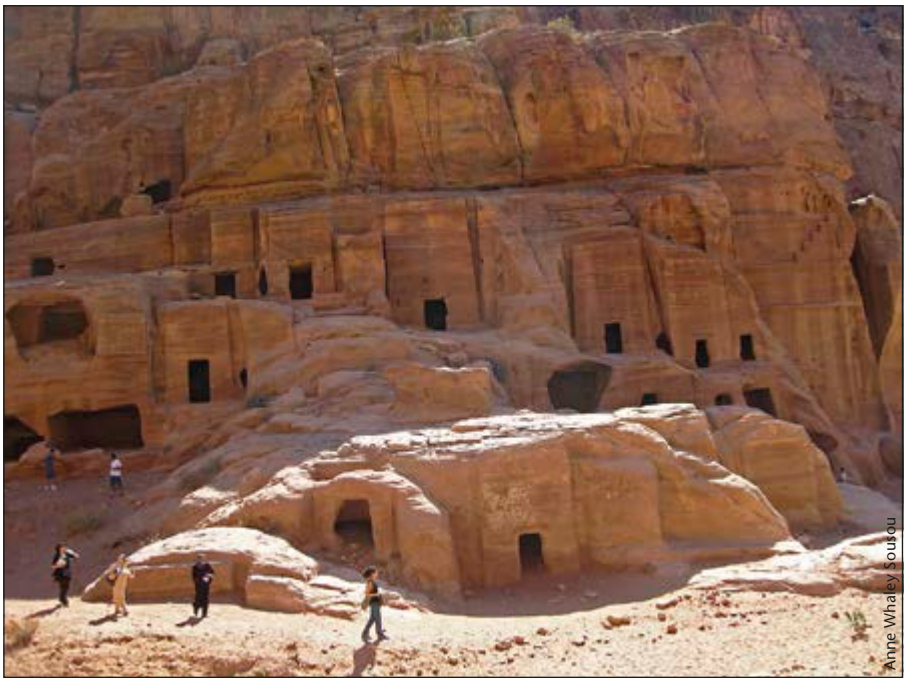
sedimentary sets, and most importantly there are mudstone beds, often showing mud cracks, all of which presumably represent playa deposits. These last are often wrongly mistaken by ill-informed tourist guides as bone fossils (as can be seen on internet videos!). There are no fossils in Petra, only pseudo-fossils of dendrites which have been observed on fallen sandstone slabs, although trace fossils have been recorded in rocks from beyond the immediate Petra area.

An important engineering feature are channels which can be observed running all the way along both walls of the Siq from its entrance. These are the remnants of cisterns used for water collection for the use of the citizens of Petra. The settlement was only made possible by the creative genius of the extensive water distribution and storage system.

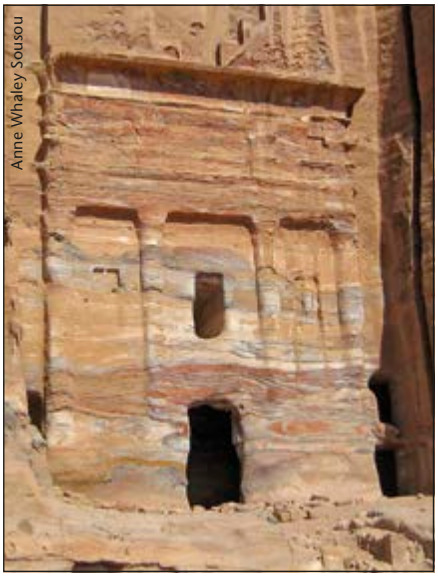


The Street of Façades

3. The Khazneh and the Street of Façades

After passing through the dark narrow Siq, the façade of the Khazneh, (Treasury) suddenly appears, bathed in sunlight – one of the most dramatic and stunning sites for even the most jaded tourist. Besides the façade, there is a magnificent view of the thick, red-colored, cross-bedded sandstone, reflecting the original sedimentary structures of presumably huge fossilized sand dunes, interbedded with playa mudstones. Some previous workers have interpreted them as dunes of a coalescing braided river system. However, looking at the regional areal distribution of these sandstones from Aqaba in the south to the Dead Sea in the north, and also in north-western Saudi Arabia, I would rather interpret them as fossilized coalescing desert sand dunes of Cambrian age, some 500 million years ago.

Turning right and then left from the Khazneh, in front of you is the Street of Façades, where tombs and monuments are to be observed on both sides of the road. All these archeological features are located in the same thick red cross-bedded sandstone facies of the Umm Ishrine Sandstone. Some of the façades have been exposed to high winds and their surfaces are weathered more than other sheltered façades, and show more internal features such as Liesegang banding. At Petra the sandstones are spectacularly color-banded in yellow, orange, red, gray, brown and mauve. These patterns, termed Liesegang banding (or rings), were presumably formed prior to uplift, deep underground by the rhythmic deposition of various iron and manganese compounds from mineral-rich water that once flowed within the rock.



Monument showing Liesegang banding

The Street of Façades descends downward to the Roman Theater, which is located on the western side of the Street of Façades. Here, the sequence is descending stratigraphically within the Umm Ishrine Sandstone. Two thick sandstone cycles separated by thin claystone beds can be seen. The theater steps were actually cut in a lower sandstone unit of interbedded redder sandstone and mudstone facies, which shows more weathering, being of softer nature as well as more exposed to erosion.

On both sides of the street there are a lot of monuments and tombs. The lower ones in the same stratigraphic level as the theater show more erosion than the higher monuments and tombs, which were cut into the thick sandstone units stratigraphically above.

After leaving the Roman Theater and the old Petra City, the road turns left to the younger Roman road

The Roman Theater

and museums, including the Byzantine Church. Most of the monuments here are younger, built by the Romans and not the Nabataeans. Beyond, to the west, is the rise of the Umm Ishrine Sandstone, with a thick sandstone facies. The mountain is full of monuments and there are also two archeological museums. At the top lies the important monument, the Monastery. At this site, the Ordovician Disi Sandstone lies over the Umm Ishrine Sandstone. Viewing from the top of the mountain further west one can see the dark rocks of the Precambrian Basement Complex.

An Essential Visit

The sedimentary sequence in Petra and the surrounding area along the Dead Sea in southern Jordan is a must-visit for amateur and professional geologists. For geological students, it is field laboratory to observe and study geological features and sedimentary structures. In sequence stratigraphy, it is a surface analog to correlate seismic stratigraphy and bore-hole information, while for petroleum geologists, the sequence at Petra is an excellent example to help understand reservoir geometry. ■

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A Note From the Author

My first visit to Petra was in January 1965, with the graduation class of the Geology degree at the University of Baghdad, and was led by the late British Professor C.M.G. Bolton, accompanied by other staff members. Petra at that time was not a proper tourist destination. We observed the fascinating Cambrian sandstone formations and learnt the fundamentals of the geology of the Arabian Peninsula from the Precambrian basement complex to the Tertiary rifting of the Gulf of Aqaba and the Dead Sea. Between 1994 and 2005, I made several further visits to Petra and southern Jordan, privately and accompanying oil companies, culminating in a recent publication on the hydrocarbon potential of Jordan in Naylor et al, 2013.

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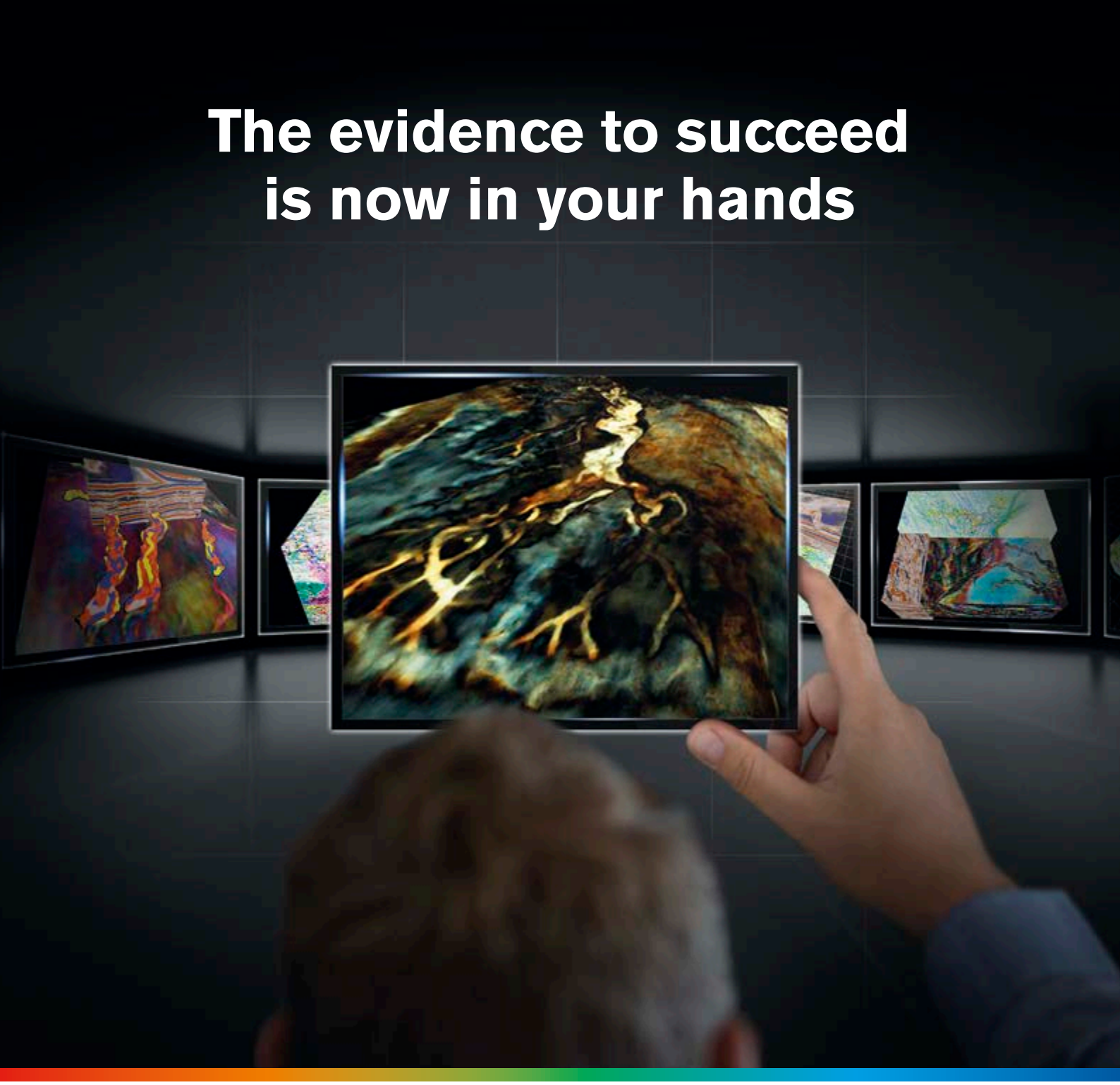

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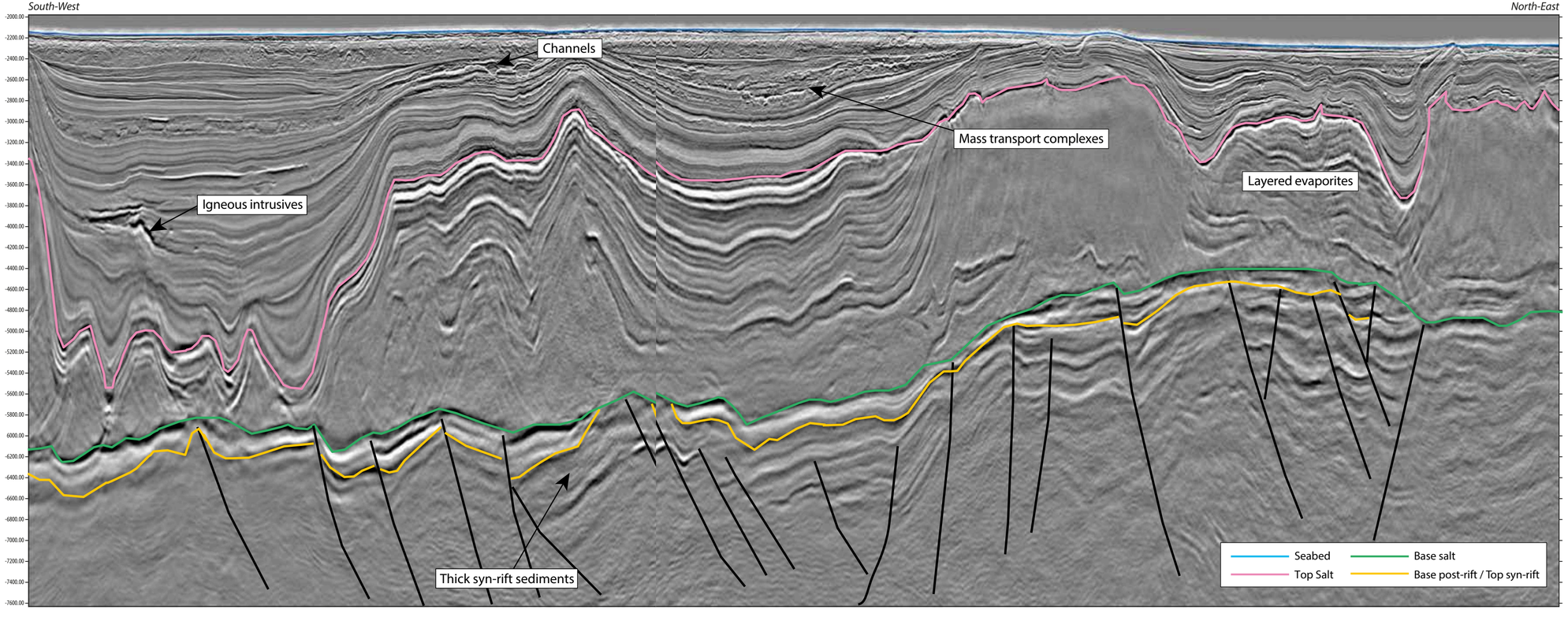
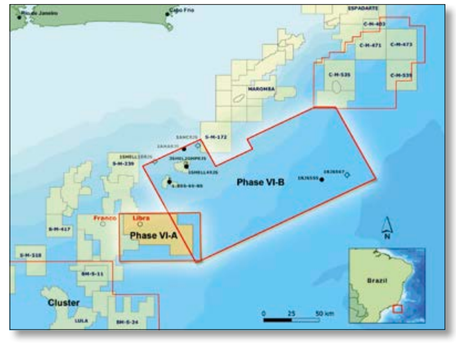
The Santos Basin, Brazil:

Unlocking the Pre-Salt Potential

The ever-growing pre-salt region offshore Brazil is a major contender for frontier exploration by the oil and gas industry. With the increasing number of pre-salt discoveries of super-giant fields, the Santos Basin is very important for future exploration. The discovery of the Lula oil field in 2006 has led to a string of subsequent discoveries such as Sapinhoa and Caracara in the southern Santos Basin. In the northern basin, the Franco and Libra oil fields have had continued success on the same scale as Lula.





The interpreted seismic line extends across the fast-track results from the Phase VI-B survey in the Santos Basin. The survey covers an area of 14,000 km² and has been acquired using CGG's new broadband technology. The dataset displays high-resolution imaging within the pre-salt and great similarities to the promising Libra discovery.

Broadband Technology:
New Benefits for Pre-Salt Exploration

CGG has acquired new conventional and broadband seismic data in the deepwater Santos Basin, creating exceptional results within the pre-salt.

JASWINDER MANN, CGG

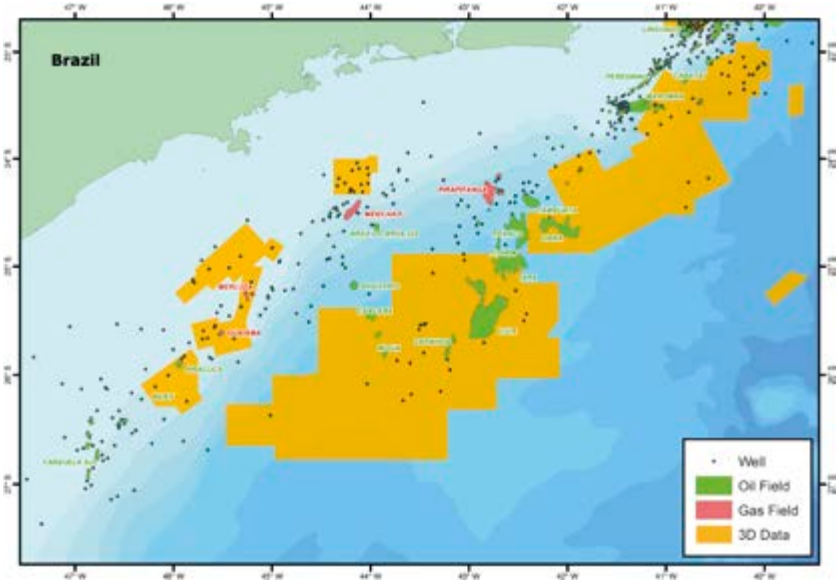
Pre-salt reservoir targets within the Santos Basin have been a major focus for oil and gas exploration, with much consideration directed to the challenge of seismic imaging below thick and complex salt bodies. CGG's broadband technology provides clearer imaging of the subsurface and therefore aids a better understanding of the petroleum systems. Data acquired using broadband technology is less impacted by tuning effects due to the broader bandwidths and sharper wavelets. The increase in low frequencies reduces side lobes to bring greater resolution and increase the texture and character of the data. Broadband data allows the interpreter to identify fine detail within the stratigraphic/structural features easily, in order to establish potential petroleum systems better.

The latest 3D data acquired by CGG provides new insights into the pre-salt section in the northern area of the Santos Basin. The examples used, from conventional and broadband data, have been taken from two of CGG's multi-client surveys, Phase VI-A and Phase VI-B. Both datasets have been imaged using Kirchhoff Pre-Stack Depth Migration (PSDM), with the main difference being that Phase VI-A is conventional seismic data that has benefitted from a full anisotropic PSDM sequence while the Phase VI-B broadband seismic data is currently a fast-track isotropic volume.

Fields and Discoveries

The Santos Basin displays great similarities to the adjacent prolific Campos Basin and is already considered as an important hydrocarbon province. In the past, the main exploration targets have been within the shallow post-salt successions. However, since the decision by Petrobras to explore below the salt and the discovery of the Lula oil field in 2006, interest has now turned towards the pre-salt. Lula has estimated reserves of 5-8 Bbo encountered in post-rift microbial carbonates. Subsequent to the Lula Field, the neighboring Jupiter Field became a significant gas discovery in early 2008, with estimated reserves of up to 60 TCF. Smaller but significant fields have been established since Lula such as Sapinhoa (Guara) and Carioca. Other recent discoveries like Franco in the northern Santos have brought attention to the prolific syn-rift coquinas. Franco consists of a distinct hydrocarbon column through two mega sequences (the sag sequence and upper syn-rift). Reservoir properties tend to differ from north to south as one might expect in such a large basin. Continuous exploration has provided a better understanding of reservoir properties and characterization of petroleum systems.

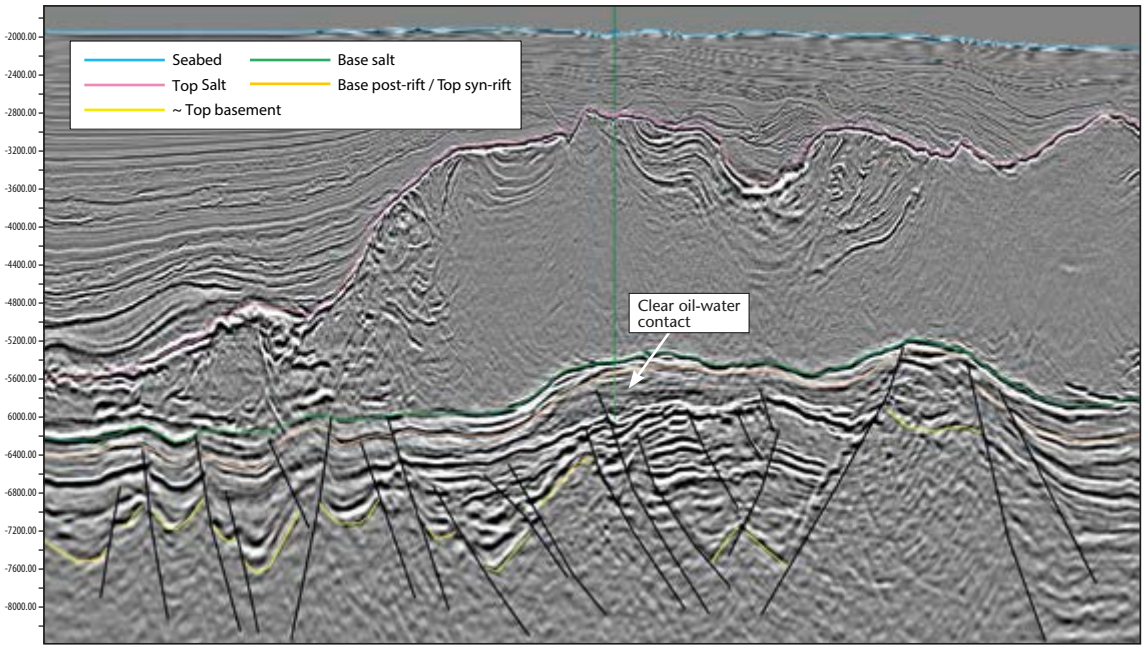
A map of fields and discoveries in the Santos Basin showing the extent of CGG's seismic coverage.



Libra Oil Field

The pre-salt Libra discovery is covered by the Phase VI-A conventional seismic survey area. This discovery is located in water depths of 2,000m, approximately 200 km south of Rio de Janeiro. Libra is an elongated, north-east to south-west trending structure situated to the east of the Franco Field. The discovery well was drilled by Petrobras, on behalf of the Brazilian federal government, to test the pre-salt interval. Analogous reservoir parameters can be seen between Franco and Libra due to their similarities in depositional environments and proximity to each other.

The Libra well encountered top reservoir within the highly prolific sag sequence at an approximate depth of 5,371m. The oil column is characterized by a strong increase in the resistivity log located within the upper syn-rift coquinas. Additionally, a distinct oil water contact can be observed from the seismic data, highlighted by a flat-lying increase in impedance (seen in the



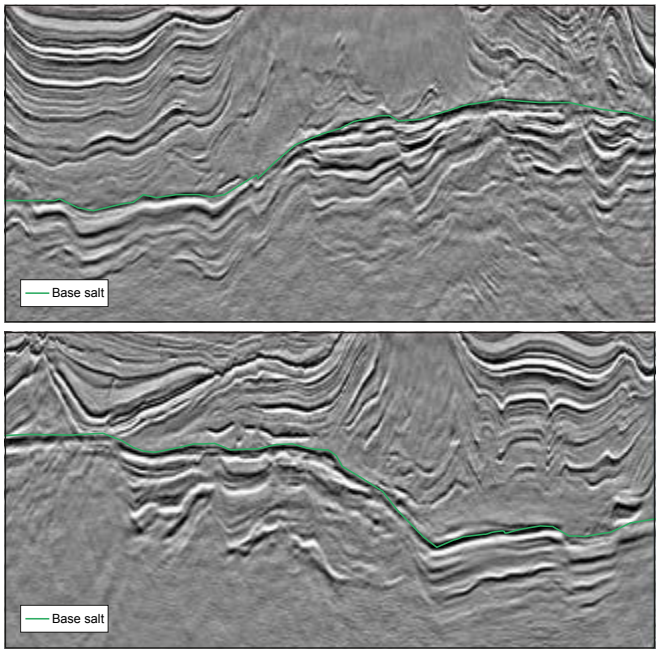
Seismic section through the Libra discovery taken from the Phase VI-A survey.

seismic section above). Continuous oil shows were recorded throughout the hydrocarbon-filled section, together with gas shows. This potentially large discovery differs from the giant Lula Field in the southern Santos due to the nature and extent of the hydrocarbons found: in Lula, the hydrocarbon-filled reservoirs are compartmentalized and trapped within intra-formational seals, whereas in Libra, there is one fairly continuous oil column spanning at least two mega-sequences. These observations highlight the differences between stratigraphy and reservoir properties across the basin.

Pre-salt Potential

Similar pre-salt stratigraphy and structural features to the Libra discovery can be seen in the Phase VI-B broadband dataset, indicating high potential for petroleum discovery. The broadband technology used to acquire the survey has been deployed over a largely unexplored, unlicensed part of the pre-salt region. The survey also extends out into the Campos Basin towards the north-east, as seen in the map on the fold-out pages.

Seismic sections taken from the Phase VI-B fast-track broadband survey displaying similar structural and stratigraphic features to Libra.



The Cabo Frio High extends across the middle of the Phase VI-B survey and is a prominent feature throughout the dataset. This high marks the northern boundary of the Santos Basin and the southern boundary of the Campos Basin. In comparison to the major Sugar Loaf High in the southern Santos Basin, where a large part of the post-rift sag sequence has been eroded, in the area covered by the broadband data it has been largely preserved. A clear, continuous post-rift sag sequence can be seen overlying a very thick syn-rift sequence. With the prospect of good reservoir properties within microbialite carbonates in the post-rift and coquina carbonates in the syn-rift, the potential is high for a similar discovery to Libra.

The syn-rift stratigraphy clearly thickens against fault planes that are easily identified with the new broadband data as definition of geological features and structures is improved due to the increase in low and high frequencies. The additional low frequencies give an envelope to the seismic signal that shapes the larger-scale impedance (or lithology) variations to improve layer differentiation and allow for a more confident correlation of sedimentary packages across fault planes.

With the upcoming Brazilian pre-salt licensing round, the northern part of the Santos Basin also emerges as a very promising area of interest. Large similarities have been witnessed in the Phase VI-B survey area, highlighting the great pre-salt potential still undiscovered within the Santos Basin. The benefits of broadband data, as shown on the left, allow more detailed images, thus helping to unlock the full potential of the Santos Basin.

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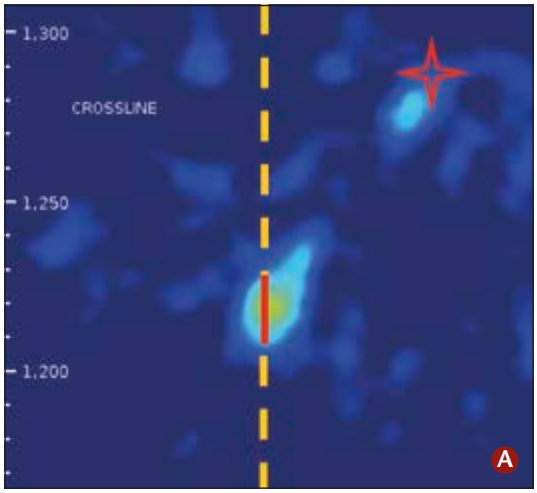
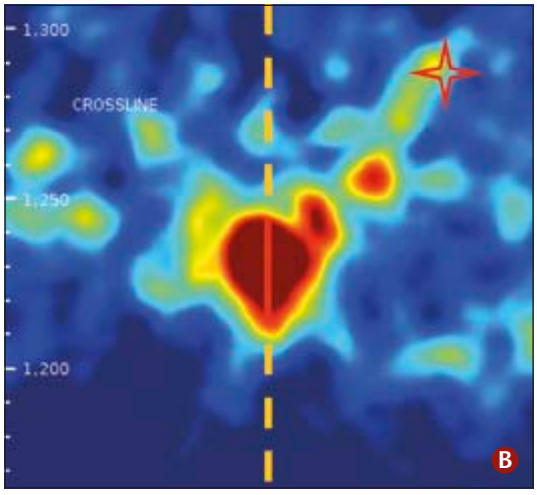
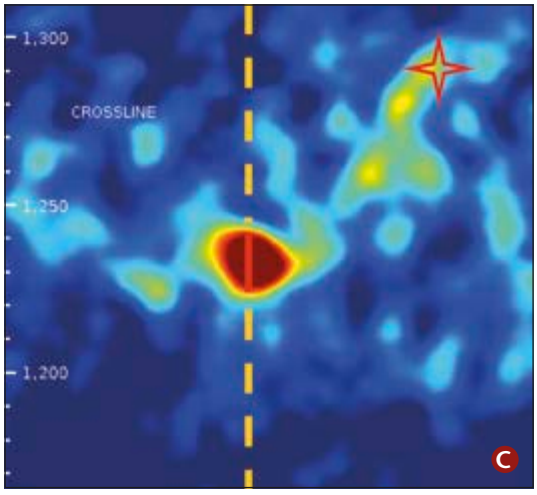
The Value of Monitoring Fractures



Activity at the beginning of stage 3: high activity at the perf location along the well that is being fracked, and some activity at the nearby well.



Formation breakdown occurs 20 minutes into stage 3 pumping, with a fracture activated in a nearby well within a three-minute interval.



Activity continues for 70 minutes near the perf location and in the fracture to the nearly well.

Real time frac monitoring shows the progression of fractures opened during the fracking process, knowledge which can impact drilling decisions.

CHARLES SICKING, Global Geophysical

Unconventional reservoirs are a growing part of the oil and gas industry in Latin America. New technologies, new tools and new understanding of the geology are necessary to properly develop these reservoirs, as international operators are faced with the challenge of understanding and applying technologies that do not have any clear analogs in conventional reservoir development. A major part of the development of these rich reservoirs is hydraulic fracturing.

Hydraulic stimulation or fracking is one of the most prominent and important of these technologies, and has played a pivotal role in enabling the economic production of hydrocarbons from shales and other low permeability formations that comprise the unconventional space. By creating new permeability pathways and enhancing pre-existing ones, this technology exploits fractures to extract hydrocarbons from formations that would otherwise be uneconomic. Assessing the effectiveness of fracking operations requires an understanding of the fracture network created or activated by the stimulation, as well as of how those fractures develop. It is this 'how' question that real time fracture monitoring is designed to address.

The number of fracture-stimulated wells in Latin America is on the rise and the case study in this article is an excellent example of the quality and importance of the data that can be attained using state-of-the-art technology.

Real Time Fracture Monitoring

Real time maps of the fractures being opened during pumping are required so completion engineers can improve their fracking projects. Monitoring the progression of fracture development in real time provides the information that they require.

The Seismic Emission Imaging method is used to create real time images of the fractures. For frac monitoring, grids of geophones are distributed on the surface or buried in shallow wells. The signals received by these geophones are recorded continuously for the duration of the frac project. Microseismic recordings from these grids are used to directly image the fracture networks that are activated by the pressure changes caused by the frac pumping, as they open new fractures and cause movements along pre-existing ones. The opening of the fractures in the rock causes seismic waves to be generated, which propagate to the recording array at the surface. The recorded seismic waves are imaged over many time windows to create a large number of seismic emission volumes, which are integrated for over large time intervals, with the final volume being the result of many minutes or hours of integration.

Dynamic Reservoir Response

The rock movements at any location in the rock are discontinuous and episodic. During pumping, fractures are opened in varying directions and at progressively larger distances from the frac point. Continuous imaging of the volume for seismic emissions allows the progression of the fracture development to be mapped in real time. This is called time lapse seismic emission imaging. The images of the seismic emissions are output at short time intervals, which allows the progression of the fractures to be monitored in real time.

In the example shown here, time lapse imaging shows the frac process from

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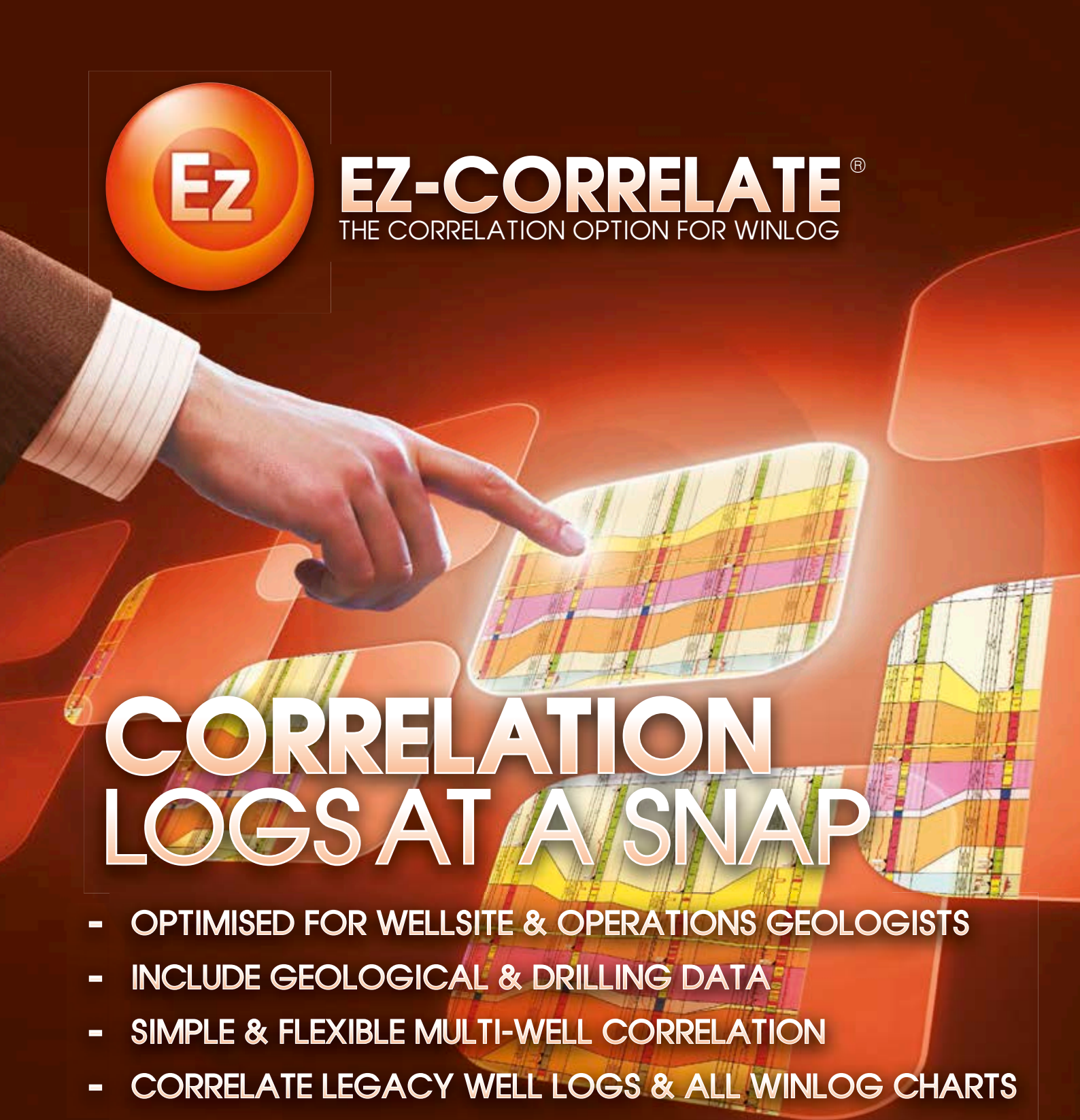

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the beginning to the end of pumping for stage 3 of the frac project. The first 20 minutes of pumping shows the desired behavior in the rock fracturing, with seismic emissions coming from the locations of the perfs (A). After 20 minutes of frac pumping, the passive imaging shows very large amplitudes of seismic emissions that last for about 3 to 5 minutes (B). During this very short period of time, the images show a fracture opening from the frac point in the well propogating to a monitor well 2,000 ft (600m) from the frac point. This fracture was confirmed at the distant well, when monitors in that well detected frac fluid during stage 5 of the frac project. The activity recorded by the geophones and imaged by the processing shows that the fracture that was opened had active movement for approximately 70 minutes after the time of the initial opening (C). This period of active rock movement was followed by an hour of quiet time during which there were no seismic emissions (D), after which, small movements in the rock along the fracture were reinitiated. The frac pumping was ongoing for the entire time. This example indicates that the rock movement during and after the fracture opening relieved the stress in the rocks; as pumping continued, the pressure in the fracture built up until it reached a level at which the stress increase caused additional movements along the fracture.

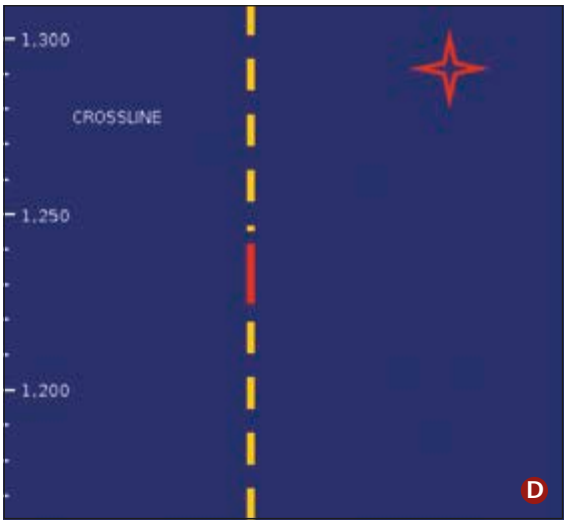
The final frame (E) shows the type of activity that was dominant during the frac for stage 4. Pumping continued to fill the very long fracture with fluid and the pressure increase at the well 2000 ft away caused the rocks at that location to be extensively fractured. During this stage, rocks at the frac pumping location were not fractured, while the rocks at the distant well had extensive induced fracturing. Real time monitoring would have provided this information to the completion engineer and the completion plan could have been modified. Instead, the frac project was stopped only after the damage had already been inflicted.

Fracture Imaging

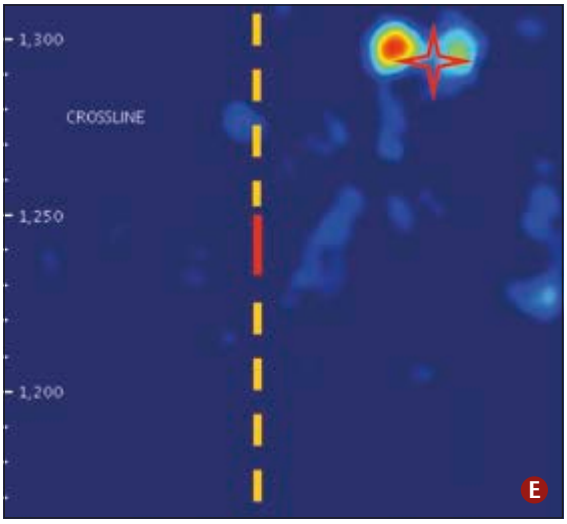
Using the emission volumes for selected time intervals, fractures that are opened by frac pumping can be mapped. The final figure (F) shows a fracture network that was mapped using the data from about 10 minutes of recorded data. The emission volumes for this period were integrated to form a single emission volume. The passive emission volumes are combined using a suite of tools that include the statistical and graphical analysis for noise editing and threshold application to remove the background, and the fracture volumes are computed from the combined passive emission volume. The volume is collapsed to fracture surfaces automatically using a patent-pending algorithm (Geiser and Vermilye, 2011).

The Tomographic Fracture Image (TFI™) shown in this figure is very complex. It passes through the frac point, through the distant well, and also wraps around and crosses the well being treated at the frac points for stages 4 and 5. This shows that the large fracture from the well being treated to the distant well was open before the pumping started for those stages, which explains why pumping for stages 4 and 5 could pass the pumping pressure to the distant well during the entire pumping time.

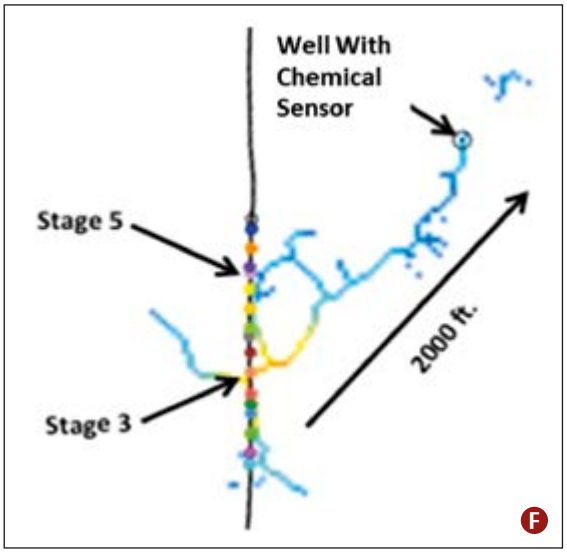
We interpret these observations as follows: As the fluid pressure in the fracture reduced the effective stress and hence the friction, the fracture became seismically active until the stress was relieved. Subsequent pumping drained into the region around the offset well until enough fluid moved into the well to cause a pressure kick and chemical tracer detection. The time lag may be explained by the time required to both pump up the pressure in the fracture system between the wells and to compensate for leak-off into the rock mass. Stage 3 was completed without knowledge of this major fracture opening because the treatment fluids did not arrive at the nearby well until stage 5 and real time, time lapse imaging was not available to the completion engineer. ■



This period of active rock movement was followed by an hour of quiet time during which there were no seismic emissions.



Stage 4 commences: activity shows that the nearby well is being fracked but there is no activity at the perf location.



A Tomographic Fracture Image (TFI) was computed using the data for the few minutes covering the time of formation breakdown.

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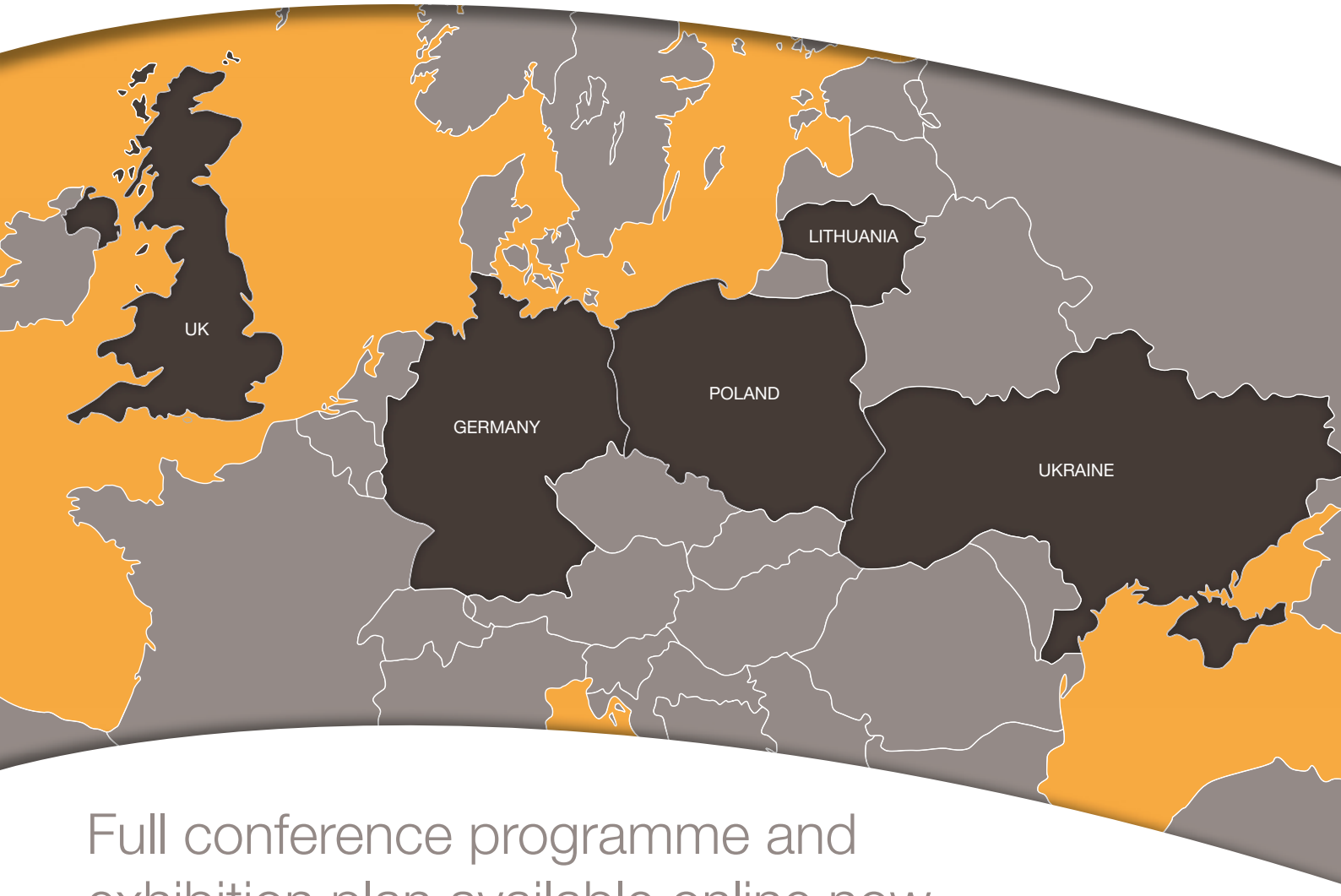

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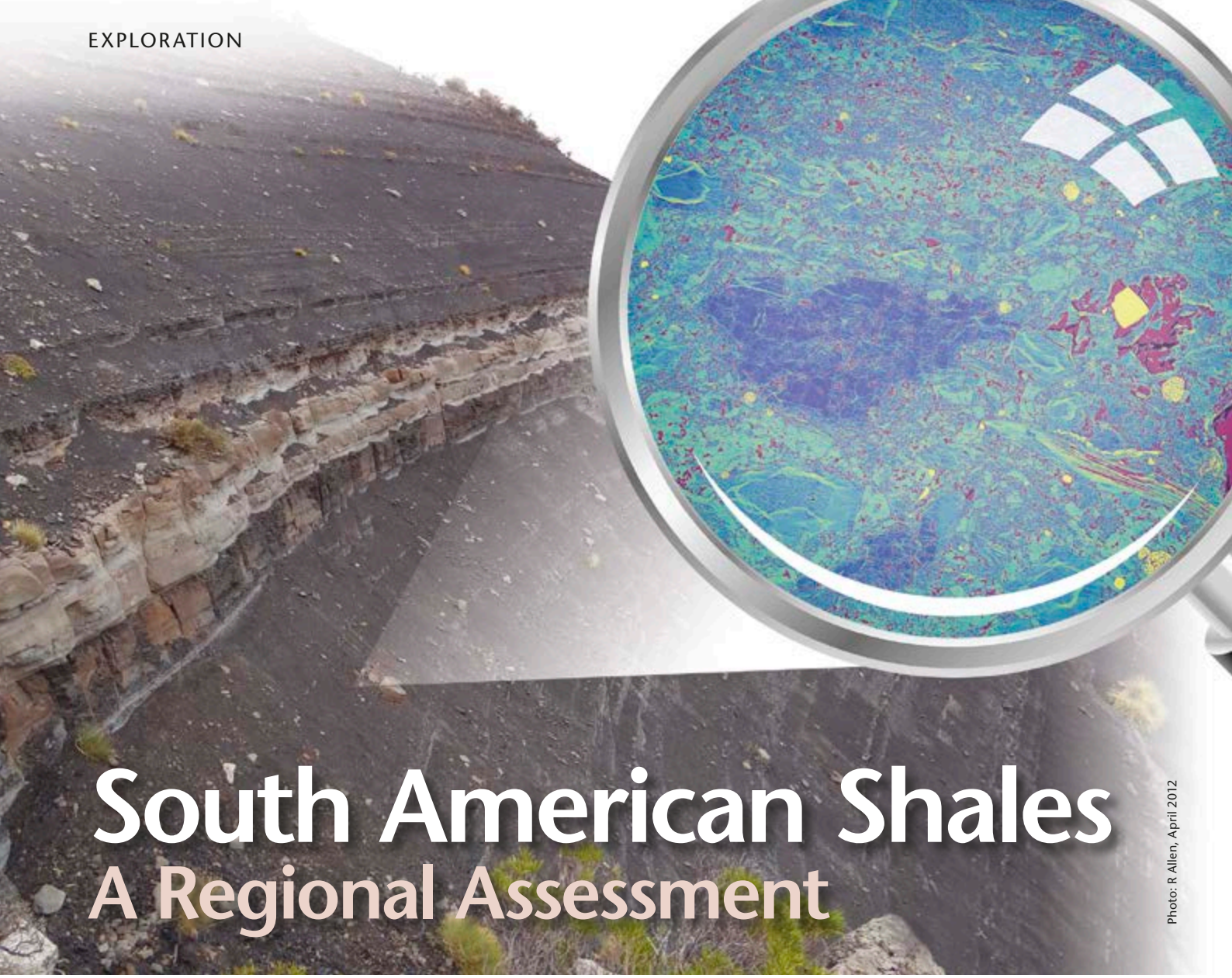


South American Shales
A Regional Assessment

Photo: R Allen, April 2012

Los Molles Formation, Chacay Melehue, NW Neuquén Province, Argentina. Petrologic and geochemical analyses were core aspects of the investigation although all available data related to the evaluation of tight mudstone were gathered.

A history of research in tight mudstone rocks, a long record of research in South America and a significant ArcGIS database of wells, seismic and samples across a number of basins on the continent facilitated research into South American shales potential.

STEVE OSBORNE

Success in the exploitation of gas and liquid hydrocarbons from tight mudstone rocks in North America has spurred interest in and fueled the search for equivalent resources internationally. South America is on the rise as a region that possesses the geological components requisite for shale resource exploration and production. In the past 15 months an assessment of South American basins was undertaken by the Energy and Geoscience Institute (EGI) in a cost-shared partnership with industry associates.

The combined strength of EGI's history of research in tight mudstone rocks, a long record of research in South America and the availability of a significant database of wells, seismic and samples in a number of basins on the continent were the foundation to assess the merit of each basin. Total Organic Carbon content (TOC), maturity, thickness, lithology and kerogen type were the principle criteria used. Onshore and offshore 136 basins were identified, and approximately 200 distinct shale formations defined. Collection and compilation of available data relevant to shale resource potential in concert with the unique expertise of the South American Shales (SAS) team has created an unparalleled and inclusive evaluation.

From the initial assessment, eleven basins (spanning five countries) and 27 shales were selected for evaluation in phase one. Geological aspects of shale potential were the primary discriminator, although other parameter data were collected when available. The geological

review had a strong focus towards geochemical and petrologic data. To target the areas of interest within a basin the core evaluation elements included an analog comparison of what we found in South America compared to what we knew about North America, a comprehensive geological and geophysical review and a multivariate analysis adaptable to each user's set of criteria and risk analysis.

Unconventional Approach

The SAS Phase 1 workflow combined conventional research methods and data gathering with novel techniques, strategic planning, problem solving, and unconventional approaches to better understand an unconventional resource. To facilitate our analysis the ArcGIS library was built to incorporate the majority of parameters that pertain to shale resource evaluation. Data sources include EGI archives, public domain, country/government oil and gas entities and universities. Sample analysis and quantities were subdivided into core, cuttings and outcrops; geochemical analysis; petrology from thin sections, XRD, QEMSCAN®, SEM/FIB and poro-

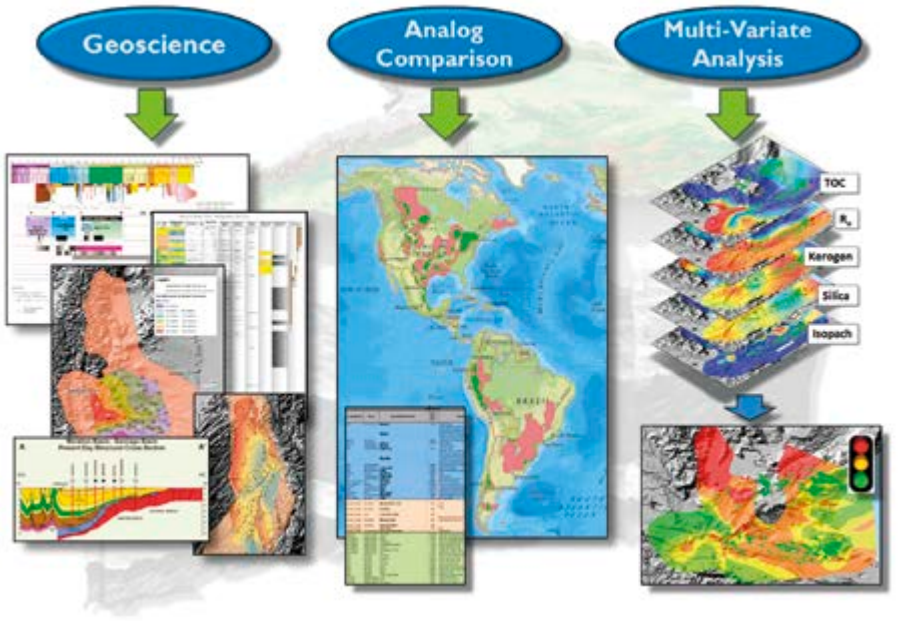
The South American Shale assessment covered 22 shales in 11 sedimentary basins spanning five countries. Also indicated are countries where agreements of cooperation were signed and where EGI has previously completed reports.

perm; seismic; and well logs.

The E&P industry has shown a significant interest in the ArcGIS library aspect of the project. The task of building this dataset is continuing at EGI and we are in the planning stages of developing this tool as an ongoing, self-contained resource for project sponsors.

Geologic Observations

Based on our geoscience evaluations a number of observations can be made regarding the South American shales included in our research. Ages span the entire Phanerozoic time, with some as old as Proterozoic. The global reserve distribution (Ulmishek and Klemme, 1990) shows significant generation/accumulation in the Aptian-Turonian and Upper Jurassic periods and correlates with the occurrence of similar prolific shale/source intervals in South America. An overall correlation between the ages of South American shales and global source rock intervals are recognized and six groupings of shale age are supported by the data. These are Upper Proterozoic, Devonian, Permo-Carboniferous, Triassic-Lower Jurassic, Upper Jurassic-Lower Cretaceous and Aptian-Turonian.



The fundamental delivery of the project was in ArcGIS in which all gathered data were spatially captured.

Where samples were available mineralogy was derived from XRD analyses of shales. Comparing the average South American shale compositions to North American shale average values, a wide range of shale mineralogies are represented, mirroring their North American counterparts. Most shales fall within the 'brittle' quadrants, although some are transitional to ductile.

Hydrocarbon phase includes both gas and liquid phases in most basins. The

Opening Doors: The EGI Approach

The effectiveness of an extensive study of this nature requires collaboration and dexterity on many levels. As a university-based research facility, EGI had the flexibility to forge several unique and synergistic relationships to implement the collection and analysis of a wide range of samples from a diverse group of agencies.

To facilitate the exchange of data, samples, and measurements, agreements were negotiated with various South American governmental agencies and universities. These agreements generally consisted of students collecting and running samples, primarily for XRD analysis. An added benefit for the industry at large is allowing the students to use certain data for inclusion in research projects (subject to confidentiality requirements and approvals). Faculties helped provide thesis and dissertation information otherwise unavailable and also provided consultative assistance.

Four agreements were made with country oil and gas agencies, wherein they provided samples, wells and seismic data and in return EGI provided analytical results and interpretations relative to data received.

The South American Shales team consisted of a 13-member, in-house group of geoscientists and engineers with diverse backgrounds, while data mining, collation, entry and sample analysis were conducted by 12 students. The ArcGIS database was created by three ArcGIS professionals and a student assistant. The cadre of scientists with both diverse and overlapping expertise brought a level of independent assessment to applied research throughout the project. Meetings with EGI research staff and Corporate Associate sponsors ensured the most current concerns and known best practices were being considered and incorporated during each step of the project.

As a research institute, EGI creates a dynamic network including a history of research across South America, in-house researchers, geoscientists from E&P companies, collaborators with specific expertise worldwide, and students enrolled in local and international universities. The full level of expertise reflected in the SAS research project is significant even if difficult to calculate based on effort alone. The value of relationships forged from this project into the future will have long-term benefits for EGI's Corporate Associate members and for future research projects.

The Energy and Geoscience Institute at the University of Utah is the world's largest university based industry cost shared upstream research program. Over 100 scientists and dedicated staff are part of EGI in Salt Lake City, Utah, with an additional 100 Affiliate Scientists worldwide.

Mesozoic foreland basins immediately east of the Andes tend to have immature to oil window maturity profiles, while the basins of the interior craton possessing largely Paleozoic aged rocks range from immature to gas mature. Most of the South American shales contain Type II kerogen, although mixed types involving Type II along with Types I and III are recognized. Representative shales with Type I, II and III are also present.

Analog Comparisons

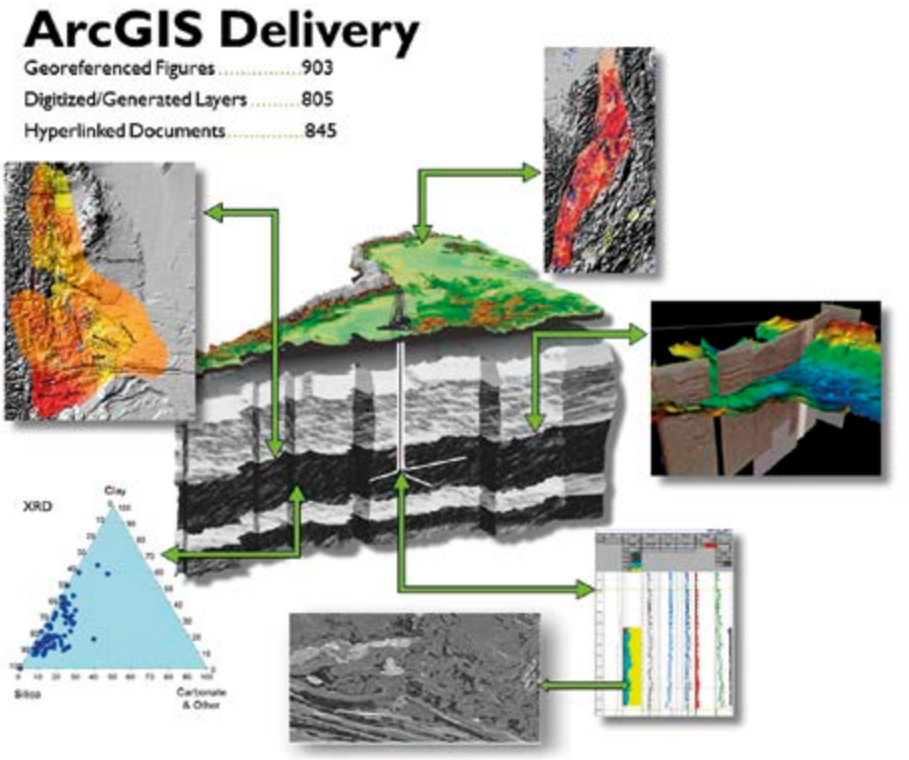
Both United States and Canadian shales were compared to South American shale information. The range of shale basin sizes is comparable between North and South America.

Average gross thickness of both North and South American shales is within the 30m to 200m average thickness range. Maximum thicknesses for individual shales in South America are in some cases greater than the average thickness of shales in North America.

The depth range of shales in South America is generally greater than 2,000m, with maximums up to about 5,000m. The shallowest North American resource shales can be at depths less than 600m, but also are exploited at depths of 1,500 to 4,500m. Given the diversity of basin types and ages and their related sediments it is not surprising that the depth ranges of North and South American shales are expected to envelope a similar range of depths.

Results of the tight rock analysis commissioned by the SAS Phase One research indicates the porosity measurements are in line with average values from North American shales. It is expected that SAS Phase 2 will commence in late 2013 and at that time the examination of more samples will provide more data for evaluation and comparison.

As designed by the SAS Phase 1 project the multivariate analysis can be customized by each sponsor. Considering the diversity of experience, internal database, risking strategies and corporate cultures among EGI's industry members, an iterative system was delivered to facilitate individualized interpretations. Using the multivariate approach, areas of greater interest in each basin can be identified, while areas of little interest can be eliminated.



Core ArcGIS elements of the project include a geoscience analysis, an analog database and a multivariate analysis.

The power of integrating analog, conventional and multivariate approaches to our data library offers a novel approach to shale resource evaluation at EGI. The ArcGIS product delivered for this project is designed to allow rapid access to data at both the basin and individual data points scale.

Shale Research – The Future

Mudstone, siltstone, classic shale, black rocks, mudrocks, unconventionals… no matter the description, tight rock reservoirs with low permeability and porosity are targets of the global energy industry and countries seeking resources to enhance national security and future growth. Deciphering these rocks and reservoirs is a primary focus for the EGI scientific staff.

In conjunction with Corporate Associate members, EGI has completed regional research projects to assess and characterize shales in China, South America, and India and has compared and contrasted them with North American analogs. EGI has examined the geomechanical and reservoir engineering aspects of shale gas systems, liquids from shales and shale gas production analysis, and is embarking on low volume hydraulic fracturing for shales, permeability and relative permeability in shales and improved liquid recovery in shales.

Future success in tight rock reservoirs is dependent on a comprehensive understanding of the relationships of shale characteristics, what priorities govern each basin, region, environment, and how the geomechanical parameters increase or decrease long-term and stable production. The combined strength of EGI's history of research in tight mudstone rocks, a long record of global research and a significant database of wells, seismic and samples worldwide supports a culture that creates applied research and technologies delivered to Corporate Associate members to enhance their ability to produce hydrocarbons from tight reservoirs.

The South American project was sponsored by 25 companies, the largest number of sponsors in EGI's 41-year history. The full Research Report including the ArcGIS element is available in both hard and digital formats to EGI Corporate Associate Sponsors. ■

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Colorful Calgary
A Modern Blend

Calgary, in Alberta, Canada, portrays the cattle and oil industry image of a Dallas with the cosmopolitan feel of a London.

THOMAS SMITH

Beginning as a western Canadian frontier town where the Bow and Elbow Rivers meet, Calgary has emerged as Canada's premier oil and gas headquarters, a booming transportation center, and the third largest city by population in the country. This rise to fame, however, has quite a colorful past.

As the bison herds dwindled across the prairies of the US and Canada from over-hunting, the valuable, high quality furs found along the eastern slopes of the Canadian Rockies became an attraction for fortune hunters. They were followed by, among others, bootleg whiskey traders, and a general lawless chaos resulted, requiring the Northwest Mounted Police to establish Fort Brisebois in 1875, renamed Fort Calgary in 1876. With law and order established, farmers and cattle ranchers soon migrated to the region to take advantage of the expansive fertile, grassy prairie.

A major turning point for early Calgary was the construction of Canada's first transcontinental railroad. Started in 1881 and built to unite the country from the Atlantic to the Pacific oceans, the railroad was instrumental in the settlement and development of Western Canada. Calgary had the unique advantage of being in the path of this transportation corridor due to its location near Kicking Horse Pass, the nearby opening through the formidable Canadian Rocky Mountains. The railroad arrived in 1883 and thus began the city's importance as a supply and transportation hub, sparking floods of early settlers.

The first real setback for Calgary came in 1886 when a great fire engulfed the townsite, burning the wooden structures and destroying most of the town. After the fire, the beautiful brown sandstone mined from the banks of the Bow River became the building material of choice. Calgary became renowned for its sandstone architecture, much of which is still standing today. The 'Sandstone City' continued to grow, reaching a population of 6,000 by 1894 when it was incorporated as a city within what was then the Northwest Territories. Ranching and agriculture were still its mainstay. Between 1896 and 1914, settlers came from all over the world with the offer of free homestead land and the cash crop economy boomed. With a 1,000% increase in population between 1901 and 1911, the city commissioned a town planner, Thomas Mawson, who presented a most ambitious plan for the city's growth in 1914. This was never implemented because Calgary was having severe financial difficulties and the start of World War I made funding even more difficult. Consequently Calgary grew up with many of the problems Mawson predicted, such as urban sprawl and traffic congestion, but did retain some of his influence with the key placement of some government buildings and the preservation of park space.

Energy's Role

While fur trading, cattle ranching and the railroad played an important part in Calgary's economy, the development of the oil and gas industry has been pivotal in forming the city's character.

Archibald W. Dingman, born in Ontario, Canada, played a key role in Calgary's oil history. He came west around 1902 after hearing accounts of oil and gas seeps appearing in the waters of nearby Sheep Creek. He made his way to Calgary and, along with financial partners, formed the Calgary Natural Gas Company. In 1908, Dingman drilled a productive natural gas well on the Col. James Walker Estate within the city of Calgary and laid pipe connecting it to the downtown Calgary Brewing and Malting Company to supply gas for their operations.

In 1914, just prior to the beginning of World War I, an event occurred that would drastically change the future of Calgary – Archibald Dingman and his associates struck gas in the Dingman #1 well in Turner Valley (see *GEO ExPro* Vol. 5, No. 6), approximately 60 km south-west of Calgary. They formed the Calgary Petroleum Products Company and continued to promote Calgary as an oil and gas business center. Oil and gas

Downtown Calgary with the Louise Bridge built in 1921 and the Bow River in the foreground.

Thomas Smith

The Calgary Stampede

In 1884, Calgary had a population of 500 and was incorporated as a town. At that time, the Calgary and District Agricultural Society was formed. The Society purchased land, later named Victoria Park, along the Elbow River and began constructing a race track, cattle sheds, and an exhibition building.

In 1908, Calgary was host to the first Dominion Exhibition where Guy Weadick, a cowboy trick roper and promoter from Rochester, N.Y, performed. By 1912, Mr. Weadick had found financial backing to produce a 'Frontier Days and Cowboy Championship Contest', later known as the Calgary Stampede. The event featured rodeo champions, horse racing, livestock competitions, and an elaborate parade attended not only by 80,000 onlookers, but also the Governor General of Canada, Prince Arthur, Duke of Connaught and his daughter Princess Patricia. The 1912 grand prize was awarded to Tom Three Persons of the Kainai First Nation who won the saddle bronc championship by "riding a horse named Cyclone in dramatic fashion to a standstill". Most major events offered a first prize of $1,000, a saddle, and a gold belt buckle.

The Stampede was cancelled due to World War I, but by 1919 Guy Weadick once again put together the second Calgary Stampede, combining it with the Dominion Exhibition. The Calgary Stampede, also known as 'The Greatest Outdoor Show on Earth' is now a ten-day event held annually in July and has become world famous, attracting up to a million visitors from all over the world.

activity subsequently quietened down mainly due to the war, until 1924 when the Turner Valley Royalite #4 well hit a naptha and natural gas pocket leading to an 'oil craze' that changed Alberta's economic future, with Calgary as Canada's oil capital.

By the 1930s further exploration found crude oil deep beneath the prolific gas fields, eventually resulting in the 1947 discovery at Leduc, south of Edmonton, notifying the world that Alberta would be a major player. World War II was winding down and numerous international oil companies located their head offices in Calgary, attracted by these discoveries. Refineries were built in the city by Imperial Oil and British American Oil and the petroleum industry continued to grow.

The 1973 Arab oil embargo further stimulated the oil and gas economy while Calgary remained Canada's administrative hub of the petroleum business. However, as with many cities so heavily based on the industry, Calgary has suffered from periodic recessions in oil prices, only to re-emerge as a vibrant international energy and financial center.

Modern Calgary

Since the early frontier days, Calgary has evolved into a more diversified economy, although energy remains an integral part of its commercial character. With a metropolitan population of approximately 1.1 million (2011), the downtown area has continued to grow along the banks of the Bow and Elbow Rivers and the city remains a hub for transportation and cargo, both by air and rail. The C-Train was one of the first light rail systems built in Canada and serves a large portion of the downtown commuters. Calgary has matured culturally as well, with a wide variety of festivals, art, and musical performances. The Glenbow Museum, located downtown, is an excellent source of Western Canada's cultural history with an extensive art collection and an archival library, and the city has its own Philharmonic Orchestra, several theater companies, and holds the Calgary International Film Festival annually.

Along with the skyscrapers and bustle of the downtown area, Calgary has become known for its wide array of outdoor and recreational opportunities for both winter and summer activities. With the gorgeous backdrop of the Rocky Mountains, it is surrounded by over 635 km of multi-use pathways, maintained ski trails, and bike paths. Calgary hosted the 1988 Winter Olympics, and the 400m Olympic Oval at the University of Calgary is famous for its outstanding speed skating rink. The city also features an impressive 18 km network of enclosed walkways and bridges, elevated fifteen feet above ground level (called the +15 Skywalk), allowing pedestrians to access many of the downtown buildings regardless of weather.

Banff National Park, located approximately 110 km south-west of Calgary, is Canada's oldest national park. It was established in 1885 and continues to draw visitors from all over the world to its spectacular setting in the Rocky Mountains (see *GEO ExPro,* Vol. 10, No. 2). The modern international airport and Calgary's close proximity to the park and other recreational destinations has made this diverse city a jumping off point for year-round tourism. ■

Originally named the Husky Tower, the iconic Calgary Tower was constructed by Husky Oil and Marathon Realty. It was built in 1967 and 1968 to honor Canada's centennial.

Technology for Virtual Boreholes

Can a technology devised from space exploration help discover hydrocarbon resources?

In the 1980s, Dr. Colin Stove, a researcher at the University of Aberdeen, Scotland, UK, was working on a project run in conjunction with the European Space Agency. Synthetic Aperture Radar signals (SAR) recorded from an aircraft flying above a beach near Aberdeen showed penetration of the signals to depths of several meters rather than the centimeters expected by theory. Similar results were later seen in the Sahara Desert on radar imagery from an instrument carried aboard a Space Shuttle.

Dr. Stove went on to establish a Ground Penetrating Radar (GPR) business. As many geoscientists will know, this technology uses high frequency electromagnetic energy (EM, or radio waves) in the microwave band (gigahertz range) to make images of the shallow subsurface by measuring energy reflections. Penetration depends on the frequencies used for the signal, but even at the lower frequency range, GPR cannot penetrate more than a few tens of meters. Thinking back to the surprising results of the earlier airborne radar work, Dr. Stove believed it would be possible to extend the depth of penetration of ground-borne EM methods, but still using high frequencies to maintain high resolution.

He moved out of GPR and started researching how these technology enhancements could be made. They turned out to be similar to the techniques used for lasers, but in the microwave band (with devices sometimes called masers). Lasers produce EM waves in the visible range as a coherent monochromatic light that does not attenuate significantly over large distances. Masers produce coherent energy at microwave frequencies. When directed at materials such as rocks, at the frequencies used, Dr. Stove determined that the returning signals measured the dielectric properties of a rock and that they could be used to distinguish various rock types and also possibly low dielectric values as seen in hydrocarbons and coals.

Atomic Dielectric Resonance

In the mid-2000s, he formed a commercial company, Adrok, to implement the technology. The name of the company comes from Atomic Dielectric Resonance, ADR, the excitation set up inside the atoms of materials stimulated by the maser sources used for the technology. Dr. Stove's son, Gordon, followed in his father's footsteps and is now Managing Director of the company.

Dr. Stove's objectives were to make measurements at much greater depths than GPR, up to the kilometers needed in hydrocarbon exploration. ADR techniques had already been used in the medical industry for very shallow tissue investigation. But ADR also uses higher frequencies than GPR, so how could it beat the tens of meters depth that were the best that GPR could manage?

Carrying out mineral exploration surveys on frozen lakes in Canada and the Arctic Circle

The answer seems to be in the maser-like nature of the source, together with other enhancements, as Gordon Stove explains: "We send a directional beam of multiple radio frequencies into the ground

The Adrok technology is highly portable

AdROK

at very low power," he says. "The beam is continually pulsing and has resonant waves inside a large carrier wave that acts as a standing wave… By using low power and a directional, coherent beam, Adrok has overcome attenuation issues." The beams are also focused. "Our beams are set up to triangulate to a focal point in the ground, converging with depth, unlike other geophysical techniques where the signal is omnidirectional and widens with depth."

Early tests of the technology in Scotland indicated that hundreds of meters of penetration should be possible. One thing that is necessary with the technique is that the measured signals are calibrated against known boreholes. As different rocks give distinctive signals that can change depending on, for instance, cementation or pore fluids, profiles are first measured at existing well sites before moving on to undrilled locations. Signals measured from cores on site or in the lab can improve the calibration. Further tests for BG Group onshore UK indicated there is potential to detect coals for coal bed methane (CBM) or organic materials in shales.

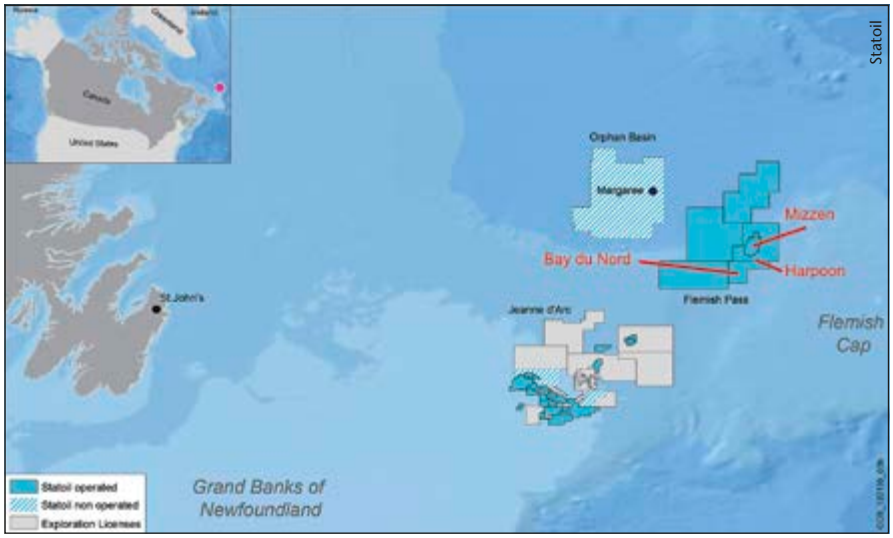
Accurate Predictions

Adrok has also conducted surveys in other countries. In a survey of wildcat locations in Morocco conducted for Caithness Petroleum, 'blind' predictions made by the company using these techniques appeared to be more accurate than the prognosis for gas made by conventional seismic-based techniques. Robert Kennedy of Caithness says: "Adrok carried out ADR surveys on four locations where (we) knew the results but Adrok did not. They successfully identified stratigraphy and gas-bearing zones within 1.5m depth of each well. Over an undrilled prospect (they) identified seven gas zones at depths between 500m and 700m, to within a meter of forecast depth."

Other Caithness results indicate the possibility of mapping stratigraphy to depths of 4,000m. In a well drilled by Caithness' American partners onshore USA, where gas-bearing sandstones were expected at about 2,300m, Kennedy says "a commercial gas discovery was made at a depth within 0.3% of the Adrok forecast".

Adrok has carried out surveys in many other locations and is working on implementing the technology offshore. ■

CANADA: Statoil success points to core exploration area



While much detail has yet to be revealed, Statoil is evaluating its newfield wildcat Harpoon O-85, located in the deepwater Flemish Pass sub-basin (Grand Banks Basin) offshore Newfoundland, which it describes as a high quality oil discovery. The Harpoon well was drilled in a water depth of 1,100m at the far northern edge of block EL 1112, and 21.3 km south-south-east of the Mizzen O-16 oil discovery. This latter is estimated to hold between 100 and 200 MMbo.

Further appraisal drilling to mature the discovery is scheduled, as Statoil plans to build up this area as a core exploration region. According to Erik Finnstrom, senior vice president for Statoil in North America, it is too early to determine Harpoon's resource potential but the result is very encouraging for the area and especially for the Bay du Nord prospect. Bay du Nord C-78 on EL 1112 is currently being drilled in 1,150m of water, targeting a tilted fault block with an objective in an Upper Jurassic age Tithonian sandstone.

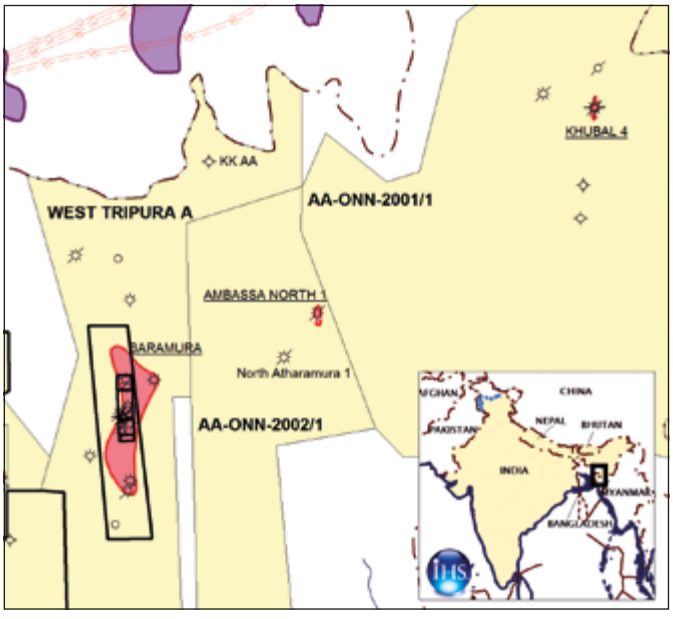
The basin is a high-risk, high-reward exploration area that is mainly unexplored, but which contains very large, undrilled faulted anticlines. Prior to the Mizzen O-16 discovery, only two exploration wells and one delineation had been drilled during the past decade in the basin. The Mizzen discovery does not have enough recoverable oil to make production viable in the Flemish Pass but if Bay du Nord comes in, Statoil believes the finds are close enough together to give significant synergies. Such an outcome would move the company closer to achieving the goal of becoming a producing operator off Canada's east coast. There is some confidence, as Finnstrom said the work the company has done so far "has pointed in the direction of a large petroleum system in the basin, not just an isolated limited system around Mizzen." ■

INDIA: Deeper objectives success for Jubilant

North Atharamura 1, the second exploratory well of the two well Phase-II minimum work program for the AA-ONN-2002/1 (Assam Shelf) onshore block, is ranked an important discovery by operator Jubilant Oil and Gas. Drilled to a total depth of 3,400m, two intervals were tested in the Miocene Bhuban Formation. The first test, conducted between 2,186m and 2,191m in Lower Bhuban Formation sandstones, flowed 3.2 to 3.8 MMcfgpd through a 32/64" choke. The second test, between 610–625m in Middle Bhuban Formation sandstones, flowed 1.7 MMcfgpd through a 24/64" choke. This is a significant result as the well targeted the hydrocarbon potential of the supra-thrust Middle Bhuban and Lower Bhuban sands and sub-thrust Lower Bhuban, Renji and Jenam sands and as such is the first exploratory well in the block targeting deeper objectives beyond the Middle Bhuban in the Atharamura anticline. Jubilant has identified significant exploration upside in this onshore block, including six leads with gross unrisked best estimates resources ranging from 82 Bcf to 1.4 Tcf. Jubilant holds a 20% participating interest in the block through its subsidiary Jubilant Oil and Gas Private Ltd., India, which is also the operator; GAIL India Ltd. holds the remaining 80%.

The Atharamura anticline is in Tripura state in north-east India and is bordered by Bangladesh to the north, south, and west, with the Indian tate of Assam to the east.

India is considering several options in its desire to boost gas production, and the urgency of the situation has been underlined by Oil Minister M. Veerrappa Moily, who has forecast a 5.7% decline in natural gas production in the year through March 2014 to 3.7 Tcf of gas a day. India's falling gas production has badly hit consuming industries such as power and fertilizers. ■



CONGO:
Major reserve boost

While Eni has so far declined to issue flow rates, the company believes it has made an important oil and gas discovery, having drilled two wells on the Nene Marine exploration prospect in the Marine XII Block, approximately 17 km from the coast. The company estimates the volume of the discovery proved so far to be around 600 MMbo, and 700 Bcf of gas in place. Perhaps more significantly, it has identified considerable additional upside that will be evaluated with further delineation wells.

The discovery was originally made through the Nene Marine 1 wildcat, which was drilled in 24m of water to a depth of 3,013m and abandoned in July 2012. The well encountered a significant wet gas and light oil accumulation in the pre-saline clastic sequence of Lower Cretaceous age. Nene Marine 2 was drilled two kilometers away from the discovery well and confirmed the significant hydrocarbon accumulation and the continuity of the reservoir. During production tests both the wells flowed commercial rates of 37° API oil. Eni operates Marine XII with a 65% interest and is partnered by New Age (Africa Global Energy) 25% and Société Nationale des Pétroles du Congo 10%.

The award to Eni of the Marine XII permit is part of an integrated project to develop the gas pote ntial of the country and guarantee the supply of 90,000 Mcfpd of gas over a 20-year period to a 300-450 MW gas-fired power plant near the Djeno terminal, as specified in a protocol agreement with Eni signed on May 17, 2006. The integrated project calls for total reserves of 700 Bcf and 20 MMb of condensate. ■

An Eni rig drilling in Congolese waters.

BGP – A Fast-Growing Company

BGP Inc., China National Petroleum Corporation is one of the world's leading geophysical service companies and undertakes more land-based geophysical surveys worldwide than any other company in the industry. We talk to **Mr. Zheng Huasheng**, Vice President of BGP, about the growth and aims of this exciting organization.

What is the history of the company?
BGP started in 1961 with 15 crews and soon became the largest geophysical services company in China focused on land acquisition, building the first data processing center in China in 1973. The company is state-owned, but is an independent legal entity.

We started working with major international companies like ESSO, AGIP and BP in the early 1990s. We learnt a lot from them and eventually began to move out of China, being awarded our first international contract in Ecuador in 1994. Over the past 20 years, BGP has been developing very fast and now is the largest land geophysical service contractor and has provided its services to more than 200 oil and gas companies. By working with these companies, and with more recent developments such as INOVA, our joint venture with ION Geophysical, we have built up our expertise and confidence so we can now work very successfully across countries and across cultures.

What prompted this move abroad?
By the 1990s China's new 'open door' policy meant that international companies were vying with existing Chinese companies, so there was overcapacity in the seismic market in China. We felt it was time to expand abroad.

What countries are BGP working in?
All over the world! Since moving into the international field we developed very fast and we are now in 51 countries worldwide, including Africa, the Middle East, South America, and Central and South East Asia, and we have offices in Houston and London. At the moment, we have 65 land crews and six seismic vessels operating in more than 40 countries overseas. We offer the full range of geophysical services, from seismic acquisition onshore and offshore and a wide range of processing techniques, to interpretation supported by powerful software packages, as well as the IT capability required to deliver these services.

We have undertaken projects for many different international companies, including NOCs like Saudi Aramco, Petroleum Development Oman and National Iranian Oil Company, and for majors like Shell, ENI and ExxonMobil. BGP has deep roots in China, but now more than 70% of our clients are from outside the country.

How many people work for the company ?
I think over 20,000 people are employed directly by BGP, but many more work indirectly, as we prefer to use local people as much as possible in our overseas operations. The BGP management has always believed that it is important to employ good local staff wherever possible, so we try to attract talented people worldwide. This is particularly true for the younger generation.

Over the past two decades we have established a massive training program, not just for the mid- to upper-level employees as tended to happen in the past, but throughout the company. We have also focused on our non-Chinese employees, as we are now a major international company. We have many training centers, including seven outside China, as we believe it is important to attract talented people worldwide.

What do the initials BGP stand for?
Bureau of Geophysical Prospecting.

What next for BGP?
We are very strong on land, so our long-term strategy is to increase our capability in the offshore and transition zone, as well as in services such as reservoir engineering. We are focusing strongly on technology and are undertaking a lot of R&D projects, with the aim of providing the best possible service to the industry.

What is special about BGP?
BGP has a unique culture; it is very stable, with 80% of the employees working for the company for their whole life. I have enjoyed growing with this company and watching it grow in turn to become so successful; it is great to be part of that. I have full confidence in BGP going forward.

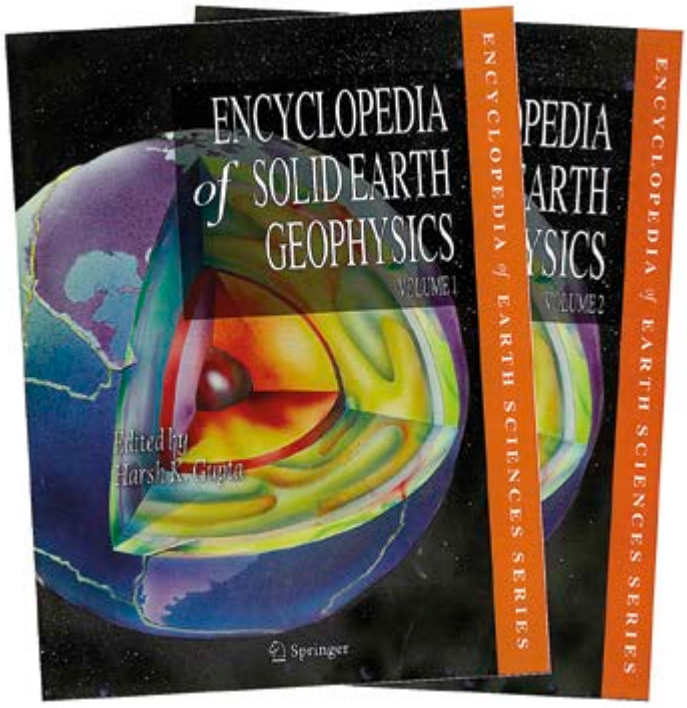

BGP

Zheng Huasheng is an accountant with a BSc from Henan Finance Institute and an MBA from the University of Calgary. He has worked for BGP since 1994 in a variety of financial and managerial roles both in China and internationally.

All About Geophysics

A new ambitious encyclopedia has covered no less than the entire field of geophysics

Encyclopedia of Solid Earth Geophysics
Editor: Gupta, Harsh K. (Springer, 2011)



Geophysics is the application of physics in geological sciences, and as such it is a vast science – or in fact, a collection of many disciplines, with both pure science and applied aspects. Specialty fields in geophysics are so advanced today that one person cannot claim to be an all-inclusive geophysicist but rather an acquisition seismologist, a paleomagnetist, or a uranium-lead geochronologist, and so forth. This state of affairs has both pros and cons. It is good, because it shows the tremendous progress made in the geophysical sciences and technology. Bad for the same reasons: geophysics has become highly disintegrated and remotely distant from the grasp of a single researcher. This state of affairs, which is true for all sciences, calls for bridges between the various disciplines of science, and in-depth encyclopedias play a crucial role.

The *Encyclopedia of Solid Earth Geophysics*, published recently by Springer, nicely brings together numerous geophysical topics and presents this sometimes dry, mathematical and abstract field in a language comprehendible to researchers, teachers, students, and professional geophysicists. The term 'solid earth' in the title indicates that the geophysics of the fluid earth (the atmosphere and oceans) is not included in this encyclopedia, and those fields aptly deserve their own separate volumes.

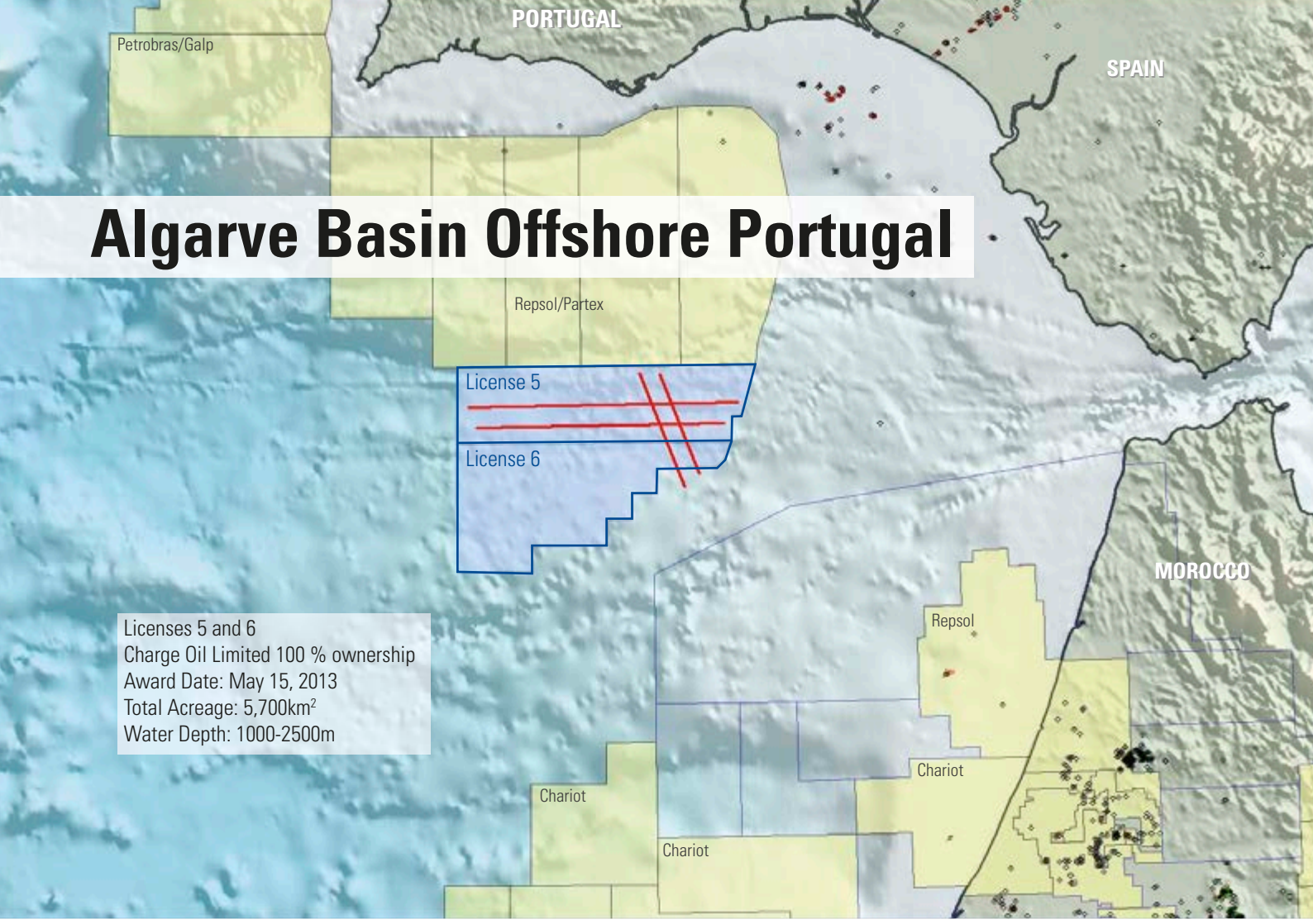
Gravity and seismic surveys were employed in the oil industry as early as the 1920s, and oil exploration has long been associated with geophysics. Nevertheless, what particularly accelerated research in geophysics was the International Geophysical Year in 1957-58. One of the fruits of this international venture was the publication of the two-volume *International Dictionary of Geophysics*, edited by S. K. Runcorn (Pergamon Press, 1967), long out of print but still a useful reference book to have on the shelf. Another classic reference book in this field is Robert Sheriff's Encyclopedic Dictionary of Applied Geophysics, published by the Society of Petroleum Engineers (fourth edition, 2002).

In the mid-1960s the Australian geologist Rhodes W. Fairbridge (1914-2006), who at the time taught at Columbia University, started an ambitious project: editing a series of encyclopedias in various branches of earth science. The first volume, on oceanography, was published by Reinhold Company in 1966. Fairbridge continued to edit two dozen other volumes. The Encyclopedia of Earth Sciences series changed hands from one publisher to another until Springer took over and modernized the whole operation, publishing both print and electronic volumes. Charles Finkl is the editor of the new series.

In 1989, when Van Nostrand Reinhold was still the publisher, *The Encyclopedia of Solid Earth Geophysics* (volume 16 in the series), edited by David James, came out. It was a massive work of over 1,300 pages. But that was more than two decades ago, so Springer has now brought out a new version. The latest *Encyclopedia of Solid Earth Geophysics*, in two volumes and over 1,500 pages, was edited by Dr. Harsh K. Gupta, a renowned geophysicist from India who was the former director of the National Geophysical Research Institute in Hyderabad and is currently the president of the Geological Society of India and the International Union of Geodesy and Geophysics. This encyclopedia (volume 38 in the series) contains 217 articles on entries from 'absolute age determination' to 'wavelet analysis,' written by 287 authors from around the world. Eight renowned geophysicists have also served on the editorial board of the encyclopedia. The result of this impressive team work is thus an up-to-date, authoritative reference book on geophysics that will be used by many libraries and individuals for years to come.

Given that the entire oil and gas industry depends on geophysical science and technology, the new encyclopedia should be of great interest to petroleum explorers, researchers and educators as well. Indeed more than one-fourth of the Encyclopedia is devoted to seismic theory and techniques. Other geophysical methods are also covered and new topics such as GPS geodesy and tsunami warning are also included. A list of references at the end of each article directs the interested reader for further research. ■

RASOUL SORKHABI Ph.D.



Algarve Basin Offshore Portugal

Licenses 5 and 6
Charge Oil Limited 100 % ownership
Award Date: May 15, 2013
Total Acreage: 5,700km^2
Water Depth: 1000-2500m

Conjugate margin opportunity on trend with recent exploration activity offshore Morocco following a surge of activity in the Atlantic "sister" basin Nova Scotia, Canada.

Charge Oil Limited is looking for partners to participate in Licenses 5 & 6 offshore Portugal, Algarve Basin.

Licenses 5 & 6 bordered by Repsol/Partex acreage to the north and Moroccan exploration discoveries to the south offer significant existing potential in the pre-salt and pre-allochthonous unit plays within the Atlantic margin.

Newly acquired 2D broadband data is a step change to improved imaging of structural trends below the historically challenging Guadalquivir Allochthon units.

The data will be available for review at 'The 12th PESGB/HGS Conference on African E&P' at Wembley Stadium, London from 11th-12th September 2013 and also the Marrakech Oil & Gas Conference from 1st-3rd October 2013.

Further information is available upon request: Contact Number: +441932376463

A Golden Age for Gas?

Will shale gas be a game changer for Brazil?

KEN WHITE

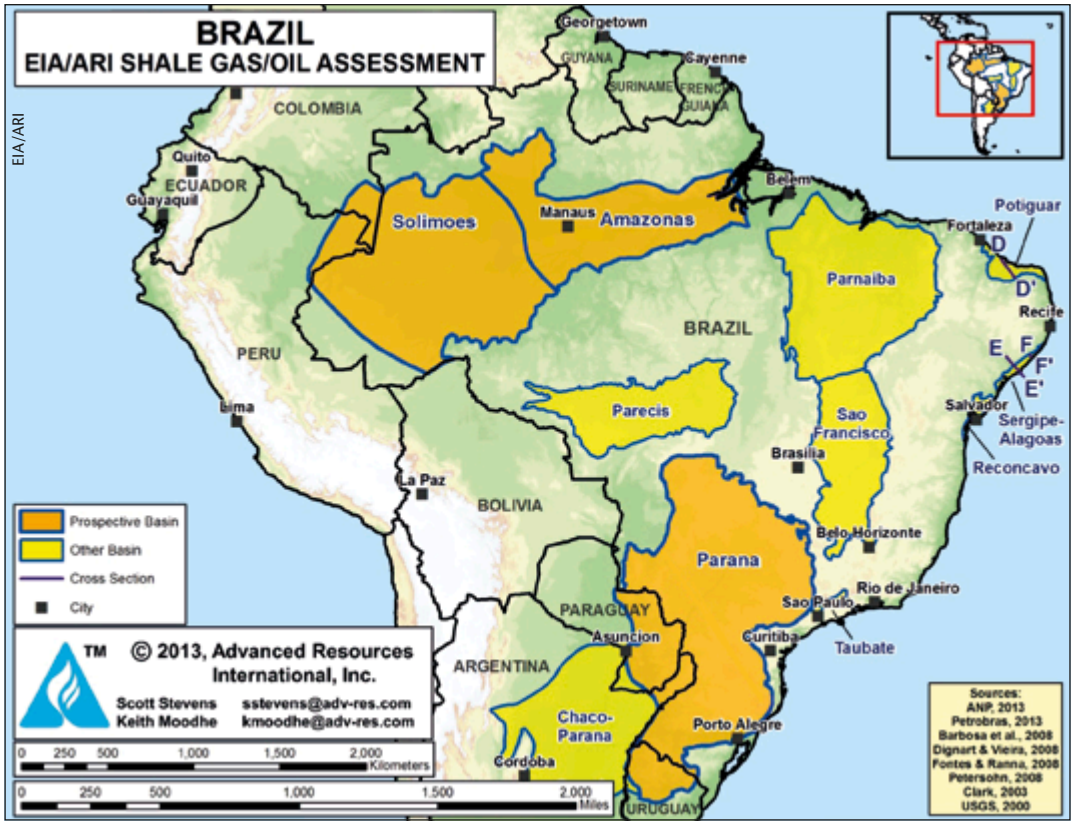
At the 2012 Rio Oil and Gas Conference it was revealed that the ANP had commenced a survey of Brazil's shale and tight gas potential in three prospective basins (Parecis, Parnaiba and Reconcavo), which has pointed to a resource potential of 204 Tcf of gas. However, many analysts have predicted that the country's true shale gas potential is much bigger, and have called for a more dedicated exploration campaign to assess the resource. Even without the ANP's suggestions that Brazil may have almost twice as much natural gas onshore as is currently estimated, the industry was positioning itself for a positive response to ANP Round 12, the first-ever auction of shale-gas acreage in the country. The ANP Round 12, the Unconventional Bid Round, will comprise 240 blocks in seven basins and will be held on November 28 and 29, 2013. There are 110 blocks covering 164,477 km^2 located in the Acre, Parana, Parecis, Parnaiba, and Sao Francisco Basins, and 130 blocks covering 3,870 km^2 in the mature Reconcavo and Sergipe-Alagoas Basins.

The government is keen to determine whether shale gas will really become the game-changer that some analysts predict. To this end it has demonstrated its desire to provide an appropriate fiscal environment for the production of unconventional gas. While there are no guarantees that natural gas prices will ever rise high enough to adequately compensate for the high costs, financial risk, and extended development periods, international players are responding to the challenge with over 40 companies allegedly expressing an interest, perhaps encouraged by the energy minister's promise of a 'golden age for gas'.

Challenges Ahead

For all its promise and large resource potential, however, Brazil's shale sector faces a number of challenges if unconventional exploration and production are to push ahead. The state has so far carried out minimal analysis on the country's true shale potential. Resources therefore need to be treated with caution, as to date there has been no shale exploration in Brazil and even if the country's unconventional resource potential were to be proven, there are a number of obstacles to be overcome. The remoteness of basins with shale potential hints at significant additional investment in transportation to bring gas from these regions to the domestic market. Policymakers are yet to crystalize views on issues such as specific regulations to govern unconventional gas exploration and production, the offer of fiscal incentives to reflect the higher costs of developing unconventional hydrocarbons, or more flexibility on local content requirements. All of which could help convert interested companies to committed investors. Another consideration is potentially strong opposition from environmental and indigenous groups in environmentally sensitive areas such as the Amazon River Basin.

None of this is likely to prevent the planned Unconventional Bid Round from proceeding as the ANP considers that geological studies by companies that are awarded blocks to be essential for a better understanding of the country's shale resource potential. ■



The true potential for shale gas in Brazil has yet to be evaluated.

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Reserves – What Do We Mean?

The term 'reserve' is often misused, and oil companies need to improve their efforts in reporting their numbers.

The total estimated amount of hydrocarbons in a reservoir, including both producible and non-producible oil, is called STOOIP (stock tank oil originally in place), or 'in place' for short. However, only a fraction of this oil (from less than 10% to more than 70%, in extreme cases) or gas can be produced, and it is only this producible fraction that is considered 'reserves'.

"Reserves are future production," says Mahmood Akbar. Akbar, of Norwegian company AGR, has specialized in advising oil companies on how to calculate and report their resource base, a matter that is certainly not always straightforward. "My impression is that many oil companies do not have the necessary focus on their reserves. It is important that one person has the responsibility, and that the results are presented in a way such that everybody can understand them easily," he says.

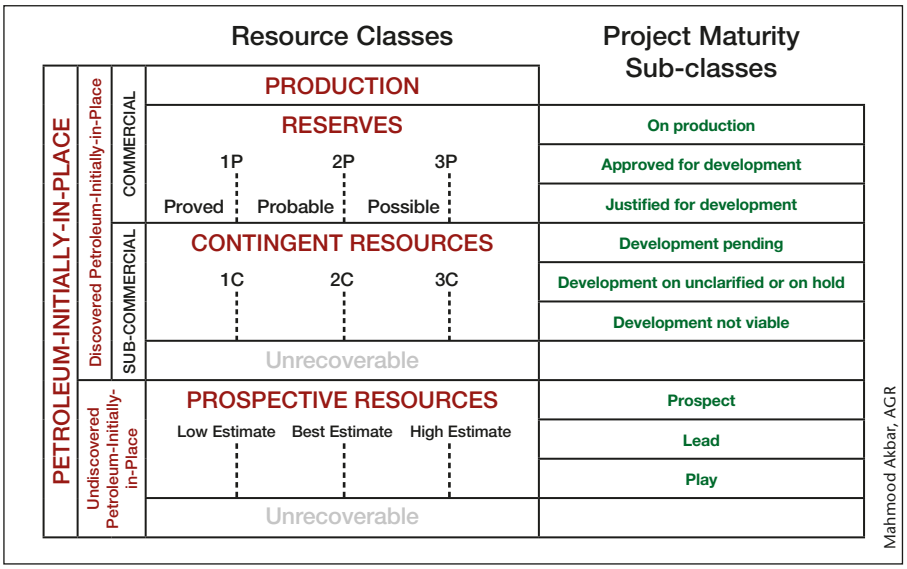
The most widely used classification system was developed by the Society of Petroleum Engineers (SPE), and this is the system that Akbar recommends. It distinguishes between Resource Classes and Project Maturity Sub-classes. As can be seen from the diagram, we can only talk about reserves when a decision has been made to develop a find – and then, depending upon the amount of information the companies have about the reservoir and the production, they should distinguish between **Proved** (low case, P1 or P90), **Probable** (medium case, P2 or P50) and **Possible** (high case, P3 or P10).

The reserve estimate is thus never a fixed number. It changes through time, as uncertainty is reduced, following the information stream from appraisal and production. Probable and possible reserves may thus be converted into proved reserves over time as the uncertainty around remaining recoverable reserves is reduced. This is also called **reserves growth**.

Supermajor BP uses this definition for **proved reserves**: "The estimated quantities of oil which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under current economic and operating conditions." BP also uses the term **ultimately recoverable resources** (URR). This is the total amount of oil that will ever be recovered and produced – a function of knowledge, technology and economics. ■

HALFDAN CARSTENS

The SPE's classification system for reserves and resources is the one most used. The system distinguishes between prospective resources, contingent resources (contingent upon for example oil price) and reserves.



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.

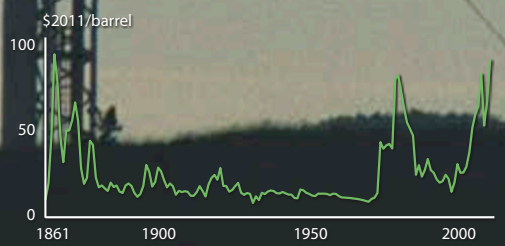
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

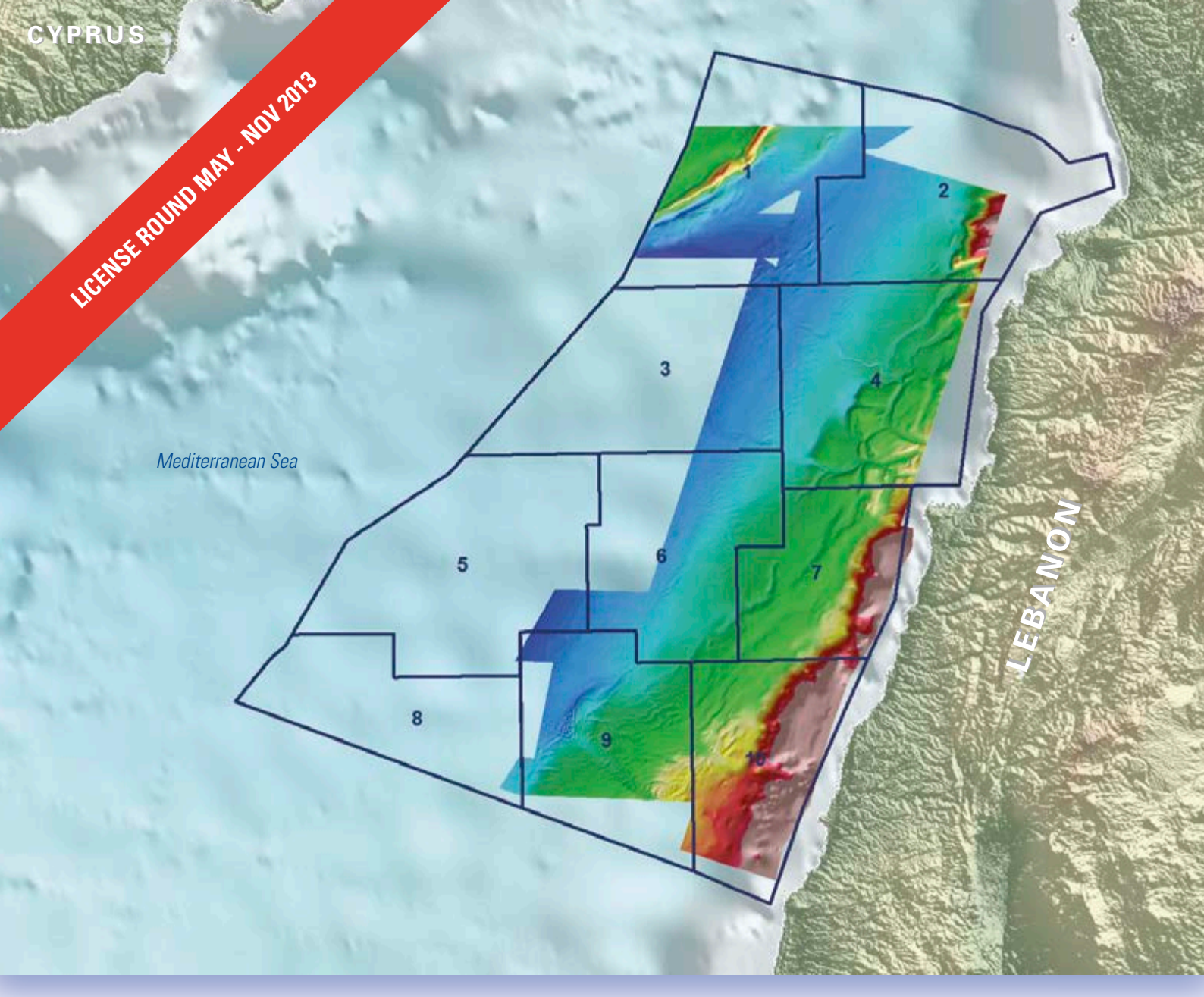
Supergiant field
Recoverable reserves > 5 billion barrels (800 million Sm^3) of oil equivalents

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





PGS MultiClient MIDDLE EAST & CIS

GeoStreamer® data ready for Lebanon License Round

The Lebanese Republic recently announced important dates for their 1st Offshore License Round.

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, the most recent survey in February 2013.

All data will be available for the license round, for more information go to www.lebanon-exploration.com

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

Supporting your exploration success

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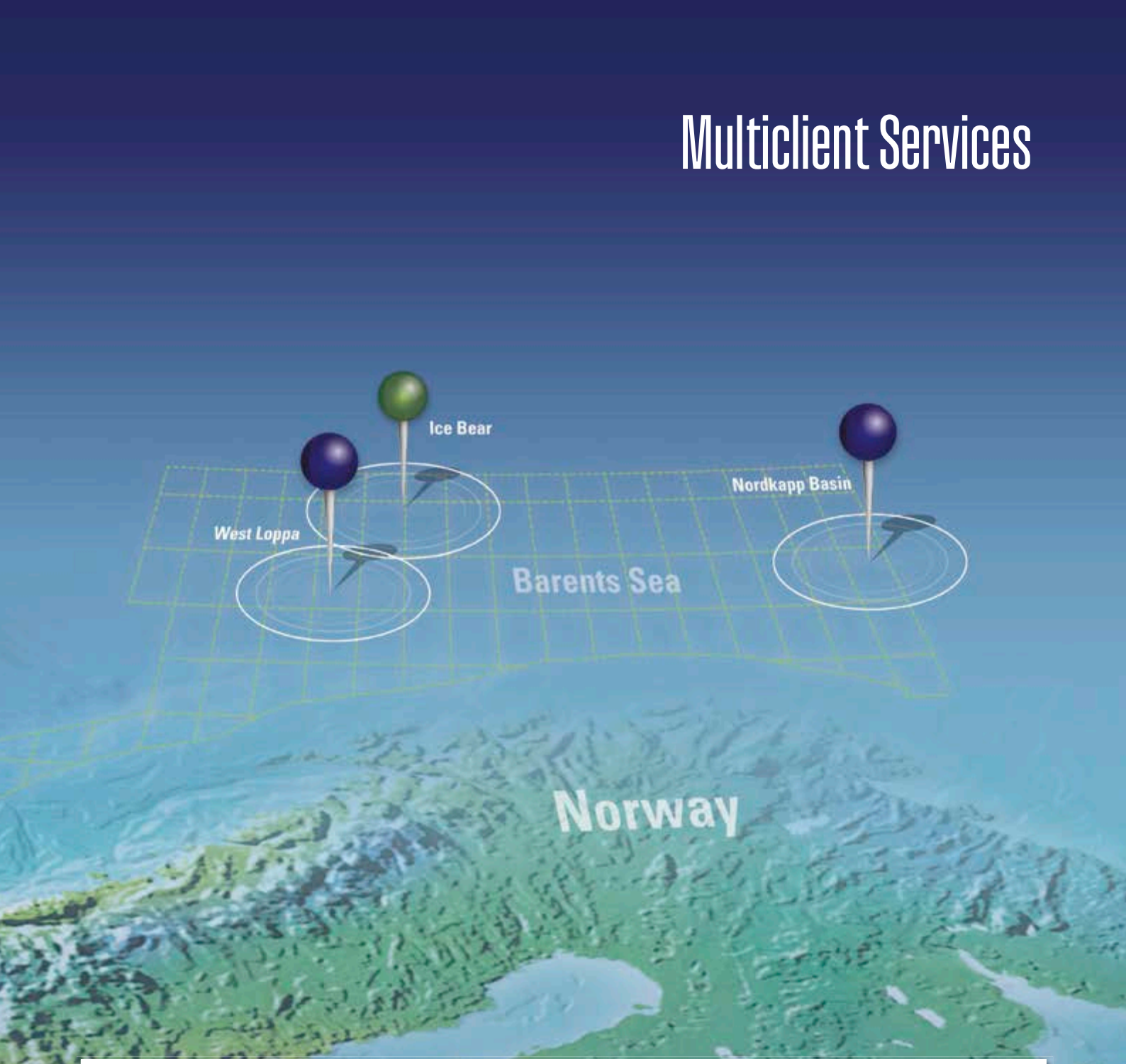

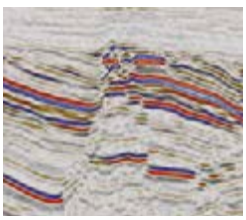

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