GEO ExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED
Vol. 5, No. 4 - 2008
www.geoexpro.com

Geotourism: Rio de Janeiro

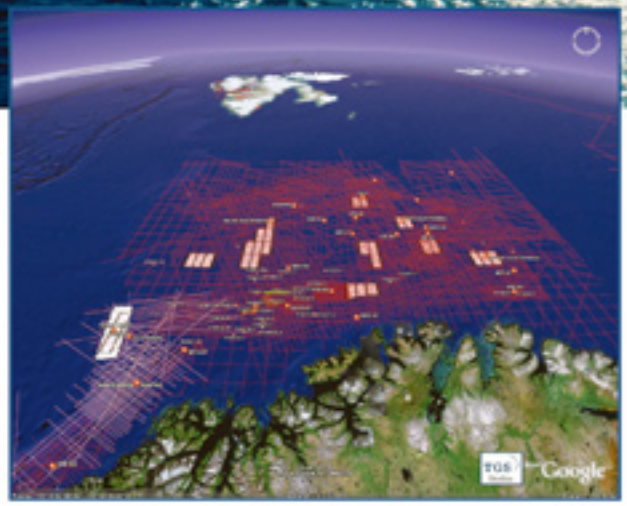
Angola:
Beautiful Beaches – Excellent Petroleum Potential

Improving Well-bore Stability in Fractured Formations

GEOLOGY GEOPHYSICS RESERVOIR MANAGEMENT

20th Round Blocks

Norway



As seen on Google Earth

TGS is pleased to present all our relevant data for the 20th Round in Norway on Google Earth.

New 2008
- 3D, 1540 sqkm in Troms III
- EM, 4 prospects in the Barents Sea

Existing Data
- 2D and 3D
- EM
- Studies & Reports

Make sure you have Google Earth and our Data Library at http:/products.tgsnopec.no installed on your PC before you open the kmz-file containing the 20th Round information.

Products and projects are organized in folders and can be selected and viewed individually.

When exiting, be sure to save your *Temporary Places*. TGS will keep the Data Library updated for you!

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GEO ExPro
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Columns

Features

18

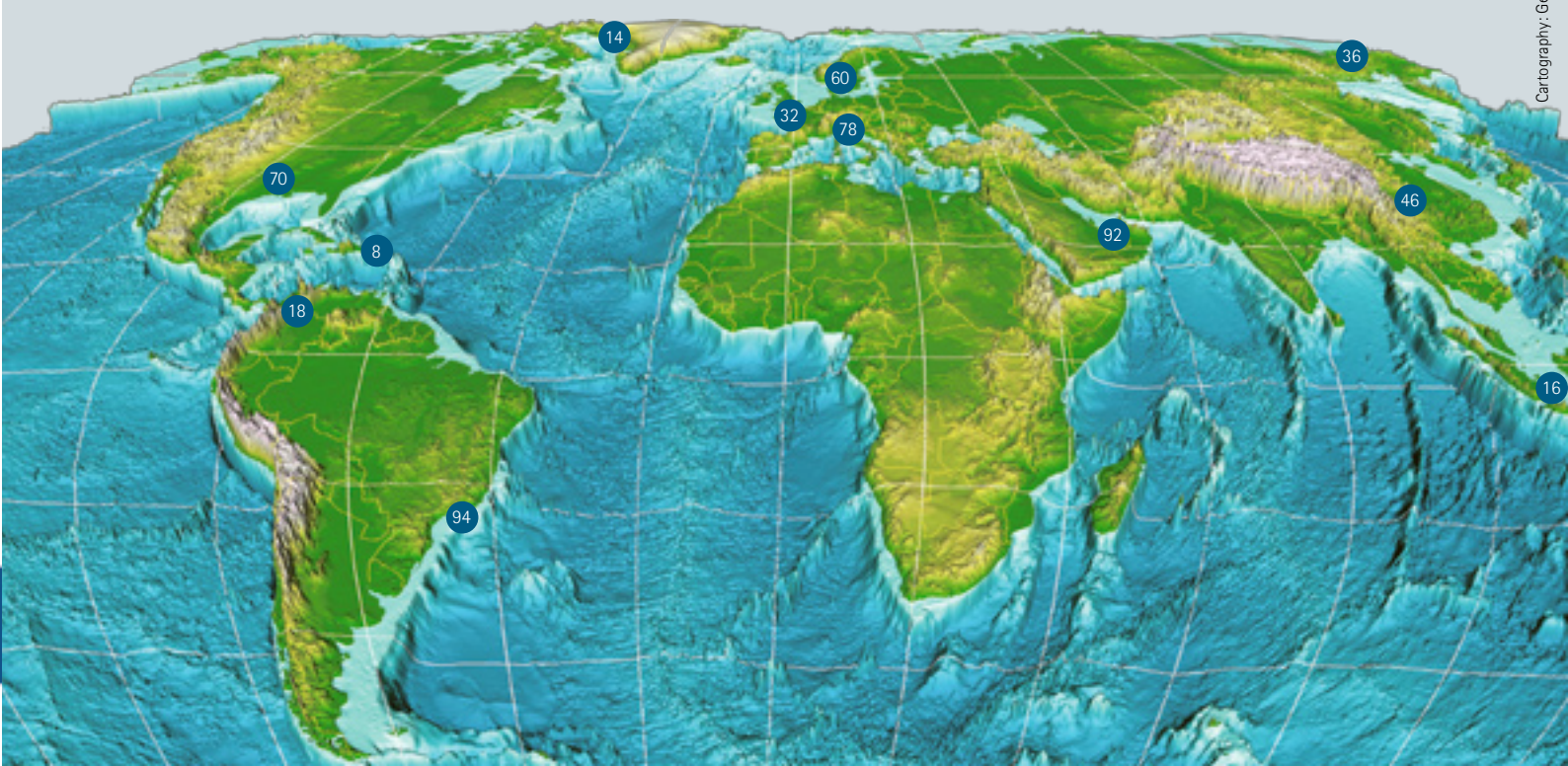
Company Profile: StatoilHydro

StatoilHydro has grown into a major player in Angola. With more than 200,000 barrels of oil produced every single day, and having assisted Sonangol to become an operator, the time is now right to take the next step. With strong support from the head office back in Norway, StatoilHydro is ready to take on operatorship in Angola.

74

Geotourism

Gateway to huge offshore oil reserves, Rio de Janeiro and southeast Brazil offers stunning scenery and geologic evidence of ancient mountains and the forces that spawned two continents.



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"The Great Global Biofuel Swindle"

It's too bad. But it's happening. Partly because of a massive marketing campaign instigated by a multitude of environmental organisations (the "green mafia"), endorsed by several governmental bodies around the world, biofuels are taking an ever larger share of the huge energy market.

As of 2008, biofuels make up as much as 1.6% of oil products consumed globally. In five year's time biofuel production may have reached 3.5% of global demand, and there are ambitions to bring production up to 16 million bopd by 2050. In other words, **the biofuel industry is growing tremendously fast, a lot faster than the conventional oil industry,** and the biofuel lobby is getting invaluable support from the self proclaimed "environmentalists". One day they will wake up and realise that they have – contrary to what they say they are fighting for – contributed to the increased output of greenhouse gases. But by then it may be too late. It's too bad.

Fertile soil is now being used for making gasoline instead of growing food in countries like Brazil, Indonesia and the USA. Huge rain forests are being cut down and vast fields are cleared to make room for growing maize, sugar, soya beans and other agricultural products that can be converted to (heavily subsidised) hydrocarbons.

The result is more expensive food and, as it turns out, increased (!) release of CO_2 to the atmosphere compared to conventional hydrocarbons. **That is what I call an "inconvenient truth".** Now it is also being termed "the great biofuel swindle".

The subject of biofuels was discussed at the recent 33rd International Geological Congress held in Oslo in August. Professor Marian Reatezki of the University of Luleå, Sweden, gave a very interesting keynote speech that ought to be read and understood by everybody concerned with our future energy mix. He clearly stated that "biofuel is not an appropriate solution" – and presented good arguments supporting his case.

"The current drive for biofuels cannot be justified, either on economic or environmental grounds," concluded Professor Marian Reatezki. We certainly agree, and the trouble is, the biofuel swindle is to a large extent sponsored by so-called environmentalists who have on their main agenda the liquidation of the oil industry. They will instead make an important contribution towards the liquidation of a sustainable future.

Halfdan Carstens
Editor in Chief

Angola – Moving Forward

Since the signing of the peace protocol in April 2002 between the Government and the rebel movement UNITA, a durable peace has taken hold in Angola. Several decades of war ravaged much of the economy outside the oil sector and destroyed much of its infrastructure. The human and social consequences were also enormous

Angola happens to be one of the richest countries in Africa in terms of natural resources, particularly oil, hydropower and minerals. It also has a favourable climate and fertile soil. Nevertheless Angola has been facing the daunting tasks of removing thousands of landmines, rebuilding and developing its infrastructure; roads, railways, airports, power and water, schools and hospitals, in order to create an environment for economic and social development and national reconciliation.

In ten years, Angola's oil production has more than doubled, from 740,000 bopd in 1991 to 1.7 MMbopd in 2007. In fact, it has doubled since 2003, i.e. in only four years.

With daily production in excess of 200,000 barrels of oil per day, representing more than 10 percent of the country's total daily output, Angola is by far StatoilHydro's largest producing asset internationally. StatoilHydro is the largest non-operator in Angola, and among the 7 dominant oil producing companies – including Sonangol.

In this edition of GEO ExPro we take a look at StatoilHydro's presence in a country with a bright future, possibly including pre-salt plays.

Photo: Halfdan Carstens

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Plenty of oil – production capacity is constrained

"Forecasting future energy mix is as difficult as forecasting future climate." That sounds like a true English understatement.

Dr Mark Moody-Stuart emphasized during his StatoilHydro lecture given at the 33rd International Geological Congress that the energy industry is crying out for technical people. Where are all the youngsters? Sad to say, the audience was dominated by men with grey hair.

"The future energy mix is more dependent on humans, because apart from the resource constraints and the technological constraints, that are both movable, it is dependent on government policy, on consumer behavior and on the economic actions by commercial organizations."

Sir Mark Moody-Stuart gave the "StatoilHydro lecture" on the 33rd International Geological Congress in Oslo in August. The theme of the day was "The energy race: What will be the future energy mix?" Sir Mark has a doctorate in geology and has worked in Shell for most of his career, including an appointment as chairman of the Royal Dutch/Shell Group from 1998 to 2001.

"While estimates of the likely rate of growth of non-fossil fuel energy sources vary, given the low base from which these start, it is likely that fossil fuels will continue to be the most important part of the energy mix for the next three decades," he concluded.

Moody-Stuart emphasized how difficult it is to make serious predictions about our future use of energy. On one side, the impact of population growth tends to be overlooked, but – he said – we all know that we are approaching nine billion people around 2050. On the other hand, the increase in demand grow more slowly while we move from an economy with heavy infrastructure to an economy with less energy intensive service and knowledge sectors.

The speaker briefly touched upon the "peak oil" debate. As a member of the Saudi Aramco board, Stuart-Moody is "enormously impressed by the technical work that company is doing", and he has "every confidence in their reservoir and production modeling", meaning that there is no reason to doubt Saudi Arabia's reserve estimates, as many "peak-oil" advocates do. Moody-Stuart still made it quite clear that "energy conservation is the most important thing we can do" with respect to our future energy needs. "Given the challenges of climate change and the ultimately finite nature of fossil fuel resources, more widespread frameworks to price carbon dioxide and hence accelerate the development of less carbon intensive energy sources are also urgent," he said.

So how will the future energy demand be met? Well, according to Moody-Stuart, who has worked world-wide as a geologist, it looks as though hydrocarbons have the capacity to provide over half of the world's energy need for many years to come.

The bad news is, however, that our production capacity for both conventional and unconventional resources is constrained by many factors, not by the shortage of hydrocarbon resources, but by the constraints on the rate of increase of production capacity imposed by the need to produce from more challenging physical environments, the shortage of human and project development resources as well as very inflated capital costs (see also page 80).

ABBREVIATIONS

Numbers
(U.S. and scientific community)

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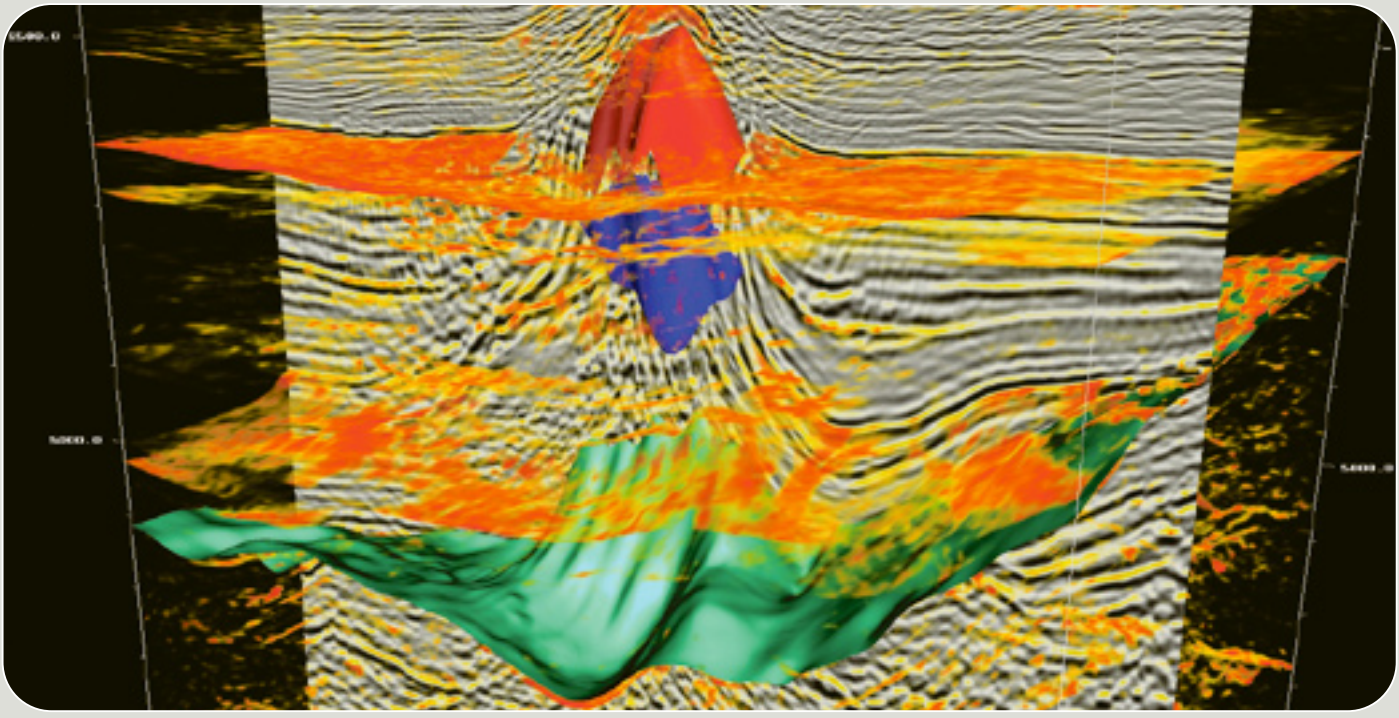

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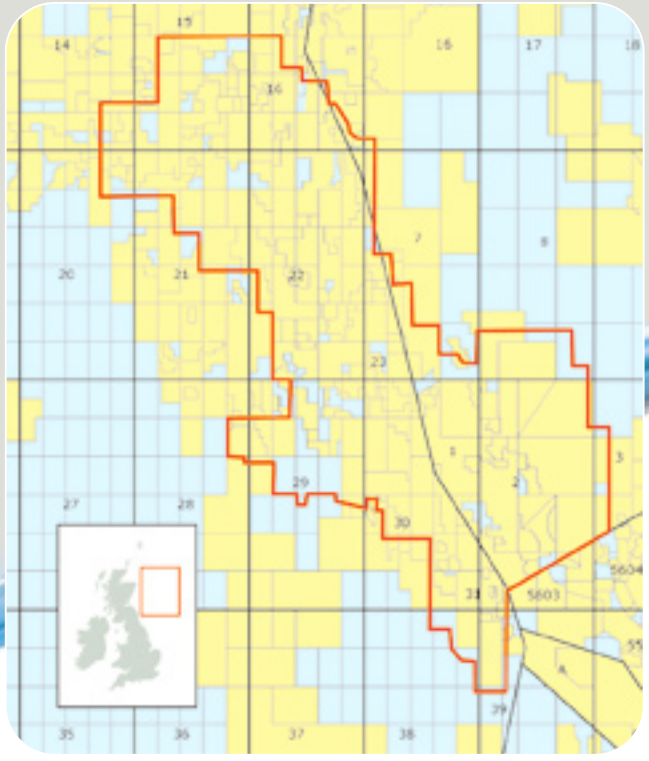

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Outstanding for Gas – Go Offshore

As much as 30% of the world's *undiscovered* gas resources may ultimately come from the Arctic, according to a recent USGS estimate.

Exploration for petroleum has already resulted in the discovery of more than 400 oil and gas fields north of the Arctic Circle. These fields account for approximately 40 Bbo, more than 1,100 Tcf of gas (198 Bboe!), and 8.5 Bbo of natural gas liquids. "Nevertheless, the Arctic, especially offshore, is essentially unexplored with respect to petroleum," says Donald Gautier in USGS, who for the last years has concentrated his efforts on understanding the Arctic resource potential.

The U.S. Geological Survey did in July release the first publicly available petroleum resource estimate of the entire area north of the Arctic Circle.

As shown in the table below, *undiscovered* technically recoverable resources in 25 geologically defined areas total some 435 Bboe, meaning that these resources account for about 22 percent of the *undiscovered*, technically recoverable resources in the world, according to the USGS study.

The Arctic accounts for about 13 percent of the undiscovered oil (most of this will probably be found in Arctic Alaska), 30 percent of the undiscovered natural gas (most of it will be found in the West Siberian Basin), and 20 percent of the undiscovered natural gas liquids in the world. It is, however, important to keep in mind that we are indeed talking about an estimate based on geological studies. It will take many, many years to prove these figures right or wrong.

USGS expects that about 84 percent of the estimated resources occur offshore.

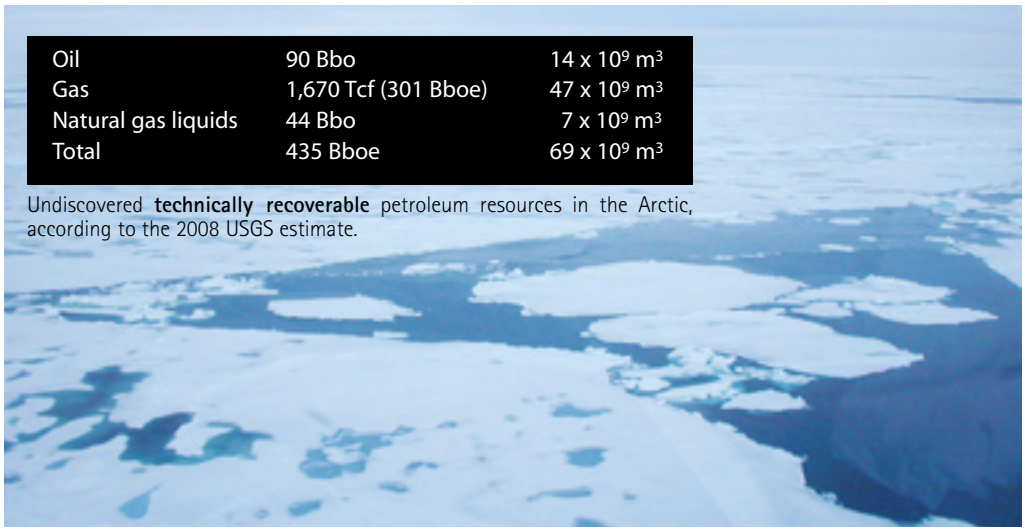
"Before we can make decisions about our future use of oil and gas and related decisions about protecting endangered species, native communities and the health of our planet, we need to know what's out there," said USGS Director Mark Myers (see GEO ExPro No. 6, 2007). "With this assessment, we're providing the same information to everyone in the world so that the global community can make those difficult decisions."

Of the estimated totals, more than half of the undiscovered oil resources are estimated to occur in just three geologic provinces - Arctic Alaska, the Amerasia Basin (Canada and northwards), and the East Greenland Rift Basins. On an oil-equivalency basis, undiscovered natural gas is estimated to be three times more abundant than oil in the Arctic. More than 70 percent of the undiscovered natural gas is estimated to occur in three provinces - the West Siberian Basin, the East Barents Basins, and Arctic Alaska.

Technically recoverable resources are those producible using currently available technology and industry practices. For the purposes of this study, the USGS did not consider economic factors such as the effects of permanent sea ice or oceanic water depth in its assessment of undiscovered oil and gas resources. The USGS is the only provider of publicly available estimates of undiscovered, technically recoverable oil and gas resources.

Oil	90 Bbo	14 x 10^9 m^3
Gas	1,670 Tcf (301 Bboe)	47 x 10^9 m^3
Natural gas liquids	44 Bbo	7 x 10^9 m^3
Total	435 Bboe	69 x 10^9 m^3

Undiscovered **technically recoverable** petroleum resources in the Arctic, according to the 2008 USGS estimate.



HUSKOPPDATERING

OIL PRODUCTION 2006

	Mbopd
Middle East	27 595
North Americ	13 700
Russia	9 769
Australasia	7 941
South Americ	6 881
Northwest Europe	4 756
West Africa	4 785
North Africa	4 586
FSU	2 473
Other	1 183
Total	83 669

Source: BP Statistical Re… World Energy

GAS PROD…CTI…N 2006

	Bi… …bic metres
Middle East	336
North America	754
Russian Federation	612
Australasia	377
South America	144
Northwest Eu…pe	255
West Africa	28
North Africa	144
FSU	148
Other	123
Total	2 923

Source: BP Statistical Review of World Energy

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Launching e-Core 1.3 – the digital laboratory

The latest version of the reservoir characterisation software e-Core improves the building and visualisation of digital rock models, thereby getting faster access to critical petrophysical properties.

Numerical Rocks has launched Version 1.3 of e-Core. The e-Core platform is a digital rock core laboratory for calculation of both petrophysical properties and multiphase flow parameters on generated rock models or imported µ-CT images.

Numerical Rocks, of Trondheim Norway, was founded in 2005 as a spin-off from Statoil, based on innovative ideas for how to obtain petrophysical parameters without going through time consuming and costly measurements in the laboratory.

"The technology simulates the natural process of sandstone formation, including sedimentation, compaction and diagenesis; utilizing cluster computing and 3D visualization techniques. The pore network, extracted from the digital rock model or imported µ-CT images, gives our clients a representation of the pore system of the rock model. The pore network is visualized in 3D, enabling the user to study the internal and external details of the pore system from all angles," says Ivar Erdal, chief executive officer of Numerical Rocks.

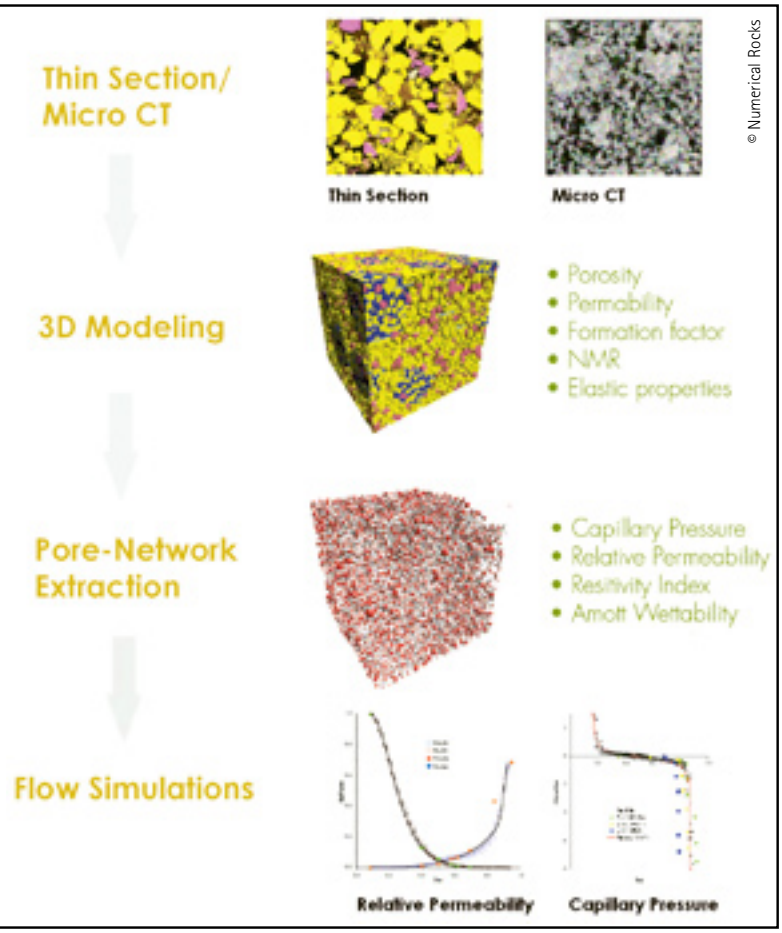
Version 1.3 includes several new features and improvements, according to Erdal: Pore network extraction from µ-CT images, additional statistical properties, such as lineal-path function, local porosity distribution, and local percolation probability, improved calculation speed, improved 3D graphics using state-of-the-art visualisation techniques, parallel batch processing, and compression leading to a considerably smaller disc footprint.

"The key for us is how quickly our client receives their accurate reservoir data. Decision making time costs clients a great deal of money, therefore our considerably faster delivery times, whilst maintaining accuracy, explains why e-Core is receiving such a positive response. Additionally, e-Core has huge potential use for special core analysis (SCAL) verification and interpretation later in the reservoir life cycle."

To date, Numerical Rocks has analysed reservoir rocks for customers in Europe, Africa, the Middle East, America and Australia, including both small and large companies.

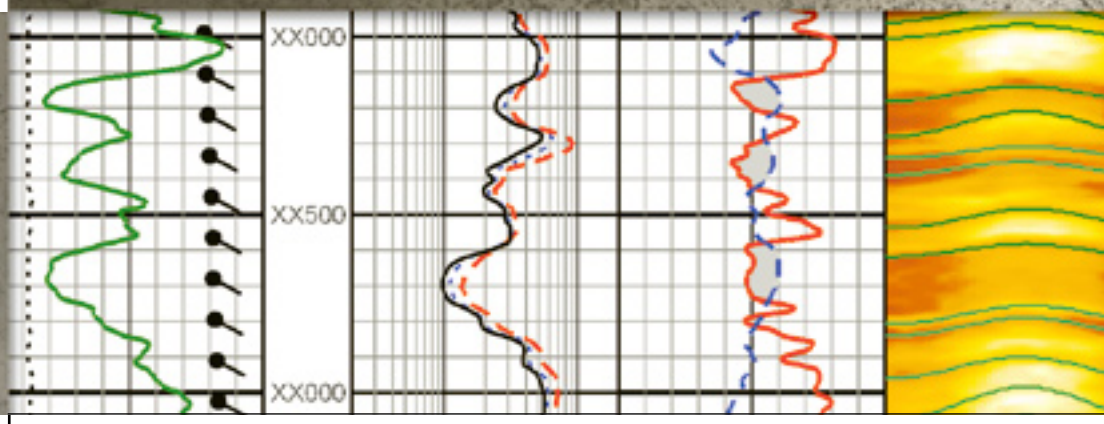
Ivar Erdal, CEO of Numerical Rocks, is convinced that proprietary software e-Core is a way for oil and gas companies to save both time and money for reservoir characterization and modelling reservoir flow.

"Numerical Rocks is the first company delivering pore scale modelling as a technical service, meaning that we have a job to do with respect to creating a market for our product. This is why it will take some time to get the necessary acceptance for the new technology amongst our potential customers, but we are working hard on it," Ivar Erdal says.



e-Core calculates petrophysical and multiphase flow properties including **Formation Resistivity Factor** (electrical conductivity is calculated for all three orthogonal directions of the rock model), **Absolute Permeability** (a measure of a rock's ability to transport fluids when only one fluid is present in the rock), **NMR** (simulating Nuclear Magnetic Resonance responses, and plots the magnetization decay as a function of time, and **Flow Simulation** (calculating the capillary pressure, relative permeabilities and resistivity index for the different two-phase displacements. 3D visualization illustrates the end state distribution of the fluids after primary drainage, imbibition and secondary drainage).

Build better real-time knowledge.



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Groundbreaking Visualising Software

Jenny Foster of BGS demonstrated the new software from BGS and Virtalis at the 33rd International Geological Congress in Oslo in August.

BGS gave the delegates of the 33rd International Geological Congress a preview of the new, groundbreaking visualization tool GeoVisionary. It will be formally launched in London later this year.

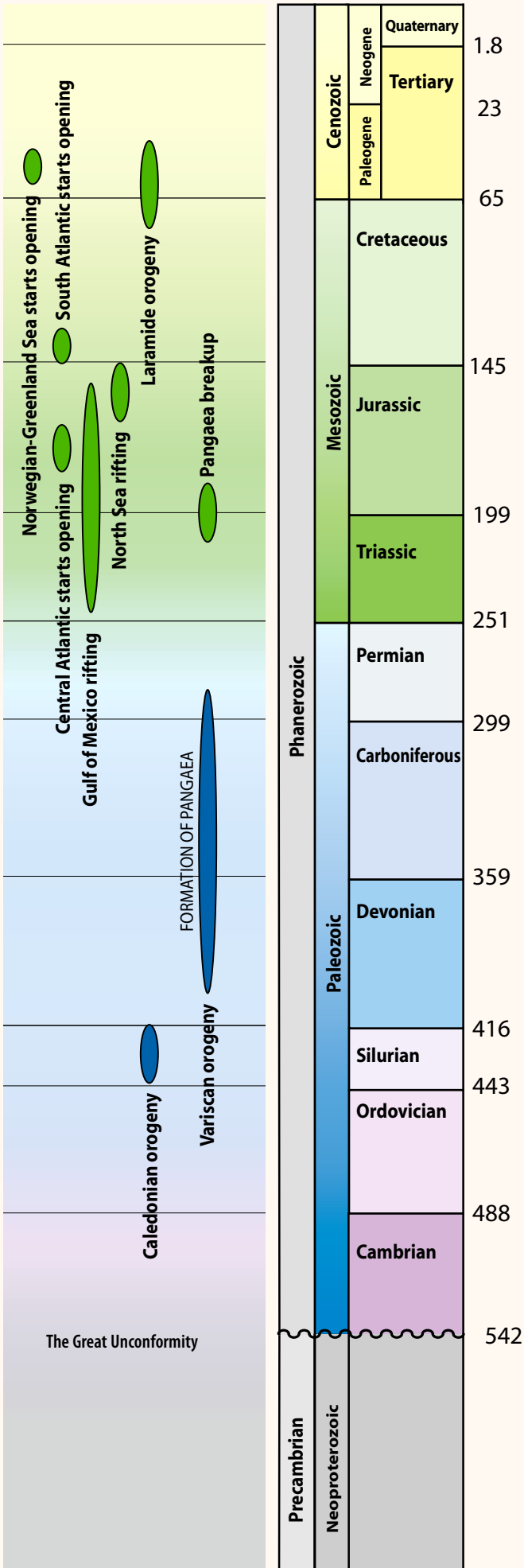
GeoVisionary enables the visualisation of terabytes of geoscience data, and allows other data, such as geotechnical, environmental and geochemical information to be overlaid onto it, giving a complete picture. The visualisation can be done at desktop level or in a large-scale collaborative projection environment with full stereoscopic 3D and immersive/interactive options.

"The main advantage with this software is for geoscientists to use when planning field work in areas that are difficult to access," says Jenny Foster of BGS.

"The potential applications for GeoVisionary are many and varied, extending far beyond geology. With our colleagues from Virtalis we have got a big and exciting challenge ahead to maximise its potential," says Stuart Marsh, head of Spatial Geoscience Technologies at BGS.

A similar visualization tool was developed by Statoil almost 10 years ago. The Norwegian oil company has, however, never made it commercially available and is instead using it for strategic purposes.

BGS has already used the application to validate and plan projects internationally and it has also gathered planetary data, such as that freely provided by NASA, and investigated how best to view and interpret such data. "GeoVisionary is a huge leap in geoscience visualisation technology," says Colm Jordan, head of the Earth Observation Team at BGS.



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New arm of Fugro

Fugro recently announced the creation of Fugro Gravity & Magnetic Services (FGMS) to market its worldwide gravity and magnetic capabilities for oil and gas exploration and production. FGMS is now the business development arm of Fugro Airborne Surveys, Fugro Ground Geophysics and Fugro Robertson (marine).

FGMS will provide the oil and gas exploration industry with a full spectrum of field tools and unique technologies including FALCON® airborne gravity gradiometry and the Fugro-LCT Software®. These services are delivered by more than 600 professionals from offices in North America, South America, Europe, the Middle East, Africa, and Australia.

FGMS incorporates more than 50 years of gravity and magnetic data acquisition and data processing experience in the field. The company has the largest inventory of marine gravity meters and magnetometers and the largest fleet of geophysical aircraft as well as the widest array of airborne geophysical technologies for potential fields data acquisition. These resources contribute to the largest combined airborne and marine multi-client data portfolio.

Largest ever contract to date

SCAN Geophysical has been awarded the company's largest ever seismic contract, an approximately US $70 million program from Petroleos de Venezuela SA (PDVSA) for 3,300km2 of 3D seismic work offshore Venezuela.

Preceded by earlier announced awards by PDVSA for seismic services offshore Venezuela, this contract calls for additional marine 3D seismic to be acquired in the Dragon Norte region. This award will backlog SCAN's proposed vessel, the M/V SCAN Resolution, into 3rd quarter of 2009.

"We are pleased that PDVSA has shown confidence in SCAN Geophysical by awarding us this contract, the largest to date for our company. Keeping our 3D vessel working in this region for a major company is consistent with our overall strategy to maintain vessel presence in the Americas and to work directly for operating entities," says Stephane Touche, Senior Vice President and COO of SCAN."

More data onshore Mexico

PGS Mexicana, a wholly owned subsidiary of Petroleum Geo-Services has been awarded a contract by Pemex for an onshore seismic survey in the states of Veracruz and Puebla, Mexico. The survey will be carried out from 2008 to 2012. The area to be surveyed is more than 2000 square kilometers, or more than 20 times the size of Manhattan. The total contract value amounts to approximately USD 165 million. The contract, starting in September 2008, includes both data acquisition and processing. PGS has provided onshore seismic services in Mexico since the year 2000.

High capacity vessel delivered

Geowave Endeavour is suited to meet the growing demand for high-density 4D seismic data and the need for wide-azimuth and multi-azimuth data acquisition.

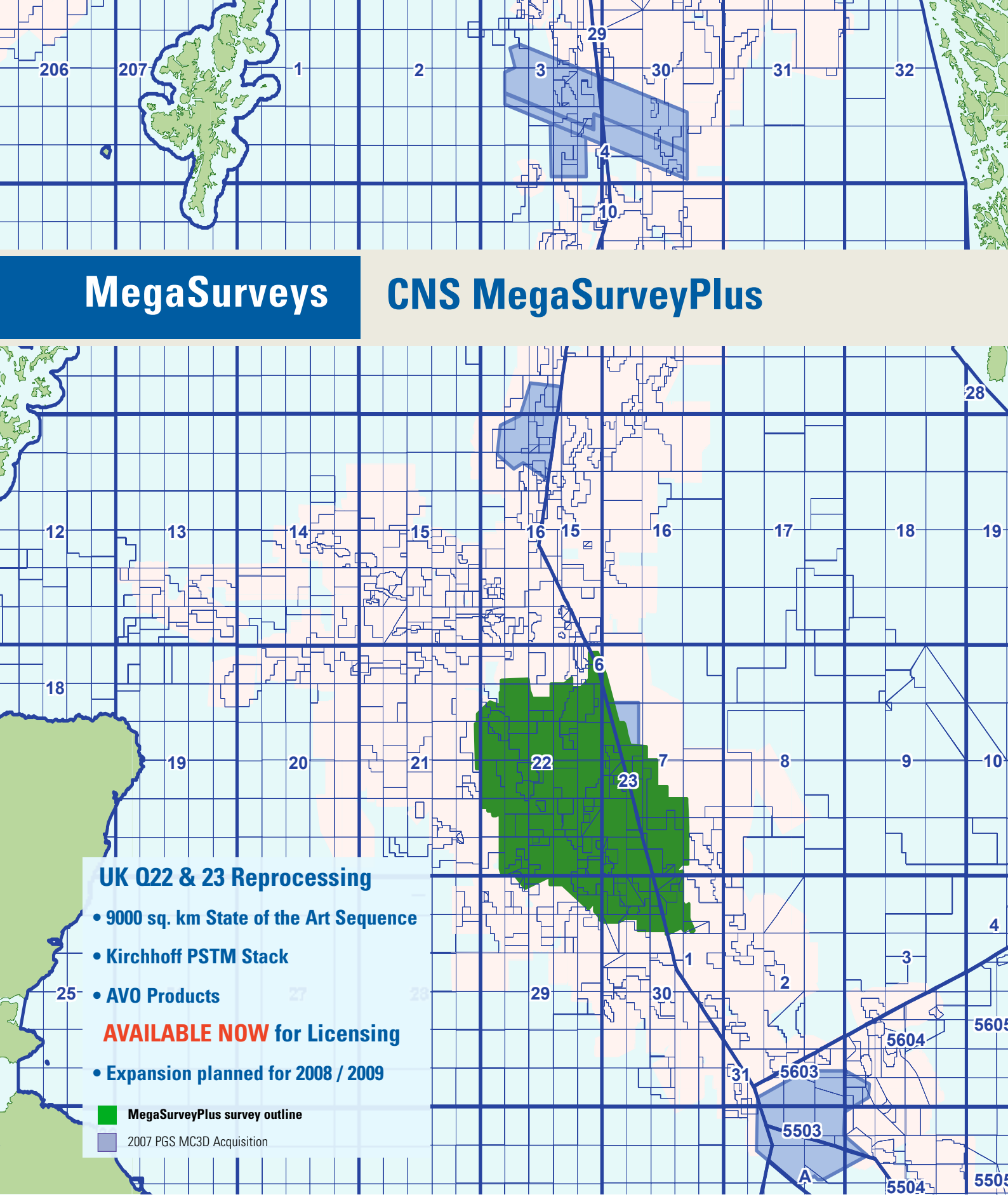
The high capacity 3D vessel M/V Geowave Endeavour was delivered from Fosen Yard and taken on a 7 year time-charter in July 2008. The vessel mobilised for their first large 3D contract with oil and gas major BG Norge in July and the vessel was fully operational and in steady production on August with 10 solid streamers of 6km length.

The Endeavour is one of the world's largest and most powerful 3D vessels with 16 streamer and eight gun strings vessel capacity. The vessel will complete the North Sea season for BG Norge in September and then continue on one of the world's largest 3D seismic contracts for BP in Libya, estimated to be completed end of 2009.

"Our strategy of building large high quality and high capacity 3D vessels and delivering them on time, has secured us a historical high contract back-log with major oil companies and positioned us as a recognized high quality Geophysical Service Company," says CEO Atle Jacobsen.

MegaSurveys

CNS MegaSurveyPlus



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MegaSurveyPlus survey outline

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Ultra high-density

CGGVeritas has been awarded a contract by Qatar Petroleum to undertake a large, ultra high-density high-resolution onshore seismic survey. The expected value of the contract is approximately $140 million dollars. Work on the project will commence around year-end 2008 and is anticipated to have a duration of about 30 months. The survey will cover the Dukhan field in Qatar that extends under desert plains, coastal salt flats, transition zones and shallow water areas.

"This industry-first survey will generate the highest possible resolution seismic image of the reservoir. A survey of this density was made feasible based on the results of our extensive research and development to create unique technologies and methodologies for continued improvement of image quality and increased efficiency of operations," says Robert Brunck, Chairman and CEO of CGGVeritas.

To ensure that this complex and industry-first high-resolution survey delivers the best results, CGGVeritas will provide the full range of acquisition and processing services deploying a 40,000-channel seismic crew, 3D VSP (Vertical Seismic Profile) and imaging services.

Geophysical Alliance in Russia

ION and LARGEO, a Moscow-based seismic data processing company, has formed an alliance to provide imaging services for seismic data acquired in the Russian market. The alliance, known as LARGEO-ION, combines the technological strengths of ION's GX Technology (GXT) Imaging Solutions group with the local market knowledge and extensive regional processing experience of LARGEO to bring best-in-class imaging services to E&P firms operating in Russia. Located in Moscow, the LARGEO-ION Imaging Center will offer a broad scope of imaging services including: pre-stack depth and time migration, reverse time migration, azimuthal velocity analysis, full-wave imaging, AVO and inversion, velocity modeling, and data conditioning. It is expected that the center will later be expanded to process data acquired onshore, including seismic datasets that require state-of-the-art, high-density, wide-azimuth, full-wave imaging.

Introducing "coil shooting" - with a single vessel

High-quality full-azimuth recordings can be achieved by acquiring data with a single vessel traveling in a circle. Also, there are no non-productive intervals for line changes.

Coil shooting single-vessel full-azimuth (FAZ) acquisition - a technique of acquiring marine seismic data while following a circular path – has the potential to take geophysics further, according to WesternGeco.

Current multi- and wide-azimuth (MAZ and WAZ) techniques (GEO ExPro 03/2008) – both proven, successful methods of seismic acquisition for complex geological areas – involve a number of vessels offset from each other, some just towing sources, others towing sources and streamers. The result is better target illumination thanks to greater azimuthal coverage and higher signal-to-noise ratios.

Typically, WAZ surveys are conducted using three or four vessels, each traveling in parallel lines. However, while conducting a project in the Gulf of Mexico, WesternGeco now recognizes that high-quality full-azimuth recordings could be achieved by acquiring data with a single vessel traveling in a circle, thereby removing the need for the multiple vessels required by today's WAZ designs.

Coil shooting single-vessel full-azimuth acquisition has been field tested in the Gulf of Mexico and the Black Sea. WesternGeco says these surveys have produced positively dramatic results that clearly show the potential for applying the technique on a global scale. Steering the vessel, streamers, and sources in a corkscrew fashion delivers a greater range of azimuths and offsets than parallel WAZ geometries, and there are no non-productive intervals for line changes.

Coil shooting can address some of the many challenges in imaging beneath salt and basalt, as well as in other complex geological situations, according to WesternGeco.

A UK "Center of Excellence"

CGGVeritas has opened a UK Center of Excellence. The new center combines the London and Crawley offices to provide resources, technology and experience. Based in Crawley, near Gatwick airport, the new center is staffed by over 200 processing geophysicists who, together with the CGGVeritas EAME (Europe, Africa and the Middle East) compute hub in Redhill, form "the most powerful processing and imaging capability in the region". New and upgraded facilities include a state-of-the-art visualization center, visual meeting rooms and the latest in IT infrastructure.

The center hosts R&D teams working closely with processing groups to ensure the fast and efficient deployment of new technologies. The new center is also the EAME headquarters for other key CGGVeritas business lines including Marine Acquisition, Data Library, Data Services and Reservoir Services.

"The new UK Center is both a strong commitment to providing the best facilities to our employees and an underlining of our determination to continuously deliver unsurpassed images of the subsurface to our clients. As the challenges within the oil and gas E&P industry continue to grow, we are dedicated to combining the right resources to address them effectively, both in terms of our facilities and the technologies they house. Our new UK Center is a proud affirmation that we are energetically meeting these challenges, says R. Ian. Thornton, Senior VP for EAME Processing and Reservoir Services.

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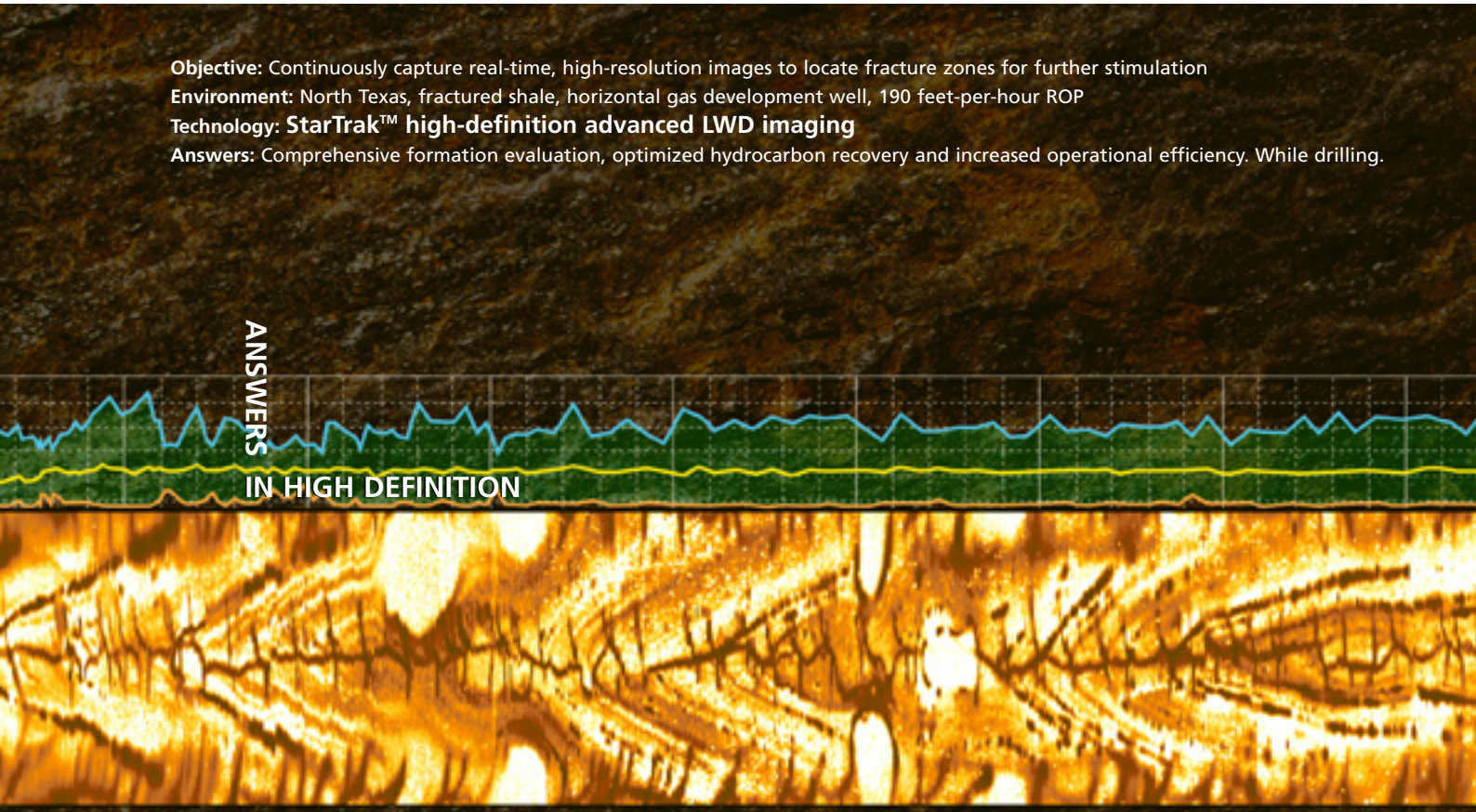

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BAKER HUGHES INTEQ

Two months to go – 20th licensing round offshore Norway

The 20th licensing round, announced in June by the Ministry of Petroleum and Energy, include 79 blocks or parts of blocks, with 51 in the Norwegian Sea and 28 in the Barents Sea. The 20th Licensing Round will contribute to maintaining exploration activities in immature parts of the Norwegian continental shelf, and provide basis for new petroleum activities and value creation in the northern part of Norway, according to the Ministry of Petroleum and Energy.

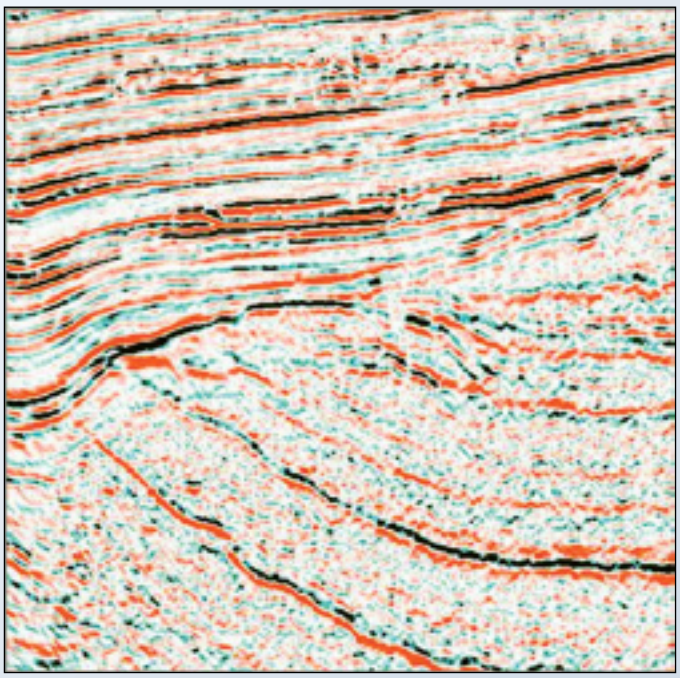
There is still a great potential for making discoveries in the Norwegian Sea. This time, the blocks announced are located further west and north-west than in previous announcements. Several of these blocks are situated in deep waters in the Vøring basin. This is a complicated and underexplored area of the Norwegian shelf, according to the Norwegian Petroleum Directorate (NPD).

The Norwegian Petroleum Directorate is concerned with sequential exploration. This means that new blocks are awarded on the basis of knowledge gained from already awarded areas. Work commitments still remain in previously awarded blocks in the Barents Sea, and these may provide important information.

Sissel Eriksen, NPD's Director Exploration, states that wells drilled in the Norwegian Sea and the Barents Sea will provide more information that may lead to the opening of new exploration areas.

The application deadline has been set to 7 November 2008. The awards are scheduled for the spring of 2009.

Seismic in Troms III, offshore Norway



TGS has made available a fast track volume of a Troms III MultiClient 3D seismic survey. The full fast track volume, 1500 km2, is on schedule to be delivered by end of August.

Still much to be found

Photo: Halfdan Carstens

While a large part of the Norwegian shelf is considered a mature petroleum province, there is still a good potential for discovering major – and possibly also giant – fields.

The total recoverable petroleum resources on the Norwegian shelf as of December 31, 2007 are estimated at approximately 13 billions Sm^3 oil equivalents (90Bboe). Undiscovered resources are estimated to 3.4 billions Sm^3 oil equivalents (23.5Bboe), with 1.175 BSm^3 (8.1 Bboe) in the **North Sea** (not included in the 20th round), 1.195 BSm^3 (8.2 Bboe) in the **Norwegian Sea** and 1.03 BSm^3 (7.1 Bboe) in the **Barents Sea**. If you want more numbers, we can add that by the end of 2007 a total of 4.811 Sm^3 oil equivalents (30BBoe) had been produced, while 5.017 Sm^3 oil equivalents (32BBoe) remain to be produced from fields and discoveries.

Exploratory wells on the Norwegian continental shelf: www.geo365.no/norsksokkel

The coming oil supply crunch

A recent report that is available on chathamhouse.org.uk argues that unless there is a collapse in oil demand within the next five to ten years, there will be a serious oil 'supply crunch' – not because of below-ground resource constraints but because of inadequate investment by international oil companies (IOCs) and national oil companies (NOCs). An oil supply crunch is where excess crude producing capacity falls to low levels and is followed by a crude 'outage' leading to a price spike. If this happens then the resulting price spike will carry serious policy implications with long-lasting effects on the global energy picture. Another analysis of the recent development of demand and supply for crude oil from Clingendael International Energy Programme also indicates that the mismatch in supply and demand growth could cause tighter oil markets than we already experience today.

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Moving Fast Forward in A

StatoilHydro has grown into a major player in Angola. With more than 200,000 barrels of oil produced every single day, and having assisted Sonangol to become an operator, the time is now right to take the next step. With strong support from the head office back in Norway, StatoilHydro is ready to take on operatorship in Angola.

Photos: Halfdan Carstens

Beautiful **Cabo Ledo**, featuring sandy beaches, friendly fishermen, outdoor restaurants and, above all, excellent outcrops below the cliffs, is certainly worth a day trip when visiting Luanda. In this location the curious geologist can look at proximal facies of source rocks, carbonates and channels cutting into the underlying shales and carbonates. In the background, to the left, a Lower Miocene channel cuts through underlying shales and carbonates that are filled in with colourful debris flows (inset). Erik Holtar, Business Development Manager for StatoilHydro in Luanda, serves as scale.

Angola

Halfdan Carstens

"We have a well-defined ambition in Angola. We want to be operator, it is as simple as that", says Bjørn Rasmussen, StatoilHydro boss in the West African country that has grown into one of the world's largest oil producing states.

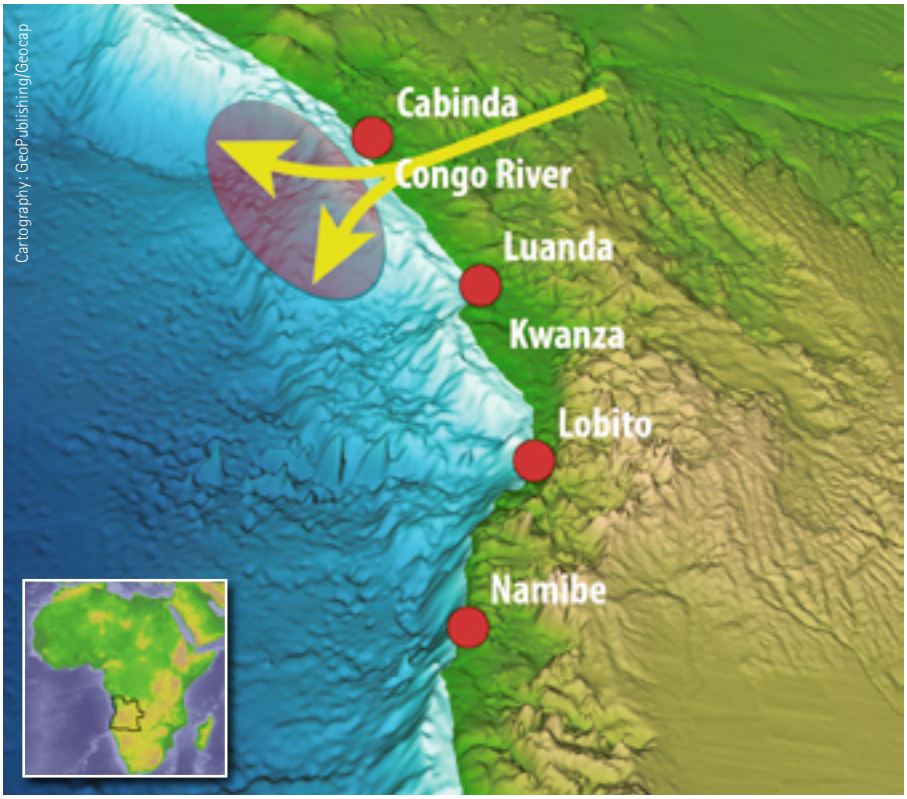
And why not - we all know that the future to a large extent lies in the deep water, and the Norwegian company claims to be in the forefront of deep-water exploration and production technology. With deep-water assets offshore Norway, Brazil, Nigeria and in the Gulf of Mexico, it has the necessary experience and the right people to be successful.

"We can see a lot of benefits of turning the company in Angola into an operator, Bjørn continues. "First and foremost we will be in a position to build a highly competent organization. Also, with more responsibility, we will learn more, thereby enabling us to make better decisions for the benefit of both ourselves, our partners, and – above all – for the Angolans."

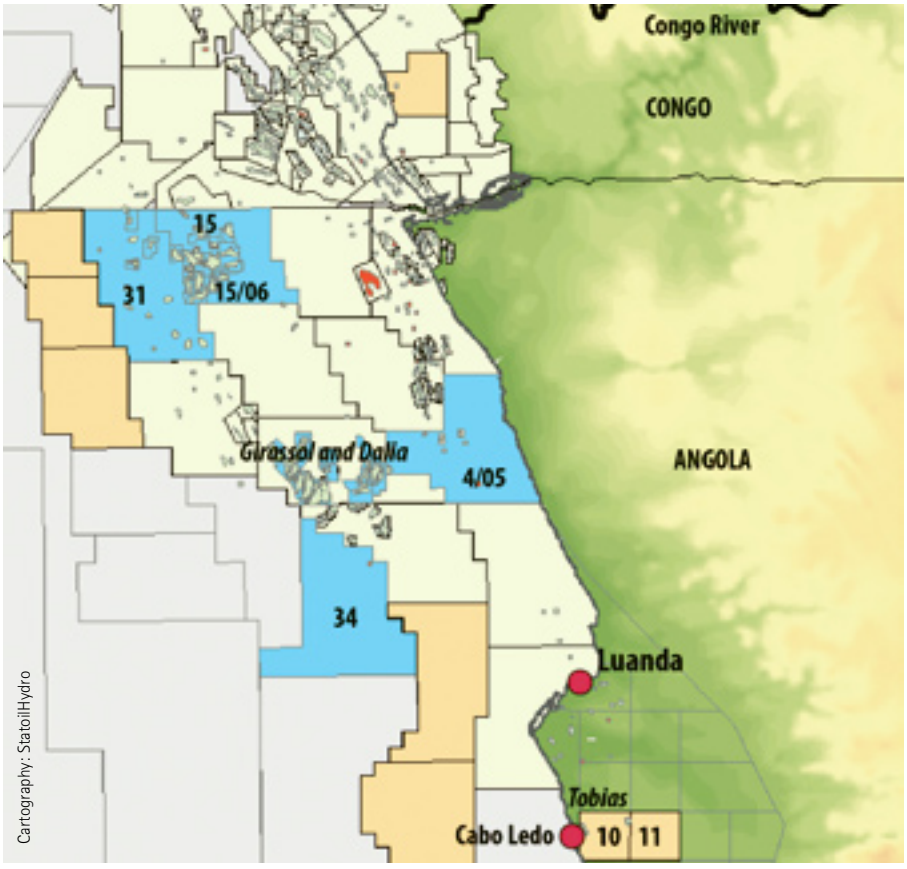
"Our success on the Norwegian shelf has a lot to do with being an operator. I consider operatorship a prerequisite to continuing our growth and making a better contribution in this country," Rasmussen says.

Plenty of resources – on and offshore

Only six years have passed since the civil war came to an end in Angola. Before that, the country was ridden by unrest and setbacks for 27 years, ever since independence from Portugal in 1975. The result was devastating, and much of the country's infrastructure outside the oil sector was destroyed. The human and social consequences were also enormous, hundreds of thousands of people were killed, tens of



Angola is a huge country with a long and beautiful coastline, situated just south of the equator between Congo and Namibia. For 27 years, following independence in 1975, the country was ridden by civil war halting its development into a modern society. Now the time has come to take advantage of the massive amounts of sand that were transported from the hinterland to the east and deposited in the deep sea during the Paleogene and Neogene, to form excellent reservoir rocks.



StatoilHydro has participated in 104 wells off Angola on a number of licenses in the offshore Lower Congo and Kwanza basins. At present, the Norwegian major has a strong position in the prolific deep-water Lower Congo Basin (StatoilHydro licenses in blue colour) with production from deep-water turbidite sands and access to potential pre-salt plays, similar to those recently proven offshore Brazil (GEO ExPro no. 3/2005 and this edition). The company is also ready to bid for more acreage in the next licensing round, due early next year (open blocks in brown colour) and this time the company is hoping to get status as operator.

thousands were disabled, and several millions were internally displaced. Today, about 70% of Angolans are still living in poverty, only about 30% have regular access to public health and clean water, and infant mortality is among the highest in the world.

The job of getting the country back on track is nothing but overwhelming. Driving in Luanda, the capital, you get the impression that they are trying – hard. The traffic itself is horrendous, but there is a lot of activity going on, and the ever-present construction work proves that there will be a change for the better. It is also encouraging to observe that people are engaged in cleaning the city and making it a better place to live.

Angola is a huge country. It covers 1.25 million km^2, equal to France and Germany combined. With 16 million people, the population is, however, quite small. If managed correctly, the plentiful geological resources – offshore oil, onshore minerals (in particular diamonds), fertile soil and plenty of fresh water – mean that the future should be bright. The downside is the enormous need for both capital and expertise.

A key building block

Oil exploration started in earnest back in 1915, but the first discovery was not made until 1955. As of today, production has grown steadily to 1.7 MMbopd (270,000 m^3/d), and according to the BP Statistical Review of World Energy, reserves have climbed from 2 Bbo (300 MM m^3) in 1987 to 9 Bbo (1,400 MM m^3) as of last year. ExxonMobil, Total and BP are the dominant players, with StatoilHydro, following the merger between Statoil and Hydro last year, now emerging as a serious competitor to the supermajors in terms of liquid output.

StatoilHydro has been exploring in Angola since 1991, its first producing asset being Girassol in Block 17, which started producing in 2000. The other main producing asset is Dalia, also in Block 17, operated by Total. The two fields contribute more than

Photo: Halfdan Carstens

Having grown up with crystalline rocks of Precambrian age in their own backyard, Erik Holtar (left) and Bjørn Rasmussen – both of them experienced exploration geologists – don't mind the one and a half hour drive from Luanda to Cabo Ledo to look at sedimentary rocks that are equivalents to offshore source and reservoir rocks.

A glance at the onshore oil history

While the first onshore well was drilled in 1915, and several more exploration wells with good shows followed in the years after, Angola did not enter the oil age until 1955. The Benfica Field, the very first discovery, is located in the Kwanza Basin not far from Luanda and was operated by a subsidiary of Petrofina. In 1961, 6 years later, another discovery was made due west of Cabo Ledo south of Luanda. The Tobias Field was at that time big enough to make Angola self-sufficient in oil. Onshore Blocks 10 and 11 in the Kwanza Basin, including the Tobias Field, which was shut down several years ago, is now to be put on tender for another round of licensing. The Lower Congo Basin is the only onshore producing basin in Angola at the moment.


Photo: Halfdan Carstens

Late this autumn, the small Gimboa field will be put on stream. Slightly more than 40 million barrels of oil will be produced using 3 production wells and 4 injectors. Sonangol is the operator, technically assisted by StatoilHydro who has seconded personnel from its worldwide operations. The Norwegian company knows all about the need for such assistance in order to be a qualified operator. In the late 1970's it was itself assisted by one of the American supermajors when developing the Gullfaks field. Here, in Sonangol's operation centre, Neil Hay is working together with Abel Cruz on production planning.

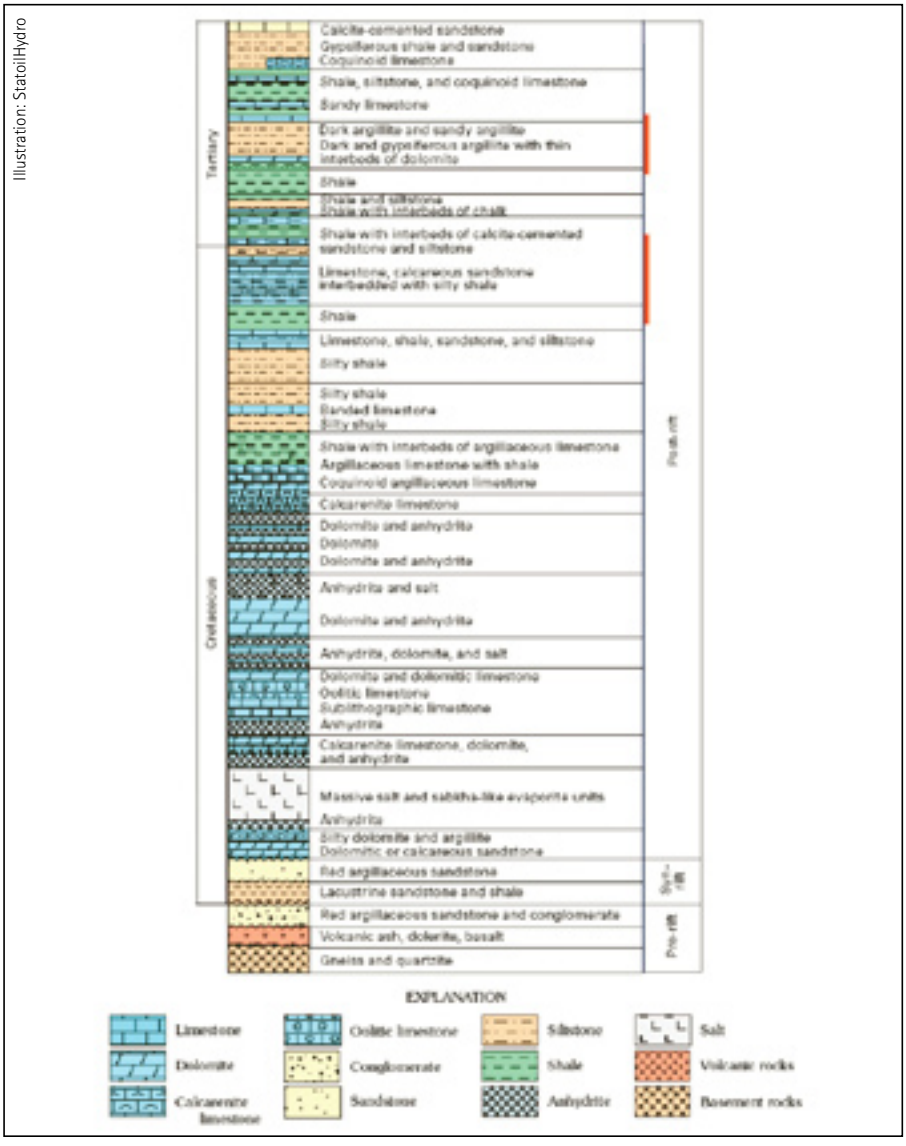
half of StatoilHydro's total production in Angola, which is now over 200,000 barrels of equity production per day, representing more than 10% of the total daily production in Angola. StatoilHydro production is expected to continue at this level for the next ten years.

The StatoilHydro asset portfolio now includes six licenses, most of them in deep water, operated by BP, Eni, Exxon, Sonangol and Total, and the company is partner in nine producing fields. However StatoilHydro has serious plans for the future and is investing heavily in exploration. This is why the company has done its homework with respect to the next licensing round and is also looking at every opportunity for farm-ins.

"Angola turns out to be a key building block for StatoilHydro's international production growth," says Rasmussen.

The Petroleum System

"The one thing you really need in order to understand the deep-water petroleum systems and play model of offshore Angola is a world map," says Erik Holtar, Business Development Manager for StatoilHydro in Angola. "Focus on the Congo River. It runs from east to west within an area of abundant precipitation, growing bigger kilometre by kilometre. The erosion is heavy, so that lots of sand, silt and clay are being transported towards the South Atlantic Ocean and dumped on the narrow continental shelf and beyond." Sediments have been carried in this way from the huge hin-



Generalised stratigraphy offshore Angola with granitic basement (Precambrian) pre-rift (Jurassic?-Lower Cretaceous), syn-rift (Lower Cretaceous) and post-rift/drift (Lower–Upper Cretaceous/Tertiary) sedimentary rocks. Note the Lower Cretaceous (Aptian) early post-rift salt that is responsible for numerous traps and the complicated tectonics of the offshore Angolan deep-water basins. Note also the pre-rift sequence with proven lacustrine source rocks and potential reservoir rocks. Visited localities at Cabo Ledo are shown with a red bar.

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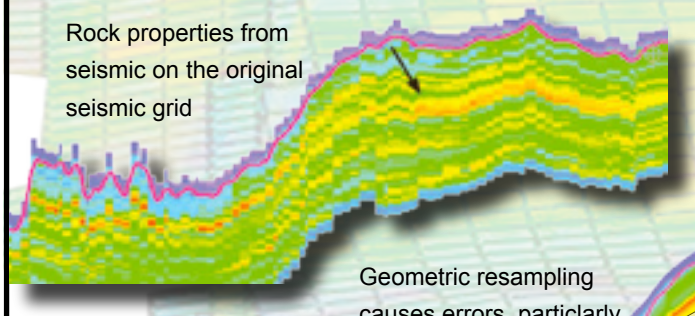

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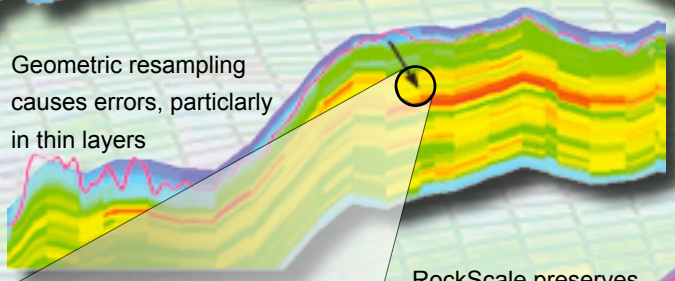

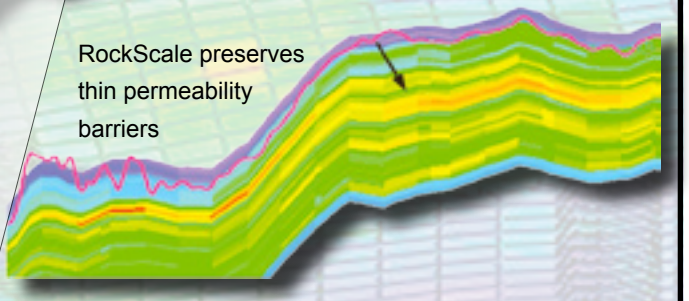

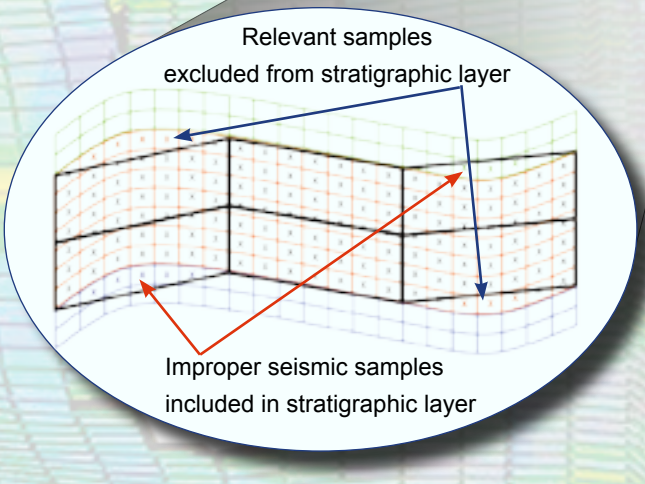

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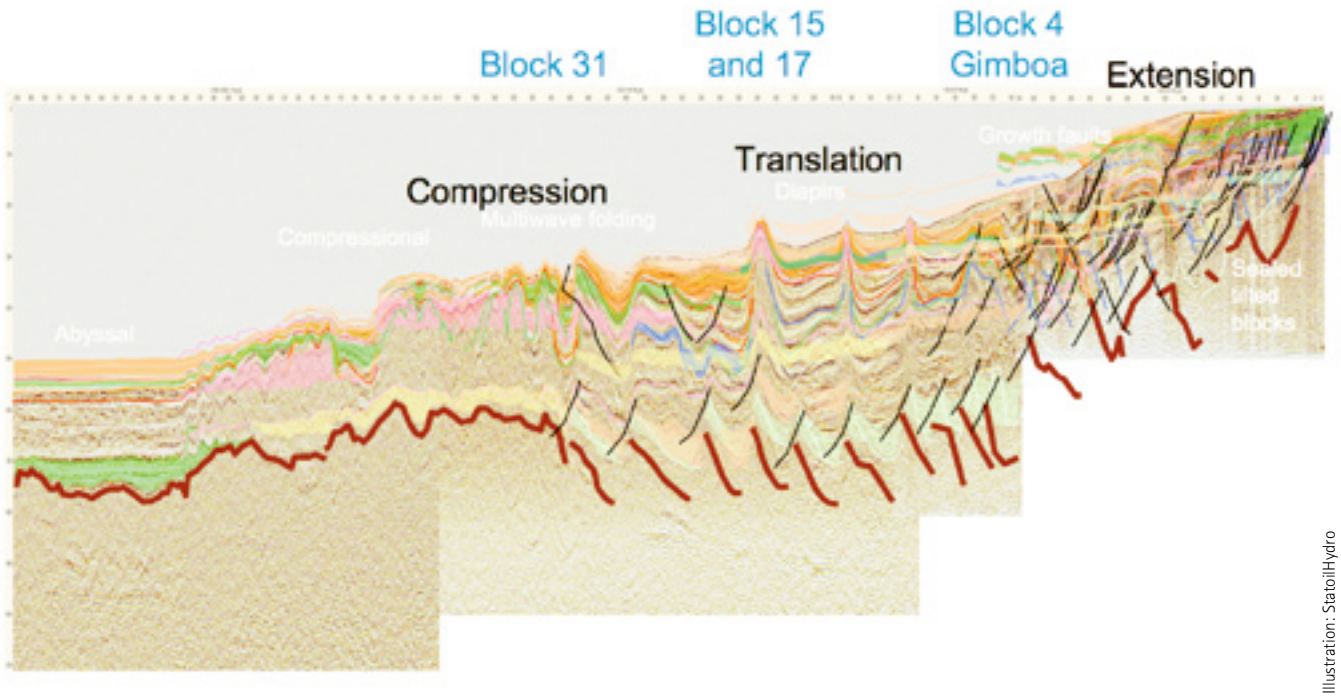
Geological provinces offshore Angola



This compressed, generalised x-section illustrates the main structural features of the deep-water Angolan sedimentary basins extending from the narrow, shallow shelfal waters into the abyssal plain. The pronounced pre-rift fault block cuts through Precambrian basement, while post-rift salt generates trapping for deep-water sands shed out from the shelf. Extensional faulting towards the shelf-edge is caused by tilting of the basin towards the west with resulting salt movement.

terland by the massive Congo River for tens of millions of years. The river today is Africa's second largest river in terms of length and has the second largest flow in the world, only behind the Amazon.

"Turbidity currents are responsible for redistributing huge volumes of shales and sand from shallow to deep water, and as time goes by, more sand is fed into the system in channel complexes, giving rise to multiple reservoir horizons ranging in age from Oligocene to Miocene. The basin then subsides because of the extra load, and the section gets thicker, almost day by day," Holtar explains.

This is the simple setting of a passive continental margin that has been evident throughout the Late Cretaceous and the Tertiary. It all started in the Early Mesozoic with the initial splitting of the Pangea supercontinent and the opening of the South Atlantic Ocean in the Early Cretaceous.

"Before the final split when the two continents drifted apart, thick beds of salt were deposited in a narrow basin. Later, in the drift phase, the salt started moving in response to tilting of the shelf. Salt pillows and diapirs developed, thereby generating traps with all kinds of curious shapes that can barely be imagined."

The main source rock of the Angolan shelf is of Late Cretaceous age. Organic rich clays were deposited over the entire shelf in an anoxic environment prior to the main input of clastics from the Congo River, as well as rivers along the coast. The maturation history of the source rocks is closely related to the amount of sediment derived from the rivers.

Further subsidence and increased temperatures during the Tertiary have matured these sources and facilitated migration into the reservoir rock, trapping the hydrocarbons in complicated salt-induced structures.

Building a master plan

Bjørn Rasmussen, long time explorationist with Hydro, now resides in Luanda and is responsible for the entire StatoilHydro portfolio offshore Angola. In the next office sits Erik Holtar, Business Development Manager, also a geoscientist with a proven record as New Venture Manager worldwide with Hydro before the merger. Colleagues both in Angola and in Norway have together designed a master plan for how to turn the company from being an active partner to an innovative operator.

"First of all, we are spending lots of time and energy getting acquainted with the local culture. Here, in this country, we are guests and have to behave in a decent way. Humbleness is extremely important to us", Bjørn says.

"It is also important to understand the country's situation, with a civil war just 6 years back in time. This is why we look upon our role as technical assistant during the

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development of the Gimboa field in Block 4 as very important. I know the importance of knowledge transfer as I was myself an employee of Statoil when we were assisted by ExxonMobil during the development of the giant Gullfaks field in the 1980's," says Bjørn.

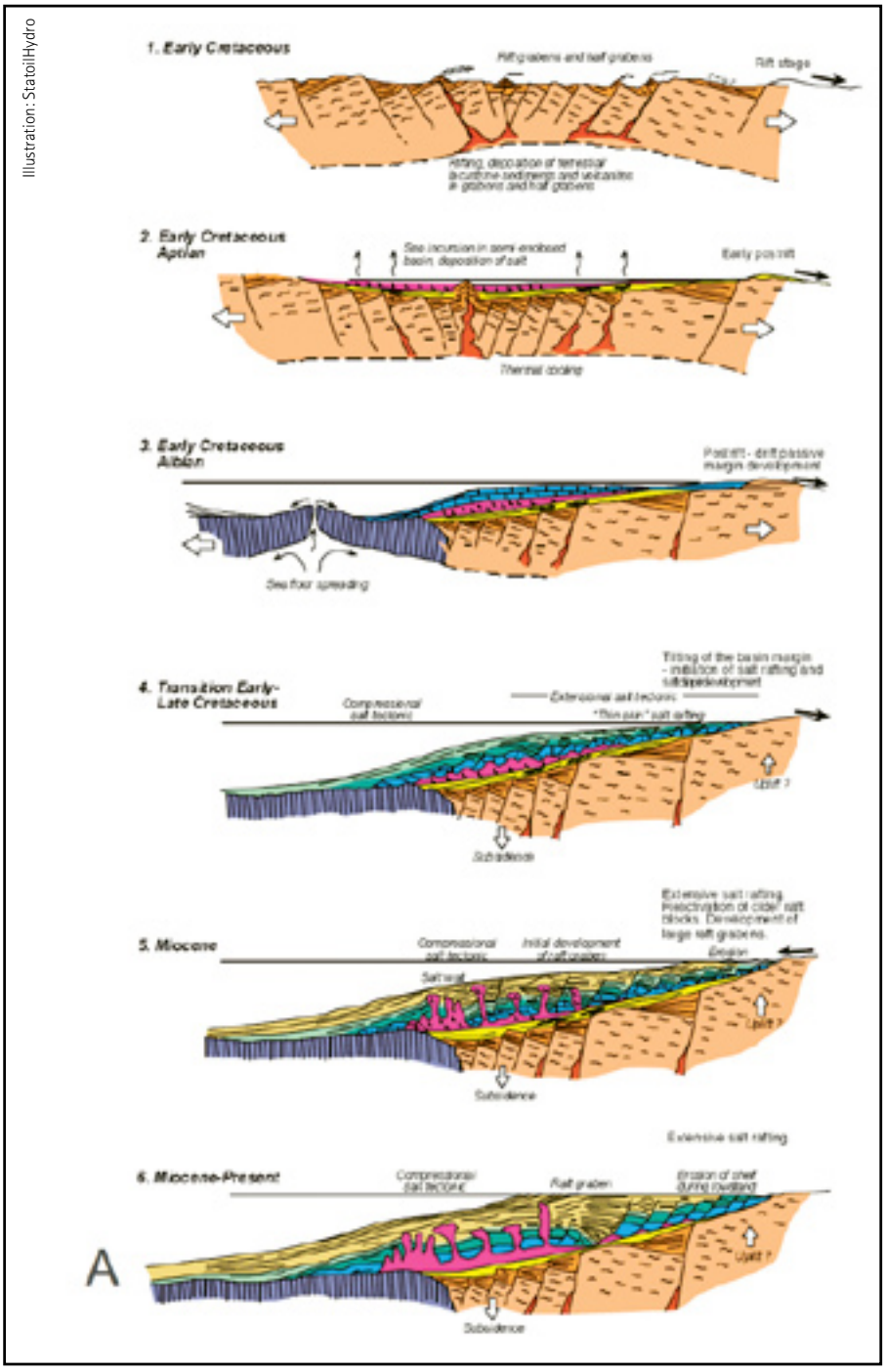
Observing the enthusiasm and dedication of the StatoilHydro team in Luanda, we are in no doubt they will succeed and will achieve their goals.

"We realise that it is a lot more interesting to work for an operator. We should be able to attract the best people that way, something that is very important when qualified people are in demand," Bjørn Rasmussen says.

Photo: Halfdan Carstens

Bjørn Rasmussen moved to Angola last year following the merger between Statoil and Norsk Hydro. Long time geologist with significant international experience, he is now head of StatoilHydro s exploration and production in a successful geologic province, with assets as a partner in 6 licenses. His next goal is therefore to turn StatoilHydro into an operator in Angola.

Illustration: StatoilHydro



Time-step evolution of the Atlantic margin in Angola illustrates the classical development of a passive continental margin with pre-rift, rift and post-rift (drift) stages.

New fields on stream

The Saxi, Batuque and Mondo fields, part of the ExxonMobil operated Kizomba C development project in Block 15 offshore Angola, all started producing in 2008. Kizomba C is estimated to produce a total of approximately 600 million barrels of oil over the life of the three fields. The Kizomba C development comprises two floating production, storage and off loading (FPSO) vessels and 36 subsea wells. It is the largest subsea development operated by ExxonMobil worldwide. ExxonMobil has a 40% stake, while StatoilHydro holds 13.33% in Block 15. And there's more to come. Block 4 is also expected to start producing in 2008, and in a few years Block 31 will come on stream.

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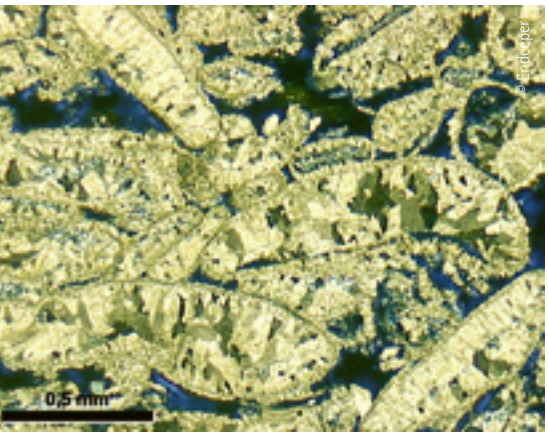


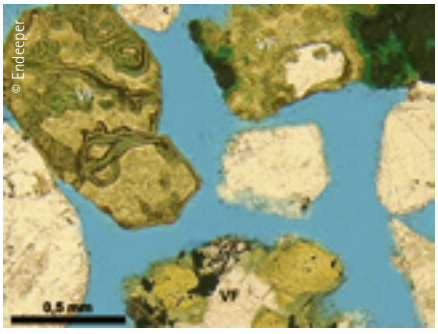
The recent discoveries of giant, early Cretaceous, sub-salt oil and gas accumulations in the deep and ultra-deep areas of the eastern marginal basins in Brazil have helped to bring petrographic studies to the center arena. Sub-salt carbonate reservoirs previously drilled in the shallow-water portion of the Campos basin, shown here, are characterized by extreme variation in porosity and in diagenetic processes and products. Recrystallized mollusk bioclasts provide the heterogeneous framework for these lacustrine reservoir rocks.

Complex and unconventional reservoirs are increasingly important to the world's energy supply, although often challenging to produce. Systematic petrographic studies take a close look at these reservoirs yielding improved characterization and quality prediction; a crucial breakthrough that will guide future exploration and production.

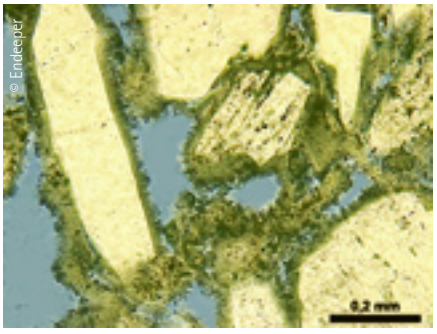
Luiz Fernando De Ros, Karin Goldberg, and Mara Abel

There are two types of new exploration targets: Conventional clastic and carbonate reservoirs with strong diagenesis, located in deeper, depositional or tectonically-complex new frontiers or unconventional plays, such as tight sands, gas-shales and coalbed methane. In spite of the spectacular advances in the acquisition, processing and interpretation of seismic and log data, the risks involved in the exploration of these new prospects using these conventional tools are huge. 3-D and 4-D models incorporating sophisticated structural, thermal, generation, and migration histories have helped to reduce exploration risks in new and unconventional settings. However, they simply lack information on an essential part of petroleum systems: *the reservoir*.

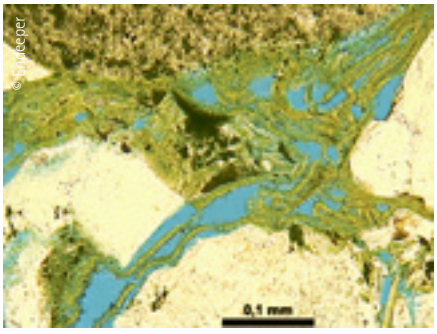
The conventional approach for dealing with the reservoir rocks through the indi-



The first example illustrates the importance of calibrating logs and seismic with rock data. In the Gulf of Mexico upper Tertiary section, seismic amplitude anomalies very similar to oil-saturated sands have been unsuccessfully drilled since the late 70's. Only lately, it was discovered that these anomalies correspond to sands containing substantial amounts of volcanic ash derived from large-scale eruptions in the Yellowstone area through the Mississippi River system. The same type of false direct hydrocarbon indicator led to dry wells in the eastern Brazilian marginal basins, where the anomalies were related to reworked, altered vitreous volcanic fragments (VF) produced by submarine eruptions (hyaloclasts). Large amounts of money could have been saved in both cases had a proper petrographic characterization been performed immediately after the first dry well was drilled.



The second example shows the importance of petrographic studies for the development of reservoir quality predictive models. Upper Cretaceous reservoirs from the Santos basin, offshore Brazil, as well as Jurassic reservoirs from the Gulf of Mexico and the North Sea contain anomalously high porosity preserved at great depths (>4,000 m). Petrographic studies revealed the inhibiting effect of chlorite rims (green) on quartz cementation and compaction. Systematic petrographic studies allow more robust modeling of the spatial distribution of chlorite and hence of the related porosity preservation.



The third example shows how petrography can help companies to squeeze more oil out of old fields with declining production. A better understanding of the "old" reservoirs can help to redesign or adjust the secondary or tertiary recovery programs; or in some cases, to extend, drill for, or re-complete new, unconventional, and/or previously neglected reservoirs. Systematic petrographic characterization has helped to plan the enhanced recovery program for mature lower Tertiary reservoirs of the Talara Basin, Peru. Detailed petrographic characterization allowed researchers to understand the heterogeneities and controls on pore geometry and permeability, and was essential for the design of engineering solutions for optimizing reservoir exploitation. The photo shows multiple smectite (swelling clay) rims (green) generating very complex pore systems (blue).

ounters with Complex Reservoirs

> *"The solution, we believe, is the incorporation of comprehensive petrographic studies into reservoir modeling.*

rect evidence of texture and composition provided by the logs, with occasional help from simplified petrographic descriptions of core or sidewall samples, is simply not adequate for complex and unconventional reservoirs.

Using effective petrography to solve complex reservoirs

The increasingly sophisticated petrologic studies of reservoirs and associated rocks incorporate, among other techniques, analyses of major and trace chemical elements through electron and ionic microprobes, stable and radiogenic isotopes, fluid inclusions and mineralogical analyses through X-ray diffraction and electron microscopy. However, the effectivity of these advanced methods depends on systematic petrographic studies through optical microscopy of the depositional structures, textures and composition, and of the diagenetic products and evolution of these rocks. The importance of petrographic studies for the characterization and modeling of complex reservoirs can be appreciated from three different cases illustrated in the photos to the left.

Empowering Knowledge

The deep sub-salt reservoirs off the Brazil coast are very complex and intensely affected by diagenetic processes, which genetic conditions and relationships with facies and primary compositional controls are yet to be understood. Systematic reservoir quality prediction studies considering petrologic, geochemical and stratigraphic aspects as well as the integration of advanced petrographic characterization with log analysis, petrophysics, and seismics will be of key importance for the assessment of risks during the exploration of these and other complex reservoirs.

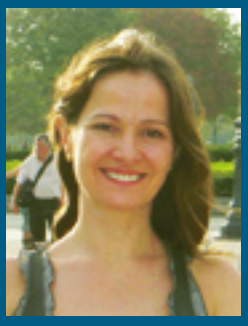
Petroledge®, a new generation software, was developed by the researchers at Endeeper to perform detailed petrographic descriptions and interpretations in a systematic workflow, and to store and process the petrographic information within a relational database. This software allows the easy acquisition and retrieval of petrographic information and its integration with other applications, such as 3-D reservoir modeling and flow simulation software.

We are crossing many new frontiers in exploration and production. The incorporation of petrographic characterization into robust, realistic reservoir quality models is one essential tool that will result in substantial increase in the exploration success and production recovery from complex reservoirs.

The authors

The authors are experts in Petrology and knowledge systems. Their work with Petrobras and other companies have led to the development of an intelligent database system that allows the integration of petrographic studies into reservoir models, as explained in the last section of this article.

Luiz Fernando De Ros is professor of Sedimentary Petrology at the Institute of Geosciences, UFRGS and a researcher at Endeeper Reservoir Knowledge Systems.



Mara Abel is a professor in Knowledge Engineering at the Institute of Informatics of UFRGS and Technical Manager of Endeeper.

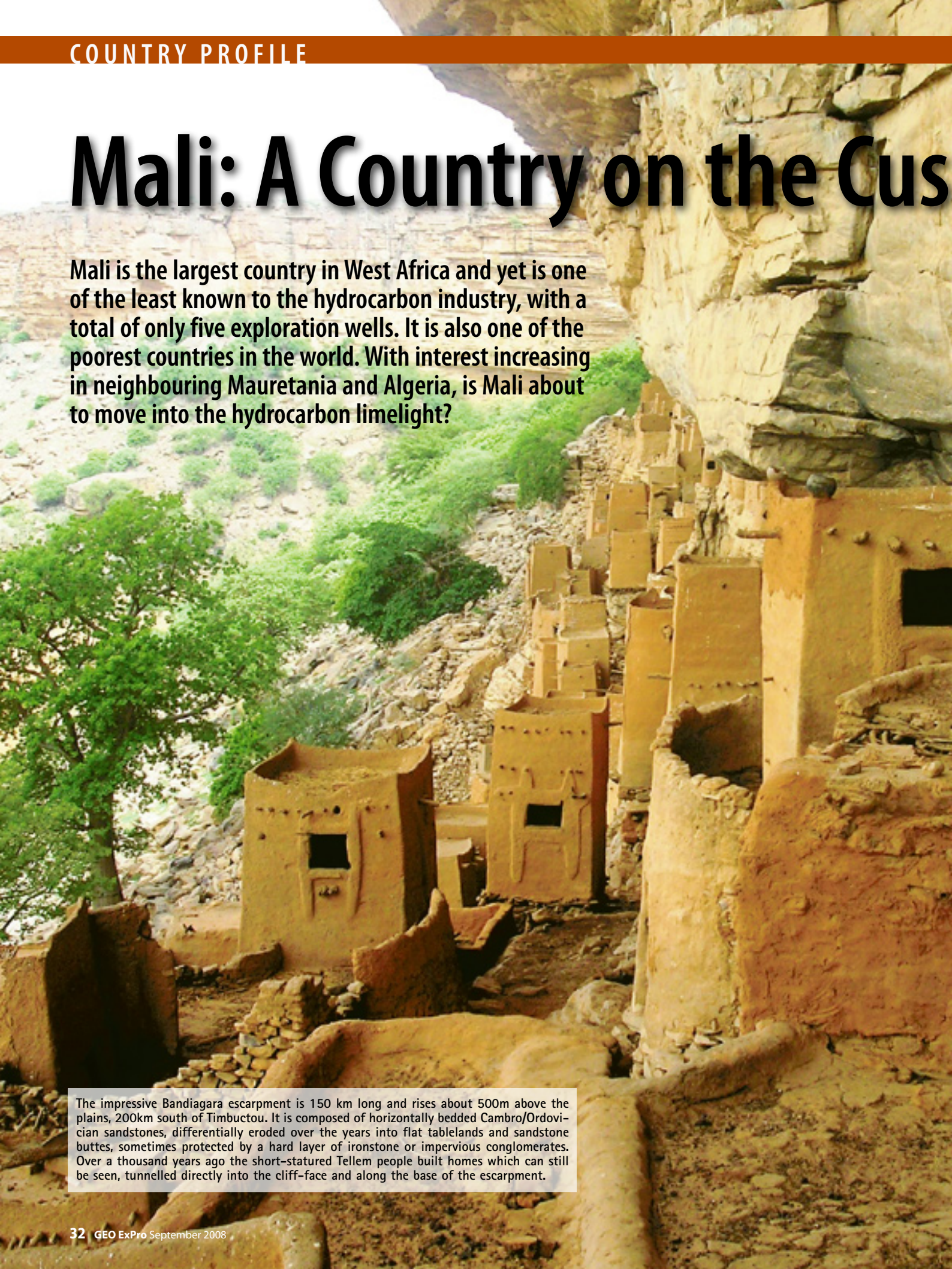
Karin Goldberg is a researcher of Sedimentary Petrology in the Petroleum Geology Program of the Institute of Geosciences at the Federal University of Rio Grande do Sul.

UFRGS

The Institute of Geosciences of Rio Grande do Sul Federal University (UFRGS) has a long tradition in petroleum geology research in cooperation with Petrobras and other companies. UFRGS Institute of Informatics runs the largest graduate Computer Science program in Brazil. Endeeper is a company created by researchers from the Geosciences and Informatics Institutes that develops innovative software systems for dealing with strategic information in petroleum exploration and other knowledge-intensive domains.

Mali: A Country on the Cus

Mali is the largest country in West Africa and yet is one of the least known to the hydrocarbon industry, with a total of only five exploration wells. It is also one of the poorest countries in the world. With interest increasing in neighbouring Mauretania and Algeria, is Mali about to move into the hydrocarbon limelight?



The impressive Bandiagara escarpment is 150 km long and rises about 500m above the plains, 200km south of Timbuctou. It is composed of horizontally bedded Cambro/Ordovician sandstones, differentially eroded over the years into flat tablelands and sandstone buttes, sometimes protected by a hard layer of ironstone or impervious conglomerates. Over a thousand years ago the short-statured Tellem people built homes which can still be seen, tunnelled directly into the cliff-face and along the base of the escarpment.

p?

Mali is the second largest country in West Africa, and interest in its hydrocarbon potential has been driven by successes in neighbouring Mauritania.

Photo: Paul Archer

Jane Whaley, Associate Editor

Mali, dominated by the ever-encroaching Sahara, is heavily dependent on foreign aid and vulnerable to fluctuations in world prices for cotton, its main export. However, some experts think the country may be sitting on large volumes of hydrocarbons, waiting to turn this poverty stricken country into a net exporter of oil.

Unexplored country

The existence of hydrocarbons in Mali has been suspected since reconnaissance airborne surveys in the 1960's. In the 70's and 80's several thousand line kilometres of 2D seismic were shot over the country, giving strong enough indications of potential resources for a few wells to be drilled. Poor results from these, coupled with a turbulent political history and lack of infrastructure, meant that the majors wiped their hands of the country, and no further serious investigations took place until 2004. But with rising prices and improved technologies, the industry is again looking for hydrocarbons in Mali, despite the remoteness of the country.

Australian Baraka Petroleum were the first to show renewed interest, taking five blocks in the north-western Taoudeni Basin in 2004. New airborne surveys were followed by seismic, while the first gravity and magnetic surveys of the southern Gao Graben since the 1970's were recently undertaken. The majority of the country is now licensed, and over ten companies hold acreage.

Five sedimentary basins

Mali has five sedimentary basins of potential interest, ranging in age from Infracambrian to Mesozoic-Cenozoic. Four of these are proven through drilling, with the fifth, the Nara Trough in the south-eastern corner of Mali, delineated through geophysical records. Most activity to date is in the Taoudeni Basin, partly due to its extension into Mauritania, a country which has itself undergone renewed interest in recent years.

As Jon North, CEO of Selier Petroleum, which has interest in a number of blocks in Mali, says, "The vast Taoudeni Basin, more than 1,000 km in diameter, has similar geology to the intracratonic basins of Algeria and Libya, but only 1 exploration well per 450,000 km² of basin area (equivalent to more than 70 UK North Sea quadrants). Considering this, Mali must be regarded as one of the last frontiers for onshore oil and gas exploration worldwide."


Photo: Jane Whaley

Dr John Scott has extensive experience in the oil and gas sector, beginning in 1971. He founded Petroleum Geological Analysis Ltd in 1979 and provides exploration advice and appraisal to clients throughout the world. Between 1987 and 1991, he was Professor of Petroleum Geology and Director of the Key Centre for Resource Exploration at Curtin University of Technology, Western Australia.


Photo: John Scott

The main target reservoirs in the Taoudeni Basin are Infracambrian carbonates, with massive fine-grained limey mudstones interspersed by horizontally laminated stromatolitic horizons. The primary reservoir potential of the carbonates is low, but fracture porosity is expected in the subsurface.

"Taoudeni Basin: 1 exploration well per 450,000 km²

Over 600 MMbo in underexplored basin

The *Taoudeni Basin* is one of the largest Early Palaeozoic Basins in Africa, with sediment thicknesses of over 5,000m in places. A 2006 independent evaluation of its potential, undertaken by industry consultants RPS Energy, suggested that just the five blocks held by Baraka Petroleum, covering half the Malian Taoudeni Basin, could hold as much as 645 MMbo and over 9 Tcfg. Very large leads mapped from seismic data suggest that this barely explored, high risk basin is worthy of further investigation, with evidence of both Infracambrian gas and Palaeozoic oil plays.


Photo: Paul Archer

The nomadic Touareg are the main inhabitants of the Saharan interior of North Africa, including Mali. They are famous for their distinctive blue head coverings and cloaks, traditionally covering the heads and faces of the men, while the women remain unveiled.

The basin is essentially a depression centred on northern Mali, comprising two megasequences. The oldest is Late Proterozoic to Early Palaeozoic, with clastics, shallow marine carbonates and interbedded black shales. This shale source and fractured carbonate reservoir system forms the main Infracambrian exploration target. In 1982 the only well in Mali to reach this level, Yarba-1, in the south-eastern Taoudeni Basin, reported gas shows in Infracambrian carbonates, although recent reprocessing of old seismic suggests that the well was probably not drilled on a closed structure. Abolag-1, drilled in 1974 to the west in Mauritania, flowed 480,000 cfgpd from Precambrian fractured carbonates. Organic-rich Infracambrian black shales, with TOCs (Total Organic Content) up to 20%, crop out along the northern margin of the Basin.

This Infracambrian petroleum system is the main interest for Mali Petroleum, which holds acreage in excess of 35,000 km² in the southern part of the Taoudeni Basin. It has mapped promising anticlinal structures, over 50 km long, which could house large hydrocarbon volumes. These are predicted to be primarily gas, with some condensate.

Links to prolific North African basins

The Infracambrian is overlain by Palaeozoic sediments, an erosional remnant of a major basin stretching from north-west Africa to Arabia, which links the Taoudeni Basin prospectively to the prolific Palaeozoic basins of Libya and Algeria. Potential reservoirs include Ordovician and Devonian sandstones, although initial geophysical evidence suggests that the Palaeozoic system is not as extensive as the Infracambrian. The only other well in the Malian part of the Taoudeni Basin, Atouila-1, had minor gas shows in the Siluro-Devonian.

The Taoudeni Basin shows interesting geological similarities to the productive North African basins, including the southern Algerian Reggane and Illizi Basins. These shared Early to Late Palaeozoic stratigraphy with the Taoudeni, covering the depositional interval of source, reservoir and seal rocks.

In the eastern part of Mali the Palaeozoic *Tamesna Basin* and overlying Mesozoic *Iullemedden Basin*, extend into neighbouring Niger and Algeria. Not much is known about these basins, as little seismic has been recorded and only two wells, In Tamat-1 in the Tamesna and Tahabanat-1 in the Iullemedden, have been drilled, both back in ▶

1983. The second of these recorded minor bitumen shows in the Lower Cretaceous and Upper Jurassic. With only these two wells on 80,000 km² of basin area, and similarities to the Cretaceous rift basins of Chad and the Palaeozoic sag basins of Libya and Algeria, as well as the probable presence of good Silurian source rocks, this remote area is worth further investigation.

"Evidence of Silurian source rocks in Malian basins"

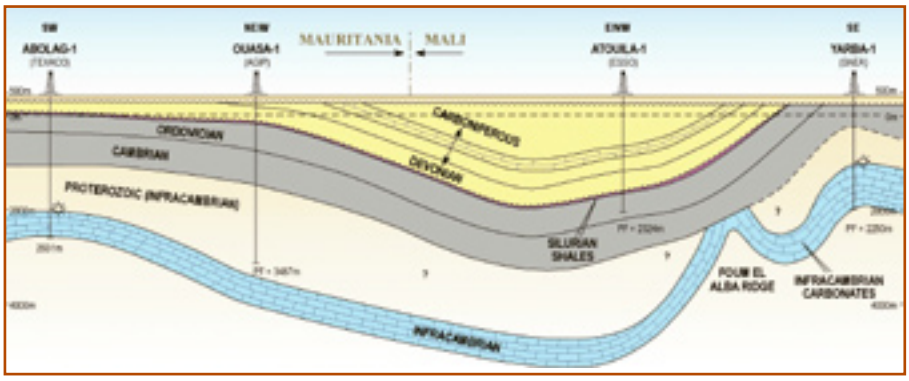


Image: Sphere Petroleum

Two of the four wells drilled in the Taoudeni Basin reached the target Infracambrian carbonates and both had evidence of hydrocarbons.

Half graben complex

Mali Petroleum also has a 37,500 km² block in the Gao half-graben complex in south-east Mali. This is part of the Central African Rift System, which formed during the Atlantic opening in the Cretaceous, extending from Nigeria and Mali in the west to Sudan and Kenya in the east and containing commercial oil in Chad and the Sudan. Only one deep well has been drilled within the Gao Graben, and one in its southern extension in Niger, both of which were dry. However, minor shows of both oil and gas were recorded in a shallow water well in the Gao Graben, indicating the presence of hydrocarbons in the area.

Dr. John Scott, Technical Director of Mali Petroleum, believes that reprocessing old seismic data has shown the potential of this area. "Ansongo-1, in the Malian sector, found predominantly sandstones and siltstones, without thick shale layers, but we think that in a classic continental half-graben complex such as this, considerable facies change can be expected down dip. We expect older lacustrine sequences which may contain potential source rocks in the deeper parts of the graben complex. Similar systems are known in grabens in the Central African Rift System and elsewhere."

In the south-west of Mali there is a totally unexplored basin, the **Nara Trough**, which is recognised solely from gravity and magnetic data. It is presumed to be of Mesozoic origin but may be Infracambrian, and aeromagnetic data suggests that it may contain a sedimentary section up to 14,000 m thick.

Geological and practical challenges

Unlike many of its neighbours, Mali has a progressive, democratic government and a reputation for being fair and open. Keen to encourage foreign investment, in 2004 it introduced a new petroleum law

Photo: Paul Archer

About 65% of Mali is desert or semi desert, and less than 2% of the land is cultivated, although agriculture is the main occupation of the majority of the population.

Ancient Cross roads of Africa

Photo: Paul Archer

Mali is famous for its elaborately decorated mosques and houses made from dried mud.

Although Mali is now among the poorest countries in the world, it has a long and illustrious past. The Malian empire reached the peak of its power and wealth during the 14th century, when it extended over almost all of West Africa and controlled the rich trans-Saharan gold trade. During this period Mali's great city of Timbuktou became a fabled centre of wealth, learning, and culture. The region's importance as a trading centre collapsed when the Saharan trade routes were supplanted by European ships.

About ten times the size of Great Britain, Mali is one of the largest countries in Africa. However, 65% of its land is desert or semi-desert, and economic activity is largely confined to the area irrigated by the Niger, meaning that the country is not self-sufficient in food. The Niger is also a major local transportation artery, but with the exception of rivers in the south of the country, other routes are limited, with very few paved roads.

In spite of the successful implementation of an IMF economic programme to help the economy, the country remains very poor, and dependent on foreign aid, with a highly unequal distribution of wealth. Almost half the population of about ten million are under the age of 15, life expectancy is less than 50, and one in every ten babies die in their first year.

aimed at attracting new entrants. This has been remarkably successful, and only a few blocks remain unlicensed.

Whether Mali ultimately enters the club of hydrocarbon producing nations will depend on the result of the ongoing analyses of the various basins. As well as questions about the viability of proposed reservoirs and the existence of sealing rocks, the level of maturity of the potential source rocks is unknown. The Taoudeni Basin, for example, is extensively intruded by Jurassic dolerites, which could have locally destroyed reservoir potential. In addition, the sills have proved a problem in the interpretation of old seismic data where they can cut bedding planes, giving rise to false anticlines. Detailed investigations to determine the extent and influence of these intrusives are required. Some answers may soon be delivered, as Mali Petroleum hope to drill in the Taoudeni Basin in 2009.

Practical issues in exploration revolve around the remoteness of the country and its lack of infrastructure. Mali is landlocked, and the eastern basins of Geo and Iullemeden are about 1,000 km from the Gulf of Guinea coast. Roads are very poor and the nearest hydrocarbon pipelines are many miles away, although there are suggestions that a spur to the proposed Nigeria to Algeria gas reticulation line could be built if sufficient resources were discovered in the Malian sector of the Taoudeni.

Gauntlet thrown down

Mali remains a basically unexplored country, offering excellent frontier basin opportunities to companies prepared to take the challenge. It remains to be seen how many of those who take up the gauntlet will be successful, but it will be interesting to follow their fortunes.

The Dogon: A Unique Culture

The Bandiagara escarpment is home to the Dogon, a tribe famous for their culture, wooden sculptures and mythology, and one of the few African peoples to successfully retained their culture and traditional way of life through colonial times. Theirs is such a unique culture that in 1989 the Dogon country was declared a UN World Heritage site.

Religion, social life and art are all interlinked in the complex culture to reflect an awareness of the harmony between the human spirit, the land, and surrounding animal life. They worship their ancestors and the spirits which inhabited them in the past, and have a complex mythology which appears to include a remarkable understanding of cosmology. Intricate ceremonies, some of which take several months to complete and only occur every fifty or sixty years, involve wonderfully carved and decorated masks.

Having been relatively isolated for centuries, the Dogon are now one of the main tourist attractions in Mali. The usual way to visit them is on foot, trekking several days to visit some of the 500 or so Dogon villages, some only accessible via steep paths along fissures in the cliff face. However, the influx of tourists means that Dogon culture, which withstood centuries of pressure from Islamic conquerors, Christian missionaries, empire builders and slave traders, is now under serious pressure. Many wooden carvings and other sacred artefacts have found their way out of the country and into the antique markets of the western world, and the profits of tourism are poorly distributed among the people.

The Dogon live in mud-brick buildings, often with elaborately carved doors and shutters, in family compounds which contain granaries topped with distinctive conical straw roofs.

The Dogon were isolated from modern life for centuries, but the recent influx of adventurous tourists has brought changes and introduced western goods to their traditional way of life.

Building a Successful A

Afren is a young business with ambitious plans: to become the premier pan-African independent oil and gas exploration and production company.


Photo: Afren

Jane Whaley, Associate Editor

Although only founded in late 2004, Afren has expanded rapidly and now covers seven countries in West and Central Africa. The company expects to produce 15 to 20,000 bopd in 2008, a remarkable achievement for such a young organisation.

Partner of choice

"At Afren we have a distinct business model, which seems to be proving very successful," explains Nick Johnson, Head of Exploration and New Ventures. "We aim to build the company through the full exploration, development and production cycle by partnering with indigenous African companies and governments and thereby acquiring equity stakes in exploration and development assets."


Photo: Jane Whaley

Dr. Nick Johnson has a degree in Geology from Bristol University and a PhD from University College London. He worked for BP as an Exploration Geologist before joining OMV in 1991, where he became Head of Global Exploration and Reservoir, responsible for the technical quality and development of OMV's global portfolio. He is currently Head of Exploration and New Ventures at Afren plc, a role he took up in September 2005.

Afren has a strong African orientation in its shareholders and partners, and the Chairman is Dr Rilwanu Lukman, former President and Secretary General of OPEC and currently advisor to the President of Nigeria. "We operate in Nigeria, Sao Tome and Principe JDZ (Joint Development Zone), Gabon, Congo, Cote d'Ivoire, Angola and Ghana, have offices in Lagos, as well as London, and our management and staff have a great track record and a deep-rooted knowledge of Africa," Nick explains. "We believe that this enables us to be the partner of choice for African National Oil Companies, indigenous organisations, and Governments.

"When we floated on the London stock exchange in early 2005, we had just one single asset, part of a block in the JDZ," he adds. "We now have 16 assets in seven countries, and the market value of the company has grown to more than 20 times its initial value, while the share price has more than tripled since floatation."

Since this is the sort of growth that many companies would aspire to, it is interesting to consider the way in which Afren have built this successful portfolio, and the criteria they use when assessing possible assets.

Rapid portfolio expansion

"To be successful, you must have a clear idea of what you want your portfolio to look like, but, at the same time, you can't wait for your 'dream' assets to become available." Nick says. "In addition to our distinct geographic focus, we know what we are looking for: acreage which we can take through the full E&P cycle. This usually includes proven undeveloped fields which have been held by the majors but undervalued, and therefore underexplored. We have been involved in the reactivation of a number of fields onshore Nigeria, which we were able to prove have the potential to be good, efficient producers. We are quite opportunistic and don't have hard and fast rules, as shown by our recent move out of onshore and shallow water into deepwater assets in Ghana, but tend to avoid tectonically complex areas, which require equally complex – and expensive – solutions, and are best left to the majors."

"In Africa there are no rigid rules about accessing the best opportunities, and deal execution with government approval is always a challenging process, although having Dr. Lukman as our Chairman helps, as he has many high level contacts. Having identified potential acreage, we undertake an opportunity screening process with extensive technical evaluation. We consider

frican Portfolio

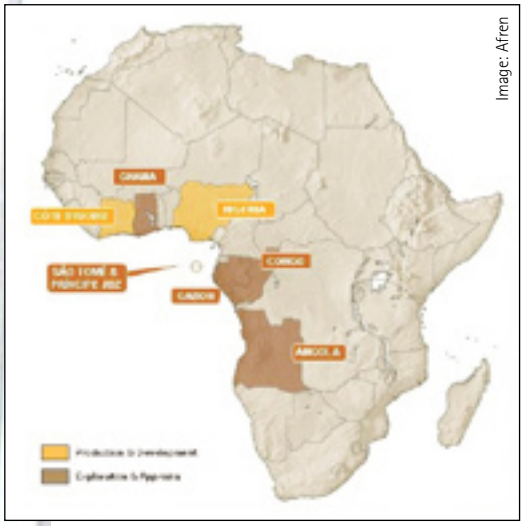


Image: Afren

Afren believe that an important part of portfolio management is a broad and balanced spectrum, with exploration, appraisal and production, as demonstrated by its present range of assets.

Afren prides itself on its competent and skilled indigenous workforce, and its Senior Management Team in Nigeria are all local.

that peer review is essential, but being a small company, we have had to devise our own method to ensure we can achieve this, usually using external consultants. Basically, it is big company methodology applied to a small organisation."

> *"Any successful oil company, whatever its size, needs to be strong technically, operationally and commercially.*

Obviously, as with any company, funding and financial risk are key, so having made the internal technical decision that an asset is interesting, commercial evaluations and negotiations are crucial. The degree of financial exposure and risk, and decisions about equity level, control and operatorship are fundamental to the potential success of a project, and in this area Afren rely on the strong financial background of the management team. "Any successful oil company, whatever its size, needs to be strong in all three areas," Nick concludes, "technical, operational and commercial."

Broad balanced spectrum

Nick believes that an important aspect of portfolio management is the maintenance of a broad and balanced spectrum. "We have an exploration portfolio with over 20 identified prospects, and a high impact exploration drilling programme for 2008," he explains. "On the development side, we recently announced first oil from Okoro Setu, in shallow water offshore Nigeria. This is a major milestone, only two years after signing the agreement with our indigenous partner, although the field was originally discovered back in the 1970's. Further appraisal and development drilling on our other Nigerian assets is also planned."

As part of its portfolio development, Afren recently acquired all of Devon Energy's assets in Cote d'Ivoire. "This has given us a ready platform with significant upside, gaining immediate production of about 3,000 boepd, and 16.7 MMboe of undeveloped reserves," Nick explains.

"We intend concentrating solely on West Africa for the moment," he adds. With the world class resources to be found in that part of the world, a solid financial position and established track record, and excellent production and reserves growth, it would appear that Afren's strategy for portfolio growth is a successful one.

Local women peeling cassava at a Shell community employment opportunity project, which also facilitates the construction of small factories and provides on-the-job training to factory workers.

Photo: Mieko Mahi/Shell

Oil in Nig

As Nigeria is overtaken by Angola as Africa's largest oil producer, is it true that the discovery of oil 50 years ago has been more a curse than a blessing? And what can the oil industry do to help?

Jane Whaley, Associate editor

Nigeria is the eighth largest exporter of crude oil, with over 36 Bbo proven reserves, according to the Oil and Gas Journal. Oil brings billions of dollars in export revenues annually into the country. Yet the Nigerian people remain some of the poorest in the world. More than 70 in every 1,000 babies die before their first birthday, average life expectancy is less than 46 and only 33% of the population have access to adequate sanitation. The amount spent annually on health services is $23 per head, contrasting vividly with over $6,000 per person a year spent in the US. Equally amazing in a country that exports 2.5 million barrels of oil a day, is the fact that only about 40% of Nigeria's total population - 10% in rural areas - has access to electricity.

After more than 50 years in the country, can the oil industry help Nigeria - or is it too late?

Dollars flooded in

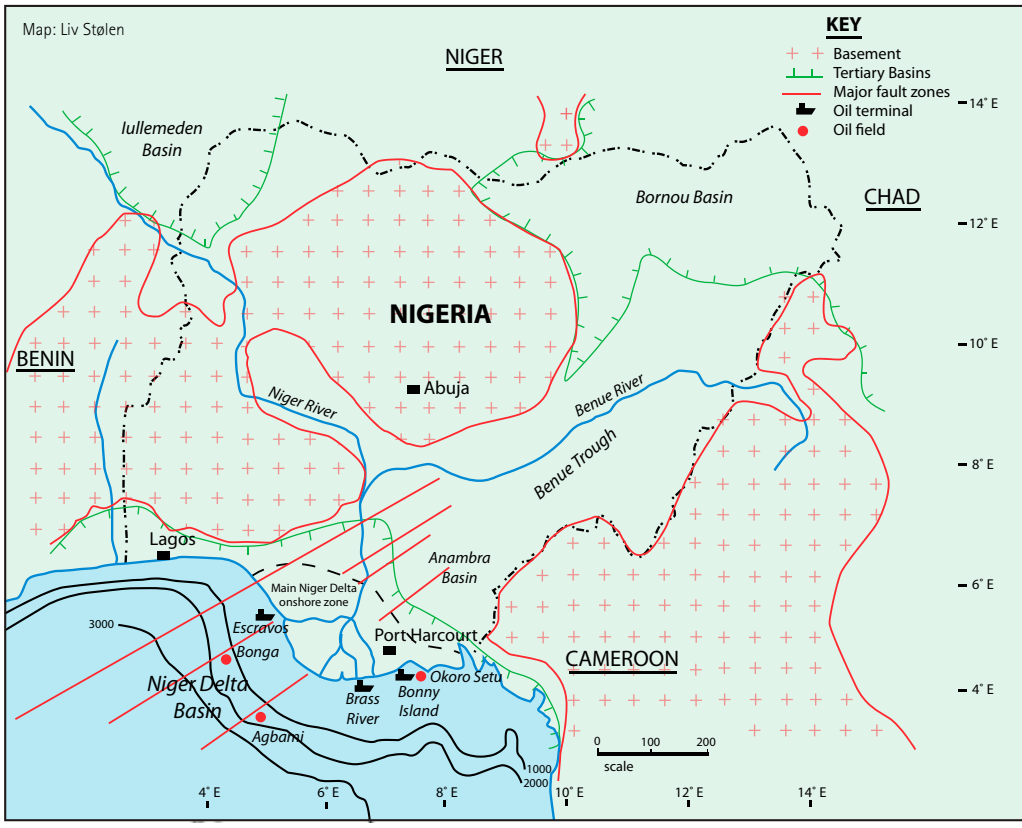
Hydrocarbon exploitation in Nigeria began at the end of the 19th century, using surface oil seeps to the east of Lagos. Shell drilled the first exploration well in 1951 and, together with BP, made the initial commercial discovery, 50 miles west of Port Harcourt in the Niger Delta, in 1956. The earliest offshore discovery came in 1963.

In 1960, when Nigeria gained independence from Britain, production was 17,000 bopd, rising rapidly to 1 MM bopd by 1970. Major and independent companies came flocking to the country when it joined OPEC

eria – Curse or Blessing?

in 1971 and nationalised the oil industry through the creation of the forerunner of the present Nigerian National Petroleum Corporation (NNPC). Any company wishing to explore for oil entered into a joint venture with the NNPC, so that the state effectively owned about 60% of all multinational oil projects onshore, whilst the oil company paid most of the exploration and development costs. Over the years hundreds of billions of dollars have flowed into Nigeria from oil revenues, contributing over 90% of the country's total economy, but a combination of inefficiency and endemic corruption means that a massive 70% of oil revenue effectively 'disappears'.

As a result, most Nigerians live on less than one dollar a day and the country, which used to be a net exporter of agricultural products, imports more food than it produces. Even more staggering is the fact that Nigeria actually buys in refined fuel, because its refineries break down so frequently that there is always a paucity of supply.



Nigeria, Africa's most populous country, has proven reserves of over 36 Bbo and 150 Tcfg (25 Bboe) in the Niger Delta, an area of swamps covering about 70,000 km².

Rise in insurgency threatens security

One of the major disincentives to exploration in Nigeria in recent years has been security. Armed robbery and street crime are rife, and the police force is unable to deal with the problems. Never considered one of the safest of countries, the transition to a form of democracy in 2003 did not result in an increase in stability, with instead a rise in insurgency groups, particularly in the Niger Delta.

> *"Rise in insurgency threatens production*

One of the main militant groups, MEND (Movement for the Emancipation of the Niger Delta), targets foreign multinational companies involved in the oil industry, blaming them for the poverty and exploitation of local people and associated pollution, which has turned many of the once fish-rich creeks into stagnant pools. This group have the stated aim of destroying the capacity of the Nigerian government to export oil. They have had some degree of success, through bombing pipelines and attacking installations, and it is estimated that at the moment as much as a quarter of Nigeria's production is kept off the market by militant violence.

Nigerian hopes lie in deepwater

This violence, coupled with poor returns after government take from onshore and shallow water contracts, has enticed many major oil companies into the deeper waters off the Niger Delta, where the government take is lower. Estimates of ultimate recoverable oil reserves in the deepwater are as high as 20 Bbo, and the potential for large and giant discoveries is high. Chevron's massive Agbami Field, for example, which went on stream in July this year, covers 182 km² and contains recoverable reserves of approximately 900 MMbo.

The first field to go on production in water depths over 1,000m (3,300 ft) was Shell's Bonga Field, in 2005, which was discovered in the mid 1990's, illustrating a major issue with Nigerian deepwater fields; the time lapse between discovery and first production. The field, operated by Shell on behalf of NNPC with Esso, Agip and Elf is reported to contain reserves of 6Bboe, with the company aiming to produce more than 2MMbo and 150 MMcfg per day.

Exploration has been moving into even deeper waters, with recent wells in depths in excess of 2,700m (9,000ft). However, the hope that moving offshore will remove oil operations from the sphere of the rebels was shattered in June this year, when MEND attacked and closed down the Bonga complex, 120km offshore. As well as indicating that Nigeria's oil platforms are within range of attack, it effectively shut down 10% of the country's oil production for several weeks

The Bonga Field was the first deepwater field to come on production. It was awarded to a consortium lead by Shell in Nigeria's first deepwater round in 1993, discovered in late 1996 and came on stream in 2005. Production is through one of the world's largest FPSO (Floating Production Storage and Offloading) vessels, which has a capacity of 2 MMbo.

in a single attack. MEND called a unilateral ceasefire a few days later, but whether this will be effective has yet to be seen.

Local participation important

Just a few western oil majors produce around 95% of the oil, but the Nigerians are keen to see many more indigenous companies involved in the oil industry. A 2003 licensing round offering a number of abandoned and marginal fields in the onshore Niger Delta proved popular with indigenous organisations in partnership with smaller companies like Afren (*see separate article*). Most of the fields involved in this have recoverable reserves of less than 20 MMbo, too small for the majors, but profitable to small scale operators.

A lot of effort is also being put into using local people in the industry. Most companies, whether national or international, believe that it is important to involve locals at all levels, both in the community and through employment. Chevron's Agbami deepwater project, for example, notched up 300,000 man-hours by Nigerians during the building of the FPSO. It is crucial to provide employment not only in manual labour, but also in professional occupations, to ensure that the trained and entrepreneurial elite stay in the country.

First oil from Chevron's Agbami Field, in water depths of 1,400m (4,700ft) was achieved in July 2008. Initial production is expected to be over 100,000 bopd, projected to increase to 250,000 boepd by thwe end of 2009.

"Gas reserves in excess of 150 Tcf

Bergen Oilfield Services

Bergen Oilfield Services AS (BOS) is a Norwegian offshore seismic survey company with a focus on subsea technology commercialisation. We manage the whole value chain from vessel ownership, data acquisition through to processing – ensuring a high-quality and on-time response.

The organisation is driven by the continuous pursuit for quality of services, innovative solutions and expertise of employees. At all stages of our operations, safety, quality and environmental preservation are paramount.

Chief Geophysicist

High competence – Strong influence – Exciting challenges

Bergen Oilfield Services (BOS) is seeking to employ an experienced Chief Geophysicist to be the "geophysical leader" within the company. The position reports to the CEO.

The Chief Geophysicist will be responsible for developing a geophysical strategy to complement BOS' long term business objectives and communicating this strategy to internal and external stakeholders. Therefore, the successful candidate will possess excellent communication skills with the ability to interface with BOS' clients, partners and employees, and have a dynamic, hands-on approach to delivering geophysical services.

Main activities:

- Develop and communicate the BOS geophysical strategy
- Interact with BOS' clients regarding the geophysical integrity of our services
- Investigate new and emerging technologies and geophysical methods applicable to the oil and gas industries
- Provide geophysical insight and solutions to the BOS mission of providing integrated geophysical services.

Preferred qualifications:

- Master's degree in geophysics.
- 10 or more years experience in an oil/seismic company
- 3–5 years in manager/supervision position
- Data processing experience (ideally)

Bergen Oilfield Services offers an informal and international working environment, competitive salary, and good insurance and pension schemes.

For further information, please contact VP – Business Development Svein Kjellesvik at Bergen Oilfield Services AS, tel. +47 905 32 906; or Mercuri Urval, Knut N. Eide, tel. + 47 975 59 054, Bjørn Liland, tel. +47 975 59 059. Please submit your application at **www.mercuriurval.com** with reference code "NO-KNE-18746" as soon as possible. All applications will be treated confidentially, also towards BOS if desired. We accept applications in English or Norwegian.

Mercuri Urval

He untapped gas reserve

Although Nigeria contains large volumes of oil and has over 300 producing oil fields, it is also a major gas province, with proven reserves estimated to be in excess of 150 Tcfg (25 Bboe). Most of this is associated with oil, and as a result gas was usually flared in the past, or reinjected to enhance oil recovery. After 2008 flaring will be illegal, and this valuable resource will start to be harnessed.

At present, Nigeria has the capacity to process over 200 MMboe of LNG and gas liquids annually through the 6 LNG trains at Bonny Island on the south coast, about 60 km south of Port Harcourt, as well as through other terminals and floating processing plants. International investment is sought for gas projects ranging from new gas-to-liquids plants to proposed pipelines across the Sahara and along the West African coast, as well as domestic market projects and local power stations.

As a result, interest in previous gas discoveries, shut-in due to the lack of a market, has increased considerably in recent years. These fields are mostly centred on the Niger Delta, but some are in the Anambra Basin to the north, opening up a less well known area to exploration. The Nigerian Government has launched a number of initiatives to encourage the development of these resources.

Pressure for peace

As can be seen, the challenges facing the hydrocarbon industry in Nigeria are plentiful – but so are the rewards. Growth will depend largely on deepwater success, but crucial to this is also the effective exploitation of the vast gas resource. A restructuring of the industry to be more operationally efficient is needed, in order to attract foreign investments. Government attitudes towards contracts and the time taken to approve field development programmes are also important factors.

"Growth depends on deepwater success"

However, the over-riding question is whether the security situation can be improved to control disruptions to exploration and production, particularly in the Delta region. That this is a huge problem, which can mainly be laid at the feet of the Government and ruling classes, is not in dispute,

Community Development – Sustainability is Key

"For oil companies to undertake effective development work in the Niger Delta, it is vital to identify the key people in the community," explains Andrew Olleveant, Head of Afren's Environment, Health, Safety and Social (EHSS) programme. "For our Okoru Setu project, situated in shallow water 12 km from the coast of the south-eastern Niger Delta, we work with a well-established community group, the Eastern Obolo Community Development Foundation. Transparency and sensitivity is crucial in these dealing, and the Foundation help us and our partners to identify projects which will contribute towards making a significant and lasting impact on wealth creation and sustainable livelihoods."

"People want jobs as a priority, so we actively recruit from the local community for jobs on the FPSO, giving people transferable skills, like mechanics and IT. Our initial projects are relatively short term but are important for confidence building, such as a micro-credit fund, assistance with healthcare provisions and college scholarships."

"We are now moving on to projects with medium to long term impact, where sustainability is crucial," Andrew continues. "It is no good drilling a water borehole, if we don't ensure that local people are able to keep it going, through appropriate training and access to parts. Similarly, the creation of a local health clinic also requires community education to guarantee it is used properly."

"Our intention is to contribute towards making a significant and sustainable impact on the lives of people in the area of our operation."

Photo: Afren plc

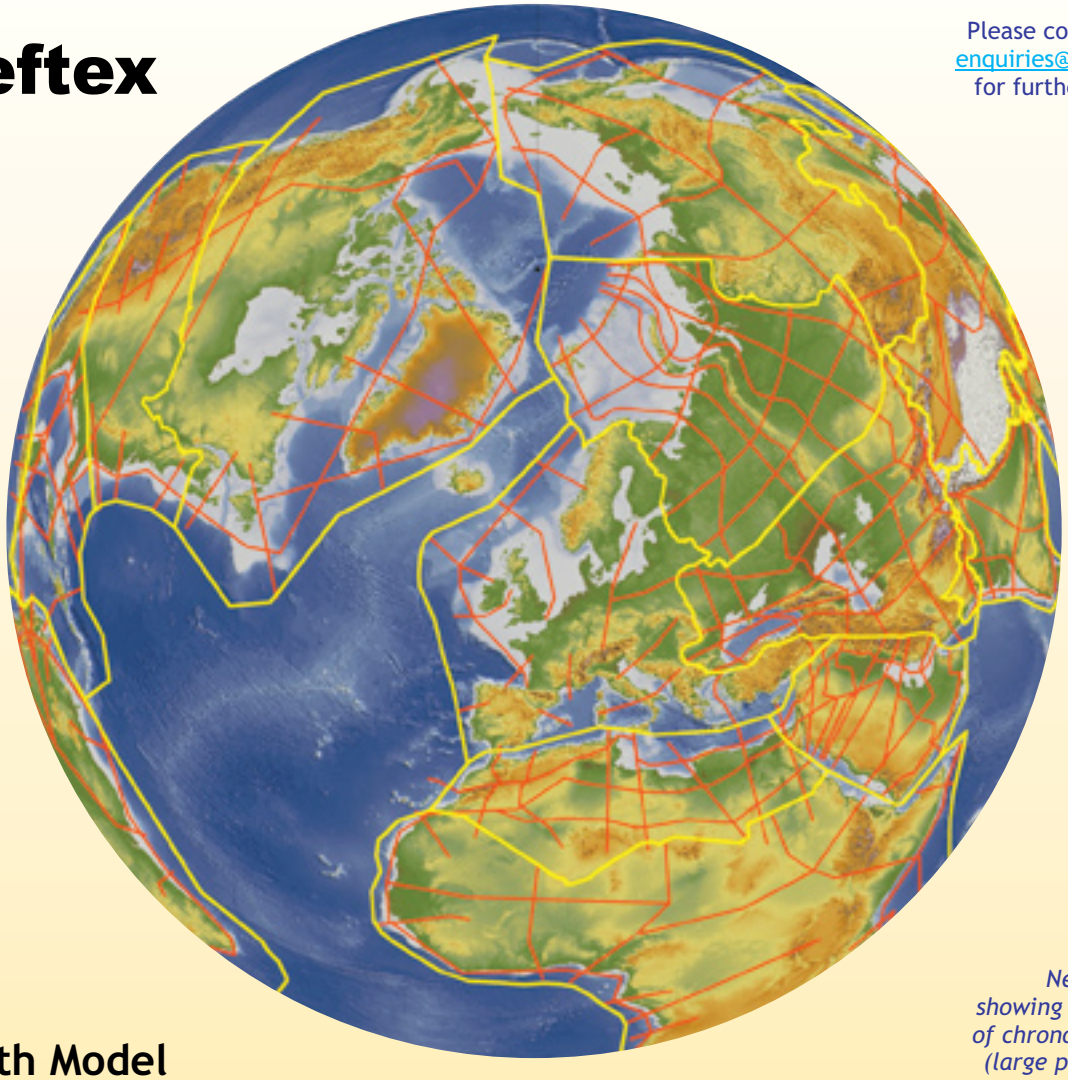
Some of the $46,000 donated by Afren in the Obolo area in 2007 helped fund a small local clinic.

Photo: Afren plc

Last year Afren provided 78 Secondary and Tertiary level education scholarships for young people in the Niger Delta Obolo area.

Neftex

Please contact us at
enquiries@neftex.com
for further details.



Neftex Regions showing current lines of chronostratigraphy (large panels 3' x 4')

Neftex Earth Model

Neftex is developing a 3D Earth Model using its own independently constructed sequence stratigraphic framework mapping over 100 sequences at global scale to unify subsurface petroleum geoscience.

- *Unifying databases, workflows, exploration and development assets*
- *Optimising team synergies, finding and accelerating new opportunities*
- *Delivered digitally from our website within 2D and 3D models*
- *Enhancing efficiency and competitive advantage*

Our Earth Model is available as individually licensed Regions and includes the following integrated products contained in the Modules below:

Products

- *Thousands of palaeogeographic maps in GIS*
- *Thousands of interpreted digital wells*
- *Detailed chronostratigraphic charts (above)*
- *Global tectonic elements in GIS*
- *Cross-sections, depth and isopach maps*
- *Petroleum occurrence and play analysis*
- *Global leads & prospects*
- *Global portfolio of play schematics*

Region Modules

- *Base*
- *Outcrop*
- *Biostratigraphy*
- *Source rock*
- *Reservoir & seal*
- *Play fairway*
- *3D exploration*
- *Geodatabase*

Delivering Excellence in Petroleum Geoscience

Photo: Elise Hay Opsahl

Nigerian women from the lagoonal area west of Lagos. Women traditionally undertake much of the agricultural work as well as domestic duties.

but the oil industry needs to be prepared to accept some of the blame. Assistance by oil companies to communities affected by the industry has been huge in monetary terms, running into billions of dollars, but it has proved difficult to channel it in the most valuable direction. Recent projects working closely at ground roots level with local people should show better returns. Industry efforts to improve the heavily polluted environment have increased in recent years, although continued attacks on pipelines do not help these endeavours.

Can the oil industry, as well as the international community, put pressure on Nigeria to bring some peace to the country, through fairer wealth distribution and an increase in social justice? Every effort must be made by all concerned, as the problems in the Niger Delta, through their effect on the price of oil, are assuming global dimensions. The industry must play a major role in bringing stability to this troubled country.

Photo: Elise Hay Opsahl

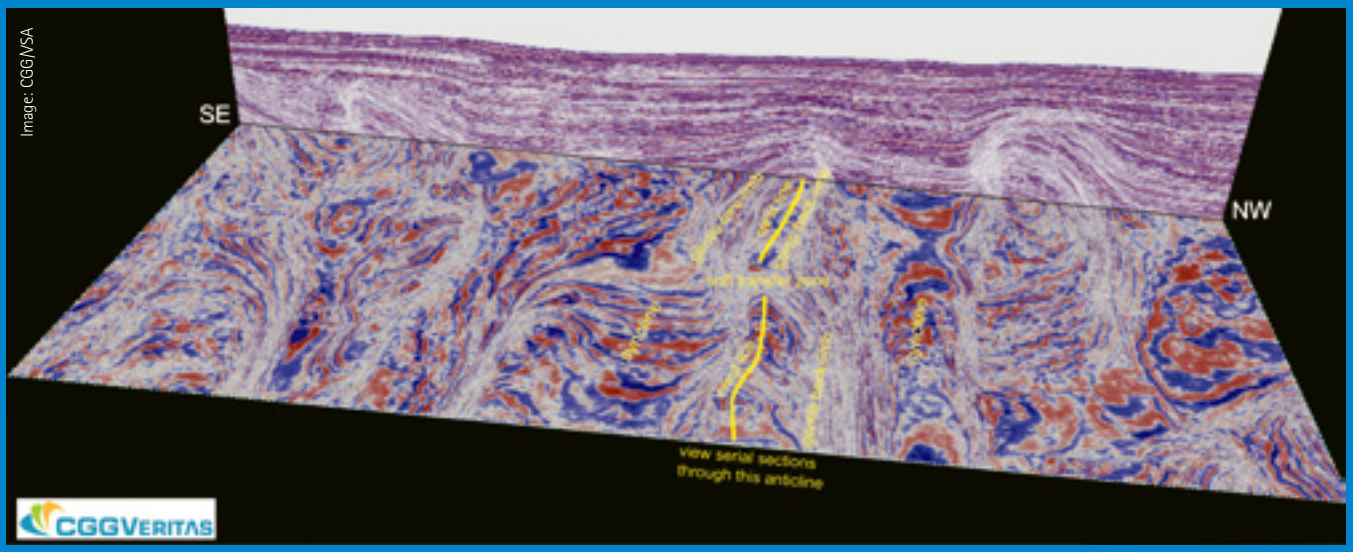
Workers on a drilling rig south of Port Harcourt.

Niger Delta Petroleum Geology

Petroleum systems in Nigeria date from Early Cretaceous times, as South America and Africa split apart, to the major sequences deposited during the Cenozoic. However, the majority of hydrocarbons come from the Tertiary sediments of the Niger Delta, both on and offshore.

The Niger Delta comprises a 'coarsening upward' sequence of Tertiary clastics over mainly Cretaceous sediments, forming a thick sedimentary cover as the deltas of the Niger and Benue Rivers developed. These sediments constitute the prolific petroleum systems of the Niger Delta. Basal marine shales, probably the main source rocks, are overlain by mainly unconsolidated delta-front reservoir sands, which exhibit excellent reservoir properties, with porosity of 40% and permeability up to 5,000 mD. Intercalating shales function both as additional source rock and as seals, and are overlain by sands thick enough to have created sufficient overburden for maturation. Migration pathways were provided by the laterally extensive sand units.

The oil found in the Niger Delta is a



A fold-thrust structure in deepwater, western Niger Delta.

'sweet' low-sulphur crude, typically in the 35-45° API range, paraffinic and waxy. The identity of the major source rocks has long been the subject of debate, primarily because there is no single rich source rock in the conventional sense, and while the assumption is that hydrocarbons are sourced from the Tertiary, there is some evidence for an older, Mesozoic origin.

The majority of traps in the Delta are structural, with syn-depositional growth-faults, rollover anticlines and collapsed crest structures all featuring. Complexity increases offshore, as shale tectonism and diapirism due to rapid sedimentation and over-pressure, is common. In the deepwater delta there is a complex pattern of channels, fan lobes and turbidites on a grand scale. Stratigraphic traps are more likely on the flanks of the basin and in ultra deepwater.

(For a more detailed description of the petroleum geology of the Niger Delta, see GeoExPro 2006 no. 4/5)

GEO EXPRO, TOGETHER WITH IHS, PRESENTS SOME OF THE MOST SIGNIFICANT DISCOVERIES MADE THROUGHOUT THE WORLD IN RECENT MONTHS.

Jane Whaley, Associate Editor

How much oil?

Our energy future depends on oil. The question is if how much is down there and if we are able to get it out of the ground fast enough.

Conventional oil and gas collectively now accounts for about 50% of world energy production, including a daily output of approximately 80 million bo and 46 million boe of natural gas, out of a total of 250 million boepd. The total includes **renewables** such as solar, wind, waves, geothermal, biofuels, hydroelectricity and biomass (16%), as well as unconventional hydrocarbons and nuclear.

"If we are going to have any sort of understanding for the future of energy delivery over the next few decades, we have to understand the future of conventional oil and gas," Ken Chew of IHS said in his keynote speech at the 33rd International Geological Congress in Oslo in August.

Conventional oil and gas make up almost 50% of our current energy mix.

"Discovered hydrocarbon liquids amount to some 6.5 trillion barrels in-place, some 1.1 trillion barrels of which have already been produced, while a further 1.2 trillion barrels are currently estimated to be recoverable. These remaining recoverable resources, currently concentrated in the Middle East but with significant volumes also in the Former Soviet Union, could be further enhanced by additional exploration in a number of key geological provinces and by increasing the recovery factor from existing fields," Chew said. He added that the IHS estimate of

Dr. Ken Chew of IHS gave a key note speech at the 33rd International Geological Congress in Oslo in August entitled "Conventional oil and gas: the global endowment."

global liquid resources in place amount to **13.4 Bbo**, a figure that includes both conventional and unconventional oil, meaning that **only 11% has been produced**.

"While production of hydrocarbon liquids and natural gas continues to increase, the rate of discovery of new accumulations appears to have peaked in the early 1960s for oil and early 1970s for gas, giving rise to concerns that production may also peak in the not-too-distant future," Chew continued.

The "key issue" is, according to Chew, when liquid production began to exceed the volumes of liquids discovered each year. The cross-over point was in 1996. "Since then, we have but one exception failed to discover as much liquids as we are producing. Obviously this is critical. Should we be worrying about it?" the experienced geologist asked, while showing a picture of bicycles replacing cars as our mode of transportation.

His own answer to this provocative question was to remind us that future production is based on what we might consider to be 4 pillars: discovered resources, reserve growth ("getting more out of what is already discovered", referring to how Apache made a "discovery" of 150MMbo by reversing the declining production when they took over the Forties field from BP), yet to find and unconventional resources.

Chew went on to point out that the resource numbers he had presented ("remaining recoverable world liquid resources") is a low-end estimate. On the positive side is that the estimate for North America only includes proved resources, i.e. the most likely recoverable resources. Furthermore, only developed resources are included, resource growth is not included, and no allowance is made for "yet to find" discoveries.

"In addition to future discoveries and additional recovery from existing fields, production growth in future will also come from less conventional accumulations of oil and natural gas," Ken Chew concluded.

The beginning was unconventional

Neither of the earliest significant commercial production operations for natural gas (shale gas, New York State, 1821) or oil (shale oil, Scotland, 1851) came from what we today consider to conventional hydrocarbon accumulations. Despite these unusual beginnings, oil and gas production from conventional hydrocarbon accumulations has a history going back 150 years.

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imaging beneath the salt

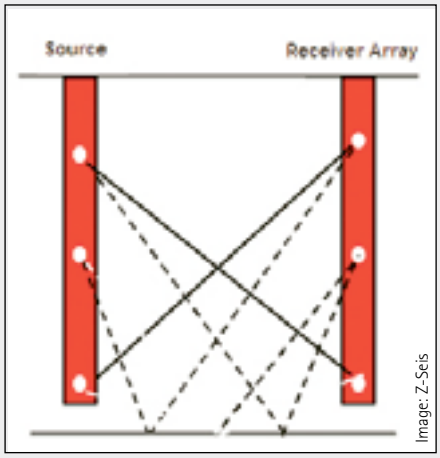
A Revolution in Resolution

The need to maximise recovery has spelt success for a seismic technique which hugely increases reservoir knowledge.

Jane Whaley, Associate Editor

Z-Seis is a specialist seismic company concentrating exclusively on the acquisition and processing of high resolution seismic between wells, known as Crosswell imaging, which can provide up to 100 times the resolution of conventional surface seismic. "Surface seismic provides a view of the earth from above, but our imagery gives us far more data from within the reservoir," explains Mark McCallum, Director of Business Development with Z-Seis. "It gives us valuable extra information and fills in the unknown parts of the puzzle."

The technique uses a seismic source emitting a high frequency (100 – 2,000 Hz) sonic 'chirp', which is lowered into a well, with the receiver array placed at the base of one or more adjacent wells. By gradually moving the source up the borehole, a fan of data is obtained, which is enhanced by changing the position of the receivers and repeating the process a number of times. Intricate data processing then produces both 2D and 3D images and models of the subsurface.



Seismic signals are sent from a borehole to a number of adjacent wells, and both direct arrivals and reflections from horizons above and below the source and receiver positions are processed to produce a wealth of high resolution data about the reservoir and surrounding subsurface.

Useful throughout field lifecycle

"Crosswell imaging is useful throughout the exploration and production lifecycle," Mark says. "For instance, in the early exploration stages it can be used to create a detailed characterization of the reservoir from the outset, as well as to identify pools missed by previous seismic surveys. It lets the geologist build up a very detailed image of the reservoir, allowing accurate placement of wells, which can ultimately reduce the total number required."

"During primary recovery the technique assists in further accurate reservoir delineation, and also helps target the highest porosity and the best potential producing zones. For example, in a survey we undertook recently in Mexico, we compared our results with conventional seismic, and discovered that what had previously been interpreted as a porous zone was shown to be an area of small faults, which were effectively compartmentalising the reservoir and reducing, rather than increasing, productivity. Detecting these potential challenges is particularly important in the fractured reservoirs of the Middle East."

This type of high resolution seismic is also increasingly being found to be a cost-efficient method for reservoir management and monitoring and for developing models.

Stepping inside the reservoir

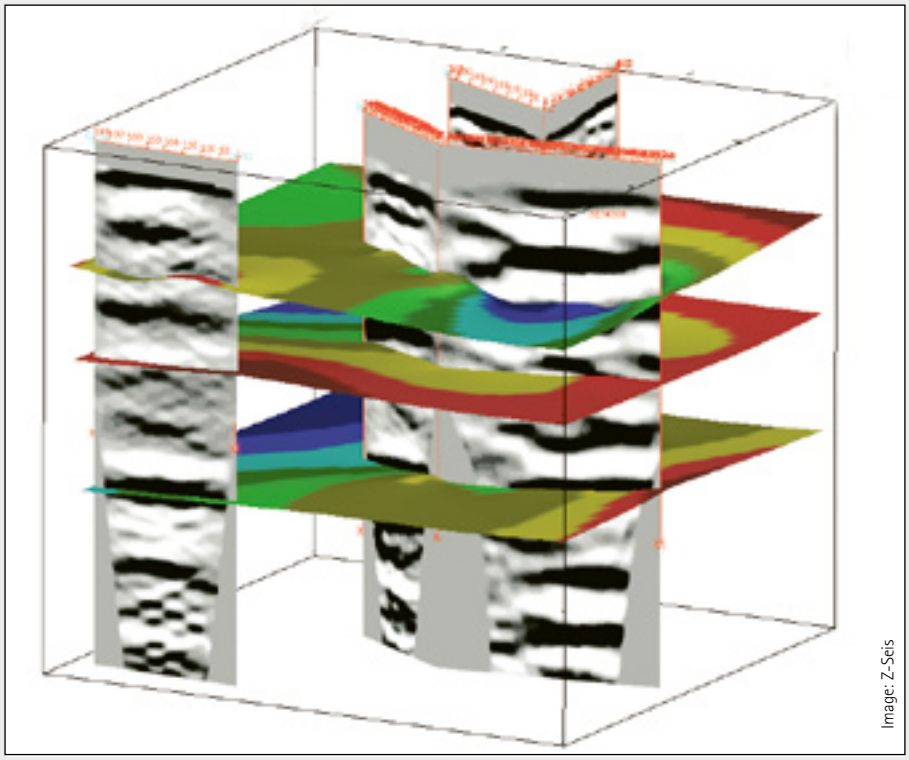
Crosswell seismic is rapidly developing as an important tool in enhanced oil recovery operations (EOR), particularly those using CO and water or steam flood, as it provides a series of detailed pictures of operations over time, checking for the efficiency of the flood between wells. Imaging the reservoir during EOR also ensures that these expensive flooding fluids are used efficiently, reducing the overall costs of EOR activities.

"The technology is useful right through to field abandonment stage," adds Mark. "It helps predict the reservoir's life through an advanced understanding of its characteristics, and provides a mass of information about the subsurface between wells, which assists the search for bypassed oil and new reserves, before a field is finally closed-in."

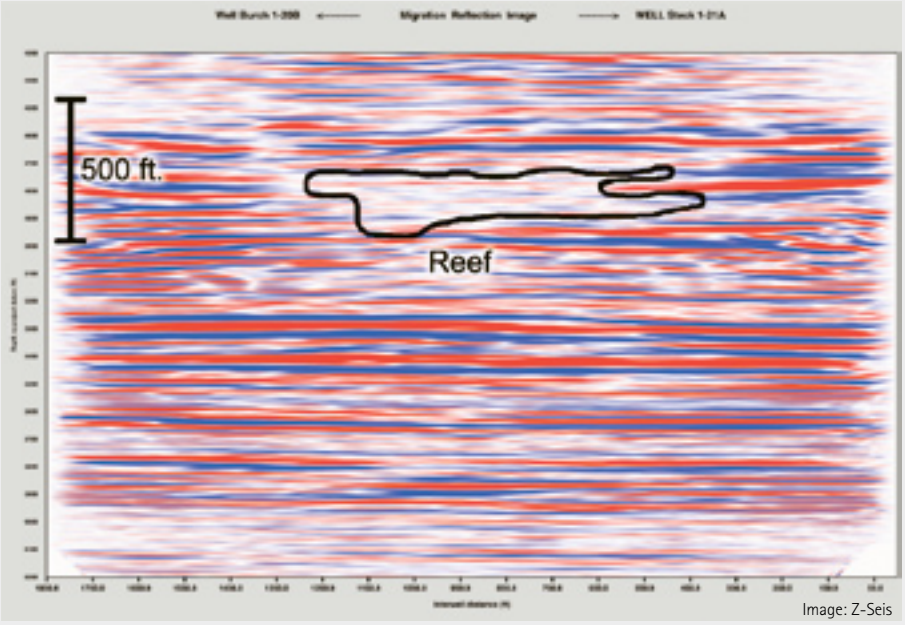
Mark McCallum is Director of Business Development GeoScience for Z-Seis, a company focussed exclusively on the acquisition and processing of Crosswell high resolution seismic.

"In the US at the moment there is a big uptake in the exploration for unconventional hydrocarbons, for stacked sands and coalbed methane, for example. To efficiently exploit these reserves, it is vital to fully understand the reservoirs and plays and their interaction, and Crosswell seismic imaging is becoming an integral part of this process. The significant increase in interest in the product in recent years has been driven by high prices and a reduction in the level of discoveries, as well as greater awareness and understanding of the technology.

"Our advertising line is 'Resolution so high, it's like being there' which sums it up well," Mark McCallum adds. "To me it's like searching for a house; when you finally find one you really like, you want to step inside it and look around. Crosswell seismic lets you do that to the reservoir."



Multiple Crosswell profiles can be connected to create a 3D volume with the colour contours representing bedding planes. This example is from the Canadian oil sands.



Crosswell seismic enhances conventional seismic imagery and can be used to identify bypassed reservoirs. In this example from northern Michigan, the high resolution achieved by this technique revealed a potential carbonate reef reservoir which had not been seen by conventional seismic methods.

Improving Wellbore Stabili

Photo: Halfdan Carstens

Photo: Jane Whaley

Jon Jincal Zhang has been working in the field of pore pressure and wellbore geomechanics for more than 10 years. Originally hailing from Beijing, China, he has a Ph.D. in petroleum and geological engineering from the University of Oklahoma. Jon is currently with Shell Exploration and Production Company in Houston.

ty in Fractured Formations

Wellbore stability is a key issue when drilling through fractured carbonates. Abnormal formation pressures and large variations in porosity are challenging.

Natural fractures in rocks cause drilling mud losses and wellbore stability problems. A recently developed "double porosity model" can make drilling safer and less expensive.

Jane Whaley, Associate Editor

Fractures occur naturally in the majority of rocks, and drilling through such fractured rocks can cause major challenges to wellbore stability that result in drilling problems. "This is because they have larger shear failure zones and smaller fracture gradient, fracture gradient being the pressure required to induce a fracture in a rock at a given depth," says Jon Jincai Zhang, until recently Geomechanics Manager with Knowledge Systems, a company specialising in services to improve well planning and drilling, lately bought by Landmark Graphics.

Stability problems are expensive

"Lack of wellbore stability brings a reduction in the quality of well log records and consequently leads to difficulties in their interpretation. It also causes mechanical problems such as stuck pipes, high torque and back-reaming, instigating further dangers when setting the casing and remov-

Huge losses

Wellbore instability due to shear failure and tensile fracturing can increase drilling time and sometimes leads to wells being side-tracked or abandoned. It has been estimated that this causes worldwide losses of several billion dollars per year, so it is important to get it right.

ing cuttings," Jon explains. "Using a heavier mud can help avoid these incidents, but the range of mud-weight we can apply in such fractured formations is narrow."

"To solve this, we need to develop methods of accurately predicting the important features affecting stability: pore pressure, in-situ stress, shear failure and fracture gradient."

"During drilling, stresses are redistributed, as rock is replaced with drilling fluid (mud), which can lead to either shear and tensile failure within a well," Jon continues. "If the mud pressure is too low, the stress on the surrounding rock is too great, and shear failure, known as wellbore breakout, occurs, possibly leading to the collapse of the wellbore. On the other hand, if the wellbore mud pressure is too high, there is a danger of tensile failure, causing the wellbore to balloon, and leading to mud loss and lost circulation."

"Variations in porosity are also a common feature of fractured formations, particularly carbonates. These lead to rapid changes in pore pressure, and compound the challenges in estimating mud-weights and fracture gradients in drilling."

In the absence of any further information to guide them, wellsite engineers often use basic trial and error based on simple mud-weight correlations to nearby or analogue wells. They maintain this mud-weight until a failure is observed, at which point corrective action is taken - not necessarily the most cost-effective route.

The mud-weight window solution

Determining the safe mud-weight range is of critical importance to improving well planning and drilling for the oil and gas industry. To tackle the problems of predicting wellbore stability, Jon considered the effects of both fractures and porous formations, and from this developed a 'double porosity model' so drillers will have a better idea of what to expect before they start working on a particular well.

"We established the model using known variables such as rock strength, pore pressure profile, and in-situ stress from well log data," Jon explains. "We then used finite-element analysis to obtain a wellbore stability solution."

"Our model was successfully tested in a case study in Oman, where we performed pre-drill analysis for pore pressure and wellbore stability, and then sent a pore pressure engineer to do real time model updates during drilling. The well encountered both weak claystones, which could cause well collapse, and heterogeneous and fractured carbonates with a low fracture gradient, which could potentially cause mud losses during drilling. When limestones and claystones are drilled in one casing interval, the mud-weight window is very narrow, as too high a mud-weight risks fracturing and drilling fluid losses, while a lower mud-weight induces wellbore breakouts or collapse. Additionally, some of the gas-bearing formations in the Omani well have very high pore pressure, which could cause kicks and blowouts, making drilling more risky. It was therefore imperative that the model predicted the correct mud-weights to avoid well failure," John emphasises. "We were happy to find that our model accurately predicted the range of mud-weights needed to drill the well with the least risk.

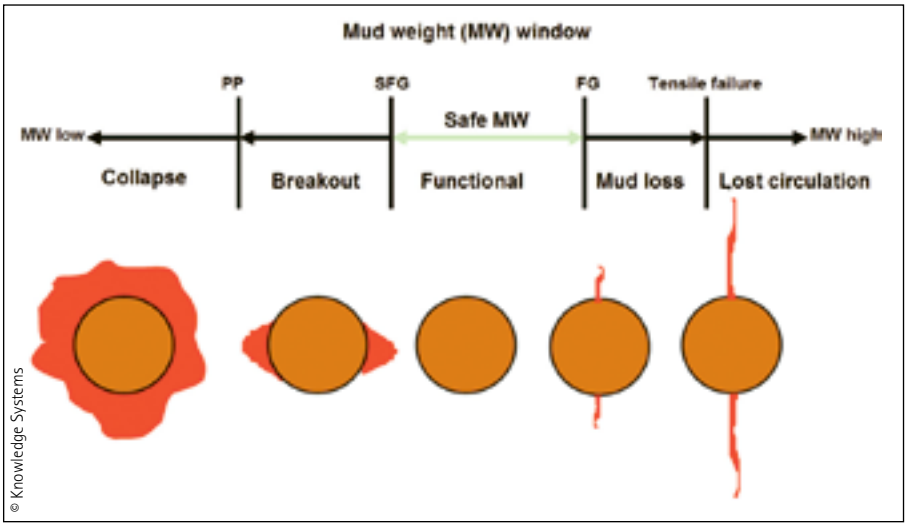
A similar pre-drill pore pressure and wellbore stability analysis project was successfully conducted in the Western Zagros foothills in Iraq.

"The geomechanical analysis combines wellbore parameters, such as inclination, azimuth and hole size, with rock properties, so as to develop a specific solution for each section of the wellbore. It is cost-effective, because predictions for multiple wells can be made from a single model."

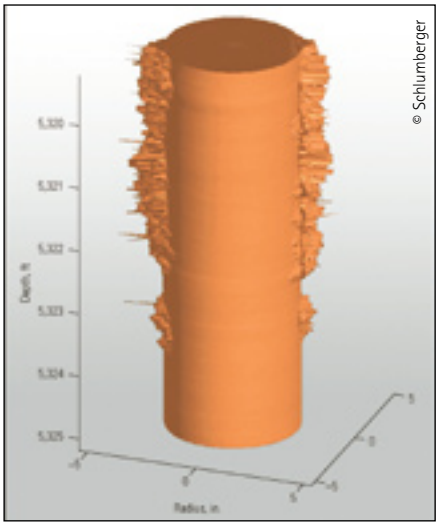
"Another advantage of the method is that if we prepare an accurate model before drilling, it is possible to react rapidly in real time as a well is being drilled," Jon concludes. "Mud-weights and casing parameters can be altered in-situ to ensure successful drilling.

A New Field of Study

"I have found working in this area very exciting," Jon says. "Studying wellbore stability in fractured rocks is a new field, and calculating the fluid properties required is very challenging. Ultimately, we are helping the oil and gas industry to understand and predict pore pressure and wellbore geomechanics, so that wells can be drilled and produced as safely and economically as possible."



Calculating safe mud pressure is vital for the stability of a well. Too low a mud pressure can lead to wellbore collapse or wellbore splintering; too high a mud pressure can create wellbore fracturing and losses.



Results from an Ulltrasonic Borehole Imager logging tool demonstrating stress-related wellbore breakout aligned along the plane of least horizontal stress.

The Dawning of two Continents

Rifting caused the breakup of Western Gondwana into two separate continents and is responsible for the key elements of a mega petroleum system that is now being fully exploited.

Photo: Tom Smith

Thomas Smith, Associate Editor

There is little mystery behind why the west coast of Africa and the east coast of South America fit together so nicely, a fact that has caught the attention of scientists for more than a century.

The existence of a single supercontinent was first suggested in the 19th century by Edward Suess, an Austrian geologist, on the basis of comparative geological evidence. He called the area that was made up of what are now Africa, South America, Australia, and India "Gondwanaland", after the Upper Paleozoic and Mesozoic formations in the Gondwana district of central India.

The dawning of a theory

The German meteorologist Alfred Wegener was also intrigued by the close fit of continents. Similarities across the oceans such as fossils of identical plants and animals and the continuation of distinctive rock strata when the continents are brought back together added more supporting evidence for his theory of continental drift. In 1915, he wrote *The Origin of Continents and Oceans* where he claimed the continents formed a single mass that has since split into pieces.

We now know that Antarctica was also joined with the other continents (possibly as long as 650 million years ago) and was around for about 520 million years. The convergence and collision of smaller continental landmasses that dominated the Paleozoic Era formed this super continent. These continental collisions were responsible for mountain building events, much like the collision of the Indian subcontinent with Asia that is forming the Himalayan Mountains today.

The roots of one of these ancient mountain ranges can be seen in southeastern Brazil, along the Santos and Campos basins. These Late Precambrian-Early Paleozoic granites form some of the spectacular scenery that makes Rio de Janeiro and the surrounding areas so special (see also Geotourism in this issue).

From the Carboniferous to Middle Jurassic, Gondwana was joined with another large landmass called Laurasia to form the supercontinent of Pangaea. At this time, the earth's landmass constituted a single, very large continent (Pangaea), which was surrounded by the world ocean (Panthalassa). The shifting of the Earth's lithosphere caused by internal currents in the mantle (a tenet based on plate tectonics concepts) started to tear this supercontinent apart. Laurasia broke off in the middle Mesozoic Period and shortly afterward Gondwana began to break apart, and the newly formed landmasses ultimately started their journey, drifting to their present day locations. They are still moving, as indicated by satellite measurements of the increasing distance between the American and African plates.

The dawn strikes a new image every day just like rifting can spawn new continents and oceans.

The rift valleys are often flanked by volcanoes such as Kilimanjaro in Africa and large areas can be covered lavas. Dinosaurs replace giraffes in the Jurassic western Gondwana rifting.

Incipient rifting

The lithosphere is that solid, uppermost 80 to 100 km of the earth's crust and upper mantle that is broken into big and small plates. These plates move a few centimeters each year riding on the earth's ductile or semi-fluid lower mantle called the asthenosphere.

A common way to develop rifting, where continental crust is extended and thinned, is above upwelling convection cells (mantle plumes) in the asthenosphere. The extensional stresses are induced by the outflow at the base of the lithosphere from one or several zones of upwelling.

The extensional sedimentary basins start as intracratonic, down-thrown blocks that are filled with lacustrine sediments, as is happening today with the East African Rift, forming large, rather deep lakes. The continued rifting results in the break-up of continental plates and the creation of oceanic crust, which is usually heralded by massive outpouring of lava flows, erupted from volcanoes and fissures.

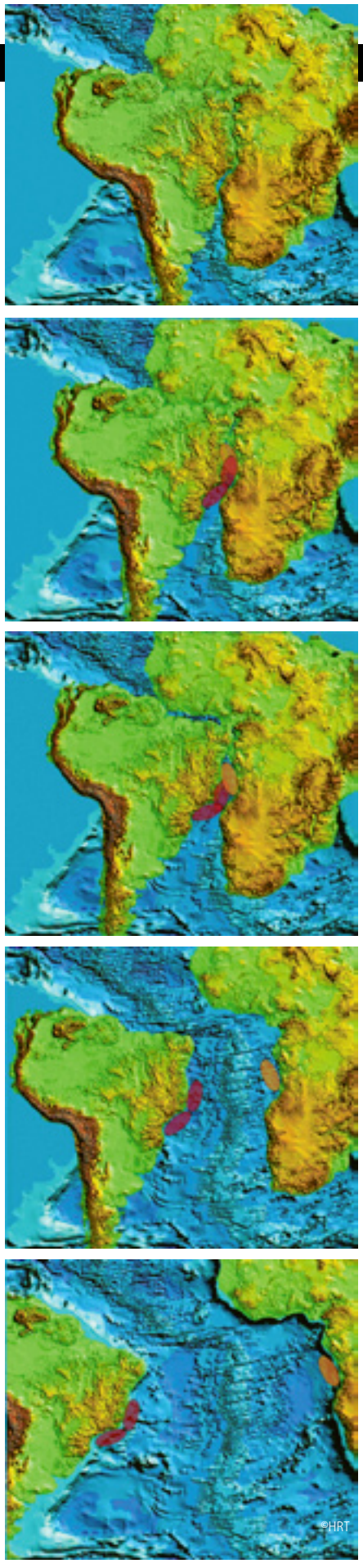
Evolution of the Atlantic Margin

The Rift Phase in the South Atlantic started with crustal extension in the Late Jurassic to Early Cretaceous. The first phases (Stage 1) were characterized by minor uplift and thinning of the continental crust and upper mantle. As uplift and extension continued (Stage 2), flood basalts filled the early phases of subsidence along the southernmost part of the South American Plate, particularly onshore in the Parana basin and along the incipient rifts that formed the southernmost Atlantic marginal basins (Pelotas, Santos and Campos). The northern rift segment lacks this magmatism.

Extensional forces at this time were concentrated along the continental margin (that area between the shoreline and the abyssal plain) forming a series of elongate and deep lakes parallel to the coast, due to extensive normal faulting. These eventually evolved into the present day sedimentary basins located on both sides of the South Atlantic margin. The continental lacustrine sediments deposited at this time are one of the key pieces to the developing petroleum systems, namely the source rocks.

The Transitional phase (Stage 3) is characterized by diminishing activity of the large faults associated with rift blocks and local volcanism, fault reactivation, and erosion. A regional unconformity (Break-up Unconformity) separates continental lacustrine sediments in rift blocks from the overlying sediments. This Lower Cretaceous (Aptian) sequence was less affected by normal faults, and was deposited in transitional to marine environments, forming substantial thicknesses of clastic and carbonate rocks well developed offshore of Brazil and Angola, as part of the 'sag basin fill'.

With the first marine incursions into the forming Brazilian-West African gulf, a shallow-water evaporite basin was developed along both margins. A second key piece of this petroleum system occurred with the deposition of high quality reservoir rocks in shallow water around bathymetric highs formed during the rifting episode. More source rocks were also locally deposited at



The formation of the South Atlantic started with rifting in western Gondwana in the Late Jurassic and continues today.

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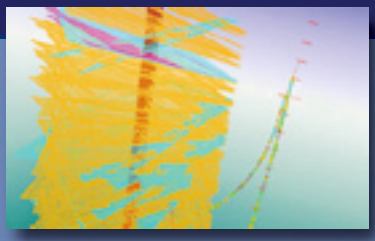

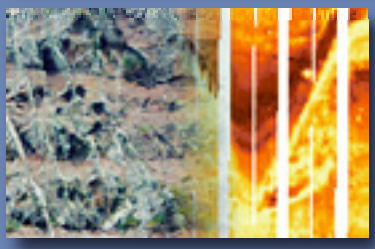

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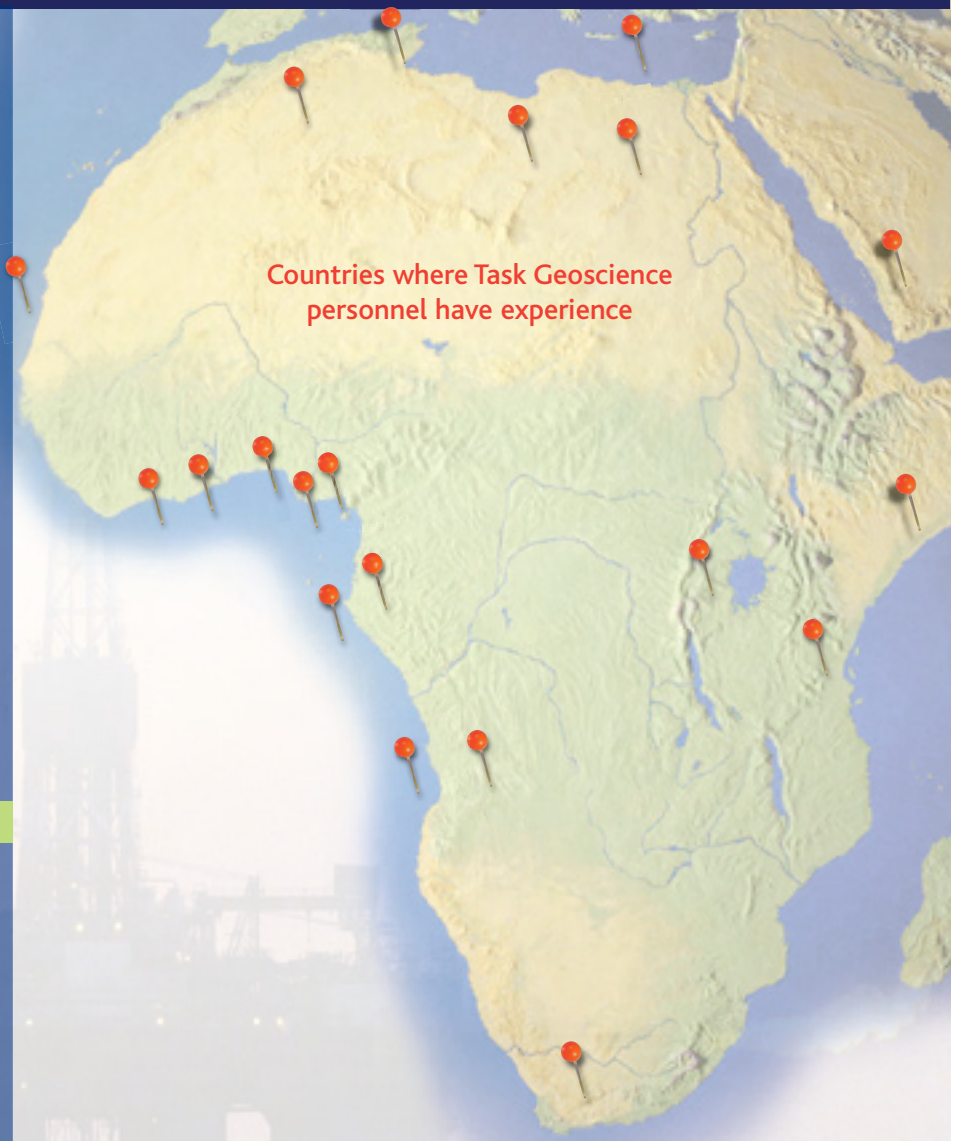

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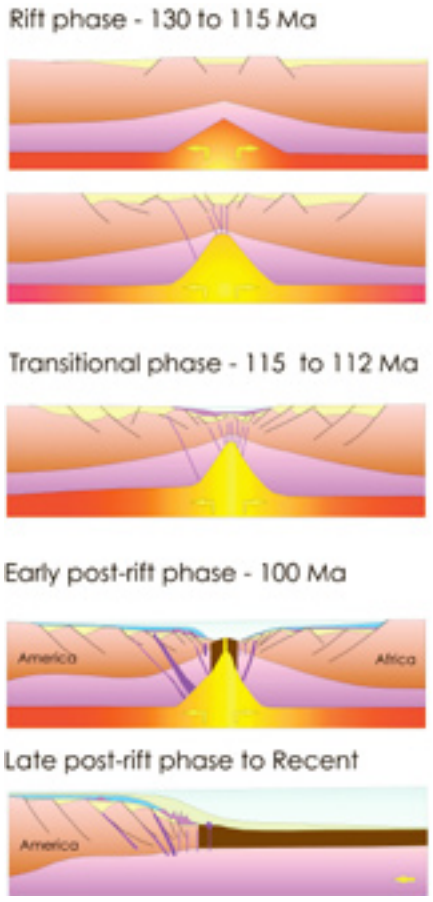


South Atlantic rifting phases described in the text.
© Mohriak

the time preceding the evaporite deposition. With an extremely arid climate and episodic marine influx, a thick evaporite sequence was deposited over most of the gulf sediments in the Late Aptian. The gulf formed by rifting was now more than 1,000 km long and locally separated by igneous intrusions and volcanic highs.

During the early post-rift phase (Stage 4) the crust was ruptured by oceaning propagators (such as a mid-ocean ridge or spreading center) that advanced from south to north. One of those is known in the northern Pelotas–southern Santos basin as the Abimael Ridge, puncturing the rifted margin with igneous intrusions, as is observed today in the region between the Gulf of Aden and the Afar Triangle. With full development of the mid-Atlantic Ridge (spreading center) and opening of the South Atlantic Ocean, the continental margin development is primarily associated with thermal subsidence typical of divergent margins. Carbonate deposition predominates during the early stages of the post-salt deposition, indicating a shallow water environment that was progressively deepening and invaded by marine waters.

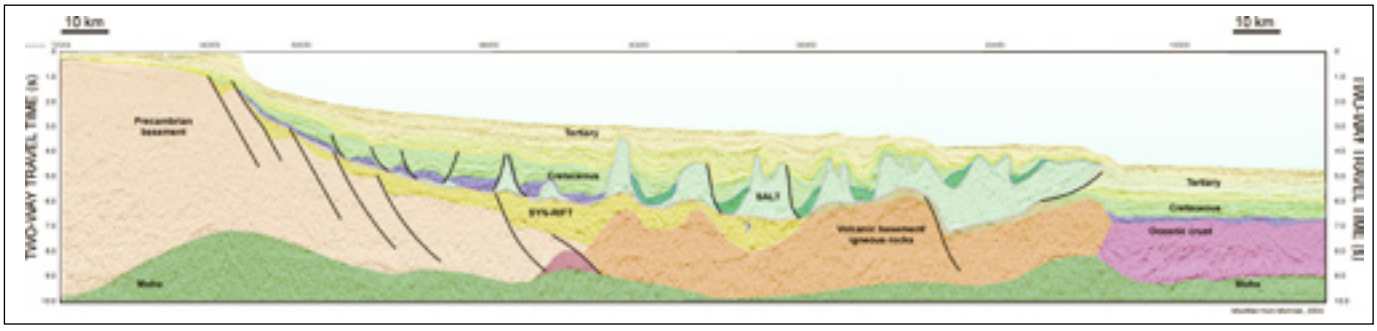
For the late post-rift phase (Stage 5) Lower Cretaceous (Albian) to the Recent, water depths along the margins continued to deepen and progradation episodes resulted in the accumulation of several kilometers of sediments. Extensional tectonics and the weight of prograding clastic wedges initiated a period of widespread salt tectonics.

"It is the salt movement during this post-rift phase that has controlled much of the structures and petroleum plays along the eastern Brazilian margin," says Dr. Webster Mohriak, Petrobras exploration geologist.

"Several magmatic events occurred in the southeastern margin basins during the Late Cretaceous to Early Tertiary, particularly in the Cabo Frio region, which separates the Santos and the Campos basins, and in the Abrolhos region, north of the Espírito Santo basin. These three basins have been the main focus of petroleum exploration in the South Atlantic because of the successful interplay between tectonics and sedimentation that occurred during and after rifting. Excellent source rock and adequate maturation, presence of several reservoir intervals in the stratigraphic column (both above and below the salt layer), and efficient oil migration and trapping have made these basins and their counterparts across the Atlantic into very productive petroleum systems."

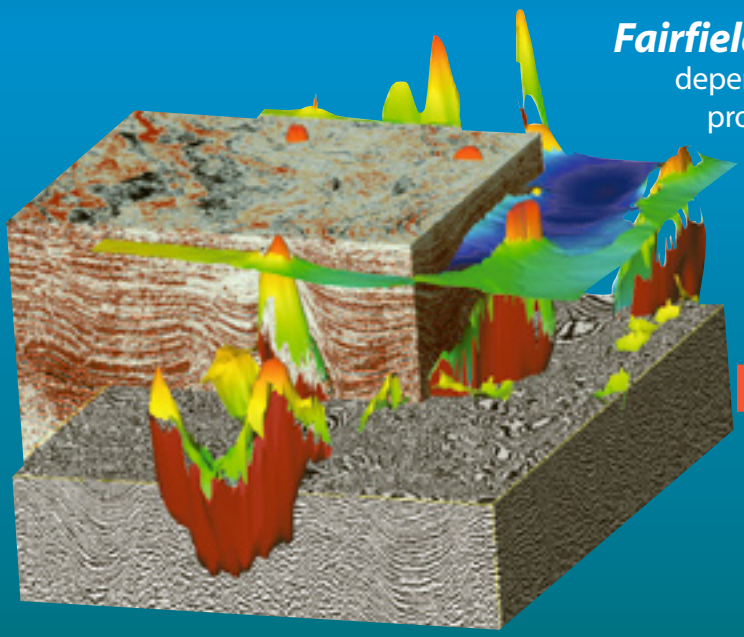
"It is the rifting activity and consequent lacustrine formations that resulted in the deposition and preservation of organic matter during anoxic events. The subsequent "capping" by the salt formation created the huge potential for oil development that we are now discovering in the ultra-deep water provinces along the Brazilian Atlantic margin. The magnitude of potential in these structures has recently been proved by pre-salt supergiant discoveries, and the promise of analogous discoveries in other areas in the South Atlantic is certain to be tremendous," concludes Dr. Webster Mohriak.

EDITOR'S NOTE: Most of this section has been taken from papers authored by Webster Mohriak and others. One recent paper discussing the breakup of the South Atlantic continental margin was published as a chapter in the book edited by Pankhurst et al., Geological Society, London, Special Publication 2008; v. 294. Dr. Mohriak, an exploration geologist with Petrobras and expert on salt tectonics and rifted continental margins, kindly edited this article.



The current Brazil margin from the continential slope to oceanic crust showing all the pre-rift, rifting, and post rifting elements.
©Webster Morhiak and Petrobras

Just who *is* Fairfield?



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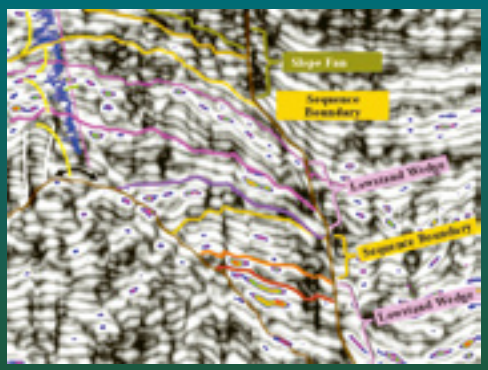

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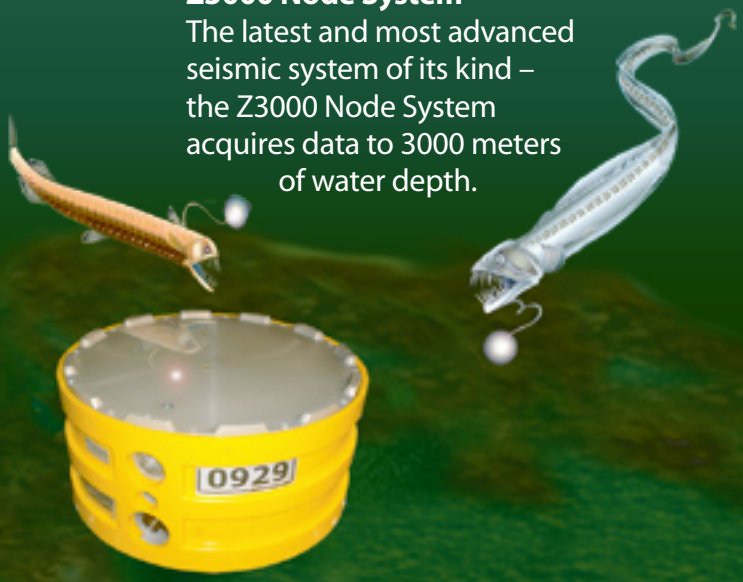

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Seismic Imaging Technology

PART III: THE SUPERIORITY OF OCEAN BOTTOM SEISMIC IMAGING

Ocean bottom seismic (OBS) produces superior seismic images compared to those from conventional 3D streamer seismic. OBS acquisition offers the prospect of full illumination and high multiplicity of signals from the same subsurface points (high data fold).

Lasse Amundsen is Chief Scientist, Geophysics, at StatoilHydro. He is adjunct professor at the Norwegian University of Science and Technology (NTNU) and at the University of Houston, Texas.

Martin Landrø is professor in Applied Geophysics at the Norwegian University of Science and Technology (NTNU), Department of Petroleum Engineering and Applied Geophysics, Trondheim, Norway.

Although conventional streamer seismic data serves exploration purposes well in many cases, the quality may not be sufficient to support an adequate model for reservoir development, in particular below complex overburden. As discussed in GEO ExPro No 1-2/2008, this experience led to the development of innovative ways of acquiring seismic data. Here, we address the OBS technique, and briefly show a few of the successful results.

Ocean bottom seismic surveys

In the early 1990's, Eivind Berg at Statoil led the development of the SUMIC (SUbsea seisMIC) system, whereby both shear and pressure waves were recorded by sensors implanted in the seabed. The 1993 pilot survey over the Tommeliten structure in the North Sea demonstrated that the SUMIC technique can successfully image subsurface structures through and below gas chimneys by the use of shear waves. For this achievement, Berg and his colleagues received the prestigious Kauffman Gold Medal from the Society of Exploration Geophysicists.

In the OBS survey every receiver station is a four-component (4C) sensing system: a three-component geophone and a hydrophone. While the sensing system is stationary on the seabed, a source vessel towing a marine source array shoots on a predetermined dense grid on the sea surface. When the shooting is complete, the sensing system is retrieved and redeployed in a nearby location and the shooting campaign continues.

The uses of 4C-OBS data can be divided into three broad categories: firstly, lithology and fluid prediction by the combined analysis of pressure and shear waves; secondly, time-lapse (4D) seismic monitoring; and thirdly, imaging in geologically complex areas.

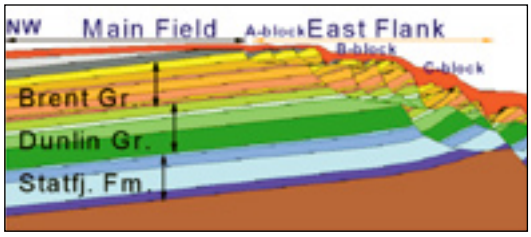
Seismic from all directions

The benefit of OBS for detailed structural imaging by the exploitation of pressure reflections was not fully realized by everyone in the seismic community before 2005. In a summary from the 2005 EAGE/SEG research workshop on multi-component seismic it was stated: "Surprisingly, the driver behind the multi-component business was not shear waves but better pressure wave data" (Lynn and Spitz 2006).

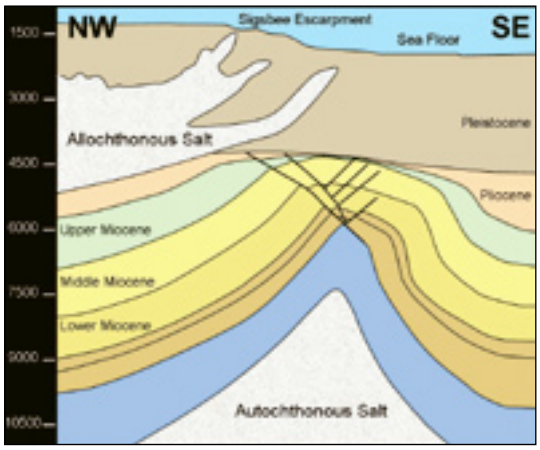
Some major oil companies, however, were fully aware of this application. In 1999 an extensive research program led by StatoilHydro's R&D group concluded that detailed structural seismic imaging of complex geology required the acquisition of high-fold seismic data from all directions around a reservoir. This result was obtained by careful planning of the world's first dedicated 3D imaging OBS cable survey over the Statfjord field offshore Norway, followed by thorough and consistent evaluation of image quality versus acquisition geometry (Thompson et al., 2002).

Elucidating the Statfjord field, Norway

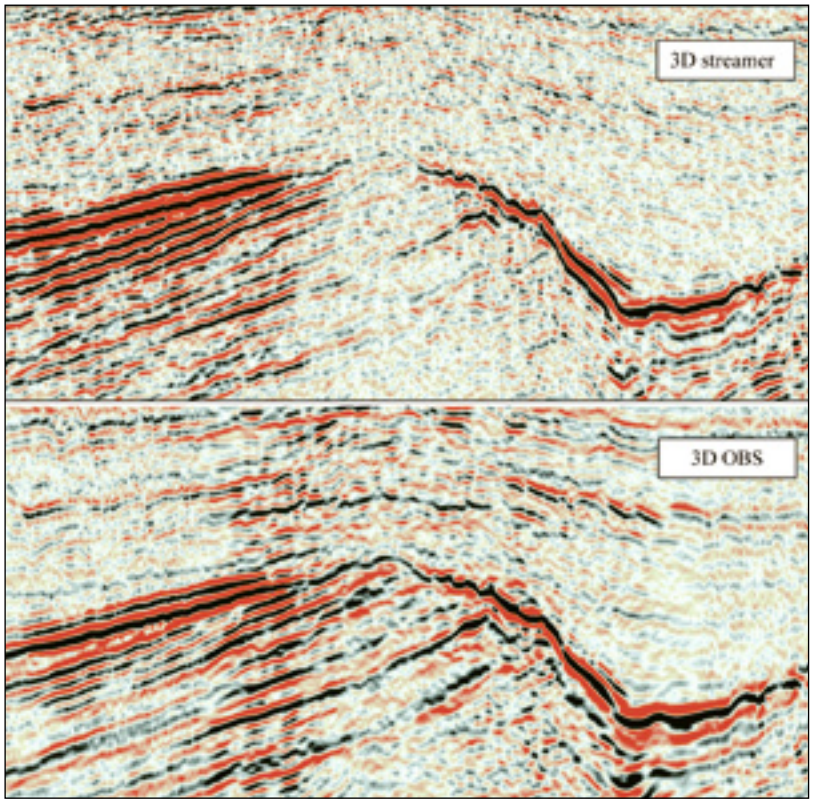
Discovered in 1979 in approximately 150 m water depth, Statfjord is one of the oldest producing fields on the Norwegian continental shelf, and the largest oil discovery in the North Sea. The reservoir units are sandstones located in the Brent group and in the Cook and Statfjord formations. Structurally the field is dominated by a single rotated fault block dipping towards the west, with a more structurally complex area on the East Flank characterized by small rotated



Statfjord field cross-section (Thompson et al 2007). Courtesy StatoilHydro.



Atlantis field cross-section. Courtesy BP.



Imaging comparison of 3D conventional marine seismic (top) and 3D OBS (bottom) illustrating improved uplift of the Statfjord East flank structure (Thompson et al 2007). Courtesy StatoilHydro.

fault blocks and slump features.

Previously, imaging from conventional 3D streamer acquisition had been difficult in this field, due to gas in the overburden and multiples in the lower reservoir zones. Therefore, an OBS cable pilot survey was shot in late 1997 with the main objective of improving the seismic imaging of the structurally complex East Flank.

Once the 3D OBS survey was processed, it was possible to see that the definition of the Base Cretaceous unconformity and the Base Slope of Failure had improved over a large portion of the survey area. More accurate definition of faults and improved resolution of small scale structural elements were also achieved. The new interpretation resulted in more confident mapping of intact rotated fault blocks with a better understanding of the areal extension and the internal stratigraphic dip within the East Flank area (Osmundsen et al., 2002, Force Meeting, Stavanger).

After the success of the 1997 pilot survey, a 120 km^2 3D OBS survey was commissioned in 2002, which showed a consistent uplift in image quality compared to the existing conventional 3D marine seismic. To date, this 3D OBS has been actively used for planning at least eight successful wells.

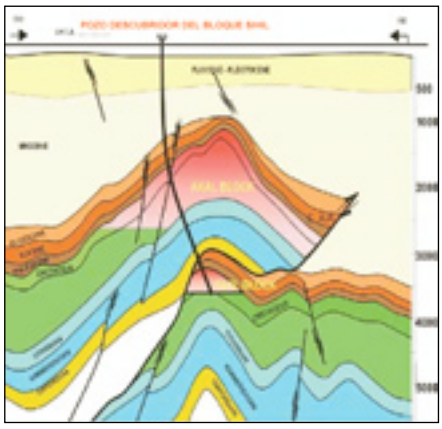
Imaging Cantarell's daughter

The Cantarell complex in Mexico, discovered in 1979 in 40 m water depth, is the third largest producing oil field in the world. The field has five blocks bounded by faults, Akal being the most important. Geologically, it is one of the most interesting oil fields in the world, because the reservoirs are formed from carbonate breccia of Upper Cretaceous age - the rubble from the enourmous Chicxulub meteorite that created the Chicxulub Crater. In addition, the region has a complicated tectonic history including major compressional and extensional episodes.

As Cantarell's production is now dwindling, Pemex is dedicating billions of dollars to finding more oil. Cantarell is believed to hide a huge secret: a daughter reservoir immediately underneath the Sihil field, which is underlying the giant Akal field. But imaging difficulties are numerous — in addition to being a fractured carbonate reservoir with salt and an overthrust structure, Cantarell is populated with dozens of platforms, with lots of vessel activity, so that traditional seismic is difficult to acquire due to the risk of tangling streamers.

Therefore, to better image the Akal field and map Cantarell's daughter, Pemex turned to ocean bottom seismic nodal acquisition. SeaBed Geophysical was awarded the contract in 2003/2004. More than 1,500 node sensor units were deployed into seven swaths in a 400 m by 400 m grid, covering a total of 230 km^2, at the time the largest survey of this type ever conducted.

Compared with the existing OBS cable 1996 data, Seabed's OBS node 2004 data demonstrated higher resolution, excellent reflector continuity, and



Cantarell field cross-section. Courtesy Pemex.

improved structural definition of both top Akal and Sihil levels below. The new data mapped structural compartments at the targeted Sihil level.

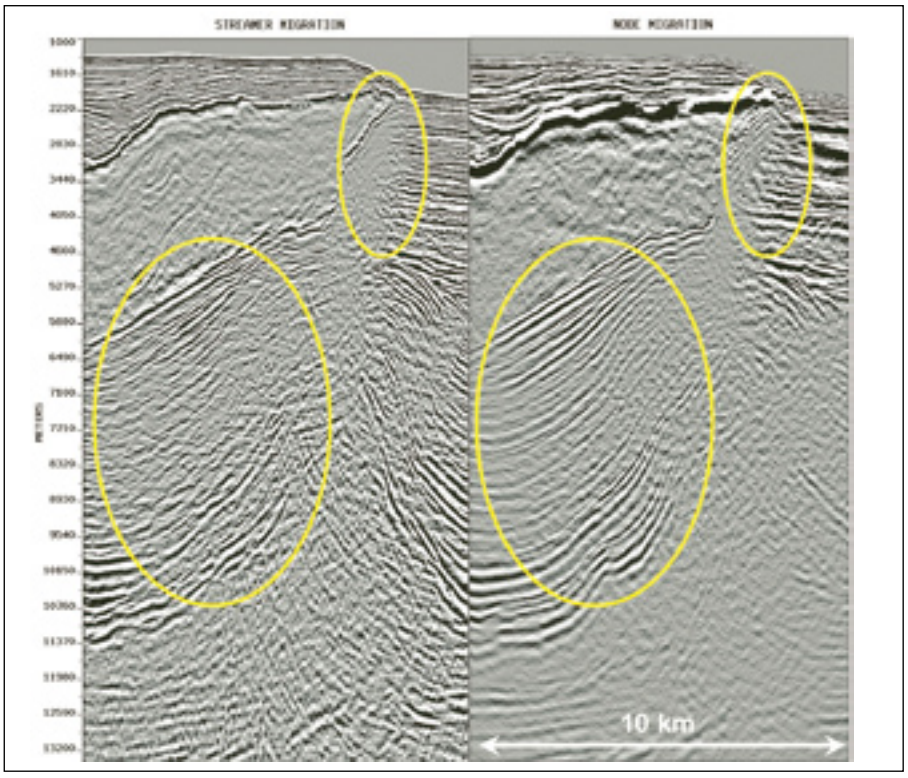
Deepwater Gulf of Mexico survey

BP has also made a strong R&D effort towards imaging challenges in the subsalt area of their developments.

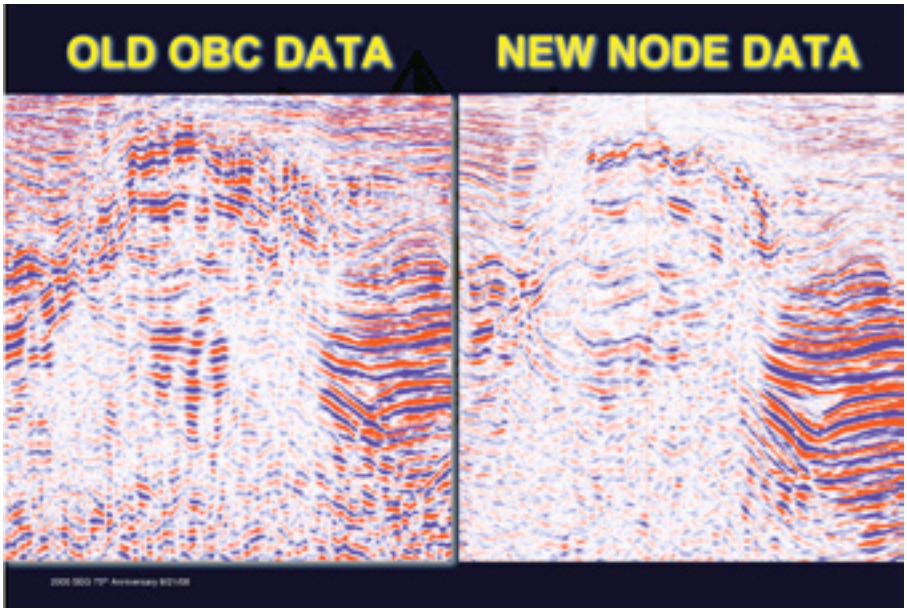
Discovered a decade ago, the reservoir structure of BP's Atlantis field, the third-largest in the Gulf of Mexico, has posed particular imaging problems which called for major innovations. Regular streamer seismic had not allowed its northern flank, where the crest of the field is partially obscured below a thick sheet of salt, to be mapped. As a result, poor seismic imaging has hindered development.

To meet the Atlantis challenge, and obtain higher-quality seismic images, in 2005 BP contracted Fairfield Industries to deploy 900 autonomous recording units in a grid-pattern on the seafloor. The acquisition program encompassed 240 km^2 in water depths between 1,300 and 2,200 m. Completed in 2006, the Atlantis project is the deepest OBS survey acquired by the industry to date.

The OBS node survey produced significant image improvement of the Atlantis field over the existing towed streamer seismic. Both the hydrophone data (P) and the vertical geophone data (Z) were used in the processing. The improved images are impacting current extra-salt field development and laying the foundation for development expansion into the sub-salt areas which make up two-thirds of the structure, previously viewed as high risk because of the very poor imaging from towed streamer data (Howie et al 2008).



Imaging comparison at Atlantis of 3D conventional marine seismic (left) and 3D OBS (right). Subsalt reflectors are clearly improved (Howie et al 2008). Courtesy BP.



Imaging comparison of 1996 OBS cable data (left) and 2004 OBS node data (right) at Cantarell. Courtesy Pemex/SeaBed Geophysical.

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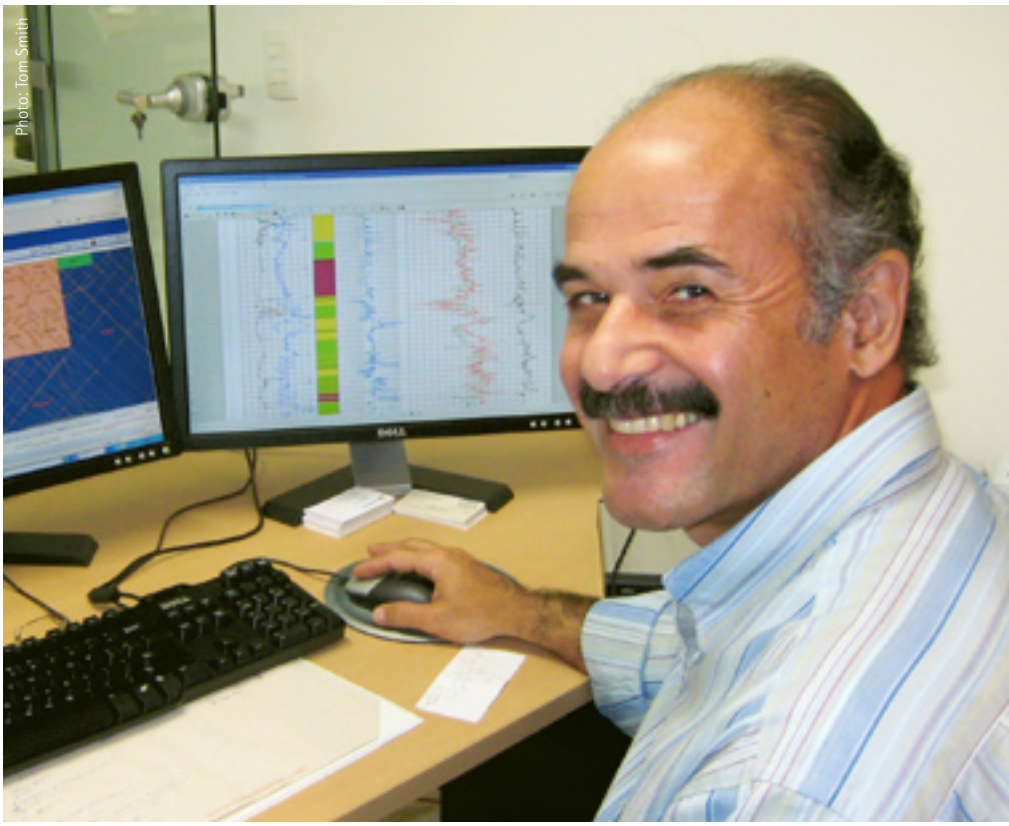
The Oil Detectives

By assembling an experienced staff and coordinating affiliates, in just four years, Marcio Mello has built a service company that has no boundaries. Along with his Vice-President, Nilo Azambuja, they are ready to tackle some of the industry's toughest problems in the search for new oil and gas deposits.

Thomas Smith, Associate Editor



Dr. Nilo Azambuja recently retired from Petrobras after 31 years to become Vice-President of HRT. Nilo is an expert in stratigraphy and sedimentology, with a PhD from Imperial College, London, and has extensively studied the passive Atlantic margin and Brazilian Paleozoic basins. While at Petrobras, Dr. Azambuja was the head of basin modeling, Exploration Manager at the Research Center-CENPES, instructor of field work, and a professor of stratigraphy applied to petroleum systems. He is currently the President of AAPG Latin American Region.

"We work much like a large city's crime scene investigation unit (CSI) made famous on many television shows," says Dr. Nilo Azambuja, Vice-President of High Resolution Technology and Petroleum (HRT). "A crime can be solved by these multidisciplinary units by finding a single drop of blood or getting DNA from a single hair left behind. In our business, *a small detail can solve the most complex problem*."

"Petroleum exploration requires the same multidisciplinary approach," Nilo continues, "the need to integrate all the data available requires experts to go deep into each technology and requires a free exchange of ideas. Experienced geoscientists are necessary for these analyses to yield the most correct results."

Reducing Exploration Risk

"Oil companies are facing difficult challenges in finding new oil and gas deposits. Most frontier areas pose considerable risks with very high costs, whether in the deep or ultra-deep offshore plays, the Arctic, or the remote onshore basins that have little in the way of data," says Dr. Mello.

"We have built a company that is knowledge-based," adds Nilo. "This is where our real strength lies. Many of our geoscientists have over 30 years of experience. Our second strong point is our Laboratory; we can get fast, accurate analyses using state of the art equipment. Finally, by *fully integrating the skills necessary to do detailed basin modeling including geochemistry, biostratigraphy, seismic interpretation, structural geology, biology, oceanography, environmental licensing and monitoring, exploration risks can be reduced*."

"A good example is found in the recent pre-salt discoveries that I have been predicting since 2002," claims Dr. Mello. (In fact, since 2002, he has given more than 10 presentations and published several articles on the pre-salt potential earning him the nickname 'Mr. Go DEEP'.) "Using our proprietary technology such as oil slick satellite detection associated with piston core surface geochemistry, oil and gas DNA analyses, and seismic reprocessing, allowed us to better understand the elements and processes that control giant and supergiant oil and gas deposits in this frontier. Interpretation of all data are put together to supply input for building a fully integrated 3-D compositional petroleum system basin model, for this and other frontier basins in Latin America and West Africa."

The importance of giving back

While working for Petrobras, both Marcio and Nilo were given the education and working experience that would set them apart from many other working geoscientists.

"Some very positive developments for geoscientists were initiated by Petrobras in the 70s," says Nilo. "Carlos Walter (appointed Petrobras Director in 1979) was an outstanding Brazilian geologist instrumental in changing the way Petrobras geoscientists received training and education in petroleum geology. Both Marcio and I ben-


Photo: Tom Smith

Dr. Marcio Mello is President and founder of HRT, During his 24 years with Petrobras, he developed specialized studies regarding petroleum systems for sedimentary basins of Latin America and Africa and has published over 200 papers on the geology and geochemistry of these areas. He is also a professor of petroleum geochemistry and petroleum systems for several universities in Brazil. Dr. Mello was the founder and first (and current) President of the Brazilian Association of Petroleum Geologists and a past President of AAPG Latin America Region.

efited from the programs he started. I went to London for my doctorate while Marcio attended Bristol. We both received a first rate education and Petrobras gave us varied assignments to round out our careers."

"Furthering my education allowed my career to take off into new territories," says Nilo. "I had field experiences all over the world. I really believe you must see the rocks; you must have this experience to be a geologist."

Another big part of Carlos's philosophy was to give back. "Marcio and I trained geologists in war torn Angola for 3 years, in addition to training Pemex, Ecopetrol and Venzuelan geoscientists," recalls Nilo. "Angola was a tough experience with curfews and the constant threat of violence, but we turned out some students that have very good positions with oil companies and with Sonangol."

Building the Foundation

After finishing his PhD in petroleum geochemistry at Bristol University, Marcio went back to Petrobras to form the best and most complete laboratory and petroleum system group in Latin America (of Petrobras/CEGEQ Center of Excellence in Geochemistry, Petrobras research center). With Marcio's leadership, more than 120 experts started to apply the petroleum system approach in most sedimentary basins of Latin America and West Africa. Support from this unit went to most of the Latin American National Oil companies, not only in oil and gas exploration, but in environmental issues as well.

"The experience at Petrobras helped me build a knowledge base about active petroleum systems present in the Southern Hemisphere," says Marcio, "and serves as the foundation for starting my new companies".

Taking risks

While Marcio's working experience provided him with a great wealth of knowledge on petroleum systems, it was his younger years that provided him with the spirit of adventure to start a new company.

"I think that to be a guy that lived a life as a big fisherman and diver, all around the Rivers of the Amazon jungle, gave me experience of adventure without being afraid of risks", says Marcio. "When I started my early career at Petrobras I had worked some years as surface geologist, first at the Onshore Recôncavo Basin, and later on the oil rigs in Cumuruxatiba, Jequitinhonha and Campos Basin. In such environments a young geologist 22 years old could make a lot of hard decisions and fail. Very early in my professional life I was put in front of the most difficult decisions a geologist could face in the petroleum industry. There, I have learned to

make decisions in less than a millisecond. I was wise and lucky enough to be the right person in the right place."

Just as he established a leading geochemical facility for Petrobras, it did not take Dr. Mello long to make his presence felt outside the confines of the large, state owned company. Upon leaving Petrobras, he started three companies that would, in just four years, become the most complete group of laboratories in Latin America. Analytical Solutions (AS), Geochemical Solutions (GSI), and Petroleum and Environmental Geosciences (PEG) would employ 400 professionals in the cutting edge laboratories all over Brazil. He left GSI and sold interests in both other companies in 2003/2004.

"After I sold interests in the other companies, I hit the road full speed," comments Marcio. "It took just four days, not years as with the other companies, to start a new oil and gas exploration and environmental services company of which I called High Resolution Technology and Petroleum (HRT). My goal was to create the best petroleum system expert consultant and oil service company around the South Atlantic realm."

Different Company and Leaders

Entering the 7th floor of a modern office building overlooking Copacabana beach in Rio de Janeiro, you know you are entering the offices of a very different company. You take your shoes off and into the slippers at the doorway; geologists, geophysicists, and geochemists are working side by side on a white carpet overlooking the expansive beach. Displayed on the computer screens are seismic, geochemical sampling, and well data. Integration is the key here, putting the expertise together with the necessary data.

A few steps past this large working area is Marcio's sparkling office, decorated with some of Brazil's finest amethyst geodes and quartz crystals. Anyone that has been to a talk or presentation given by Marcio Mello will know what I mean and meeting him in person at his office was no different. He is direct and to the point; he is a person that casts a different shadow than most of us. In his presentations, he involves you to think about what he is saying and makes his informative presentations interesting and enjoyable. Marcio's dynamic personality echoes his aggressive business practices, striving to do more than the competition.

Nilo, second in charge, is unassuming, smiling and more than willing to share an experience or two. While Marcio may be

Field work is Nilo Azambuja's first love. He is pictured here working in the Amazon basin.

Marcio Mello working in the new HRT laboratories, Rio de Janeiro.

managing the business side of things, Nilo is quietly managing a team of very experienced geoscientists. As recent head of the Basin Modeling group at the Petrobras Research Center, he is more than qualified to steer the HRT analysis teams.

Both men are highly patriotic and would like to see Brazil's potential fully realized. To this end, HRT is pioneering new geochemical technologies that are applicable to a growing number of both explored and frontier areas in Latin America and Africa.

"We are striving to make information readily available to our clients so they can have fast access to our data, wells, and seismic anywhere on their laptop," says Nilo. "This is just part of what we do. After all the data is assembled, the real detective work starts. To be creative, you need a lot of data and experience to build the basin models. Once a model is built, then we go back to the data to see what opportunities lay ahead. This can lead to ideas on where reservoirs can be filled, which may be the best blocks to bid on and drill."

"The integrated approach is the best way to reduce exploration risk, not only in frontier areas, but to resuscitate mature basins," adds Marcio. "We live by our motto 'NO MORE DRY WELLS."

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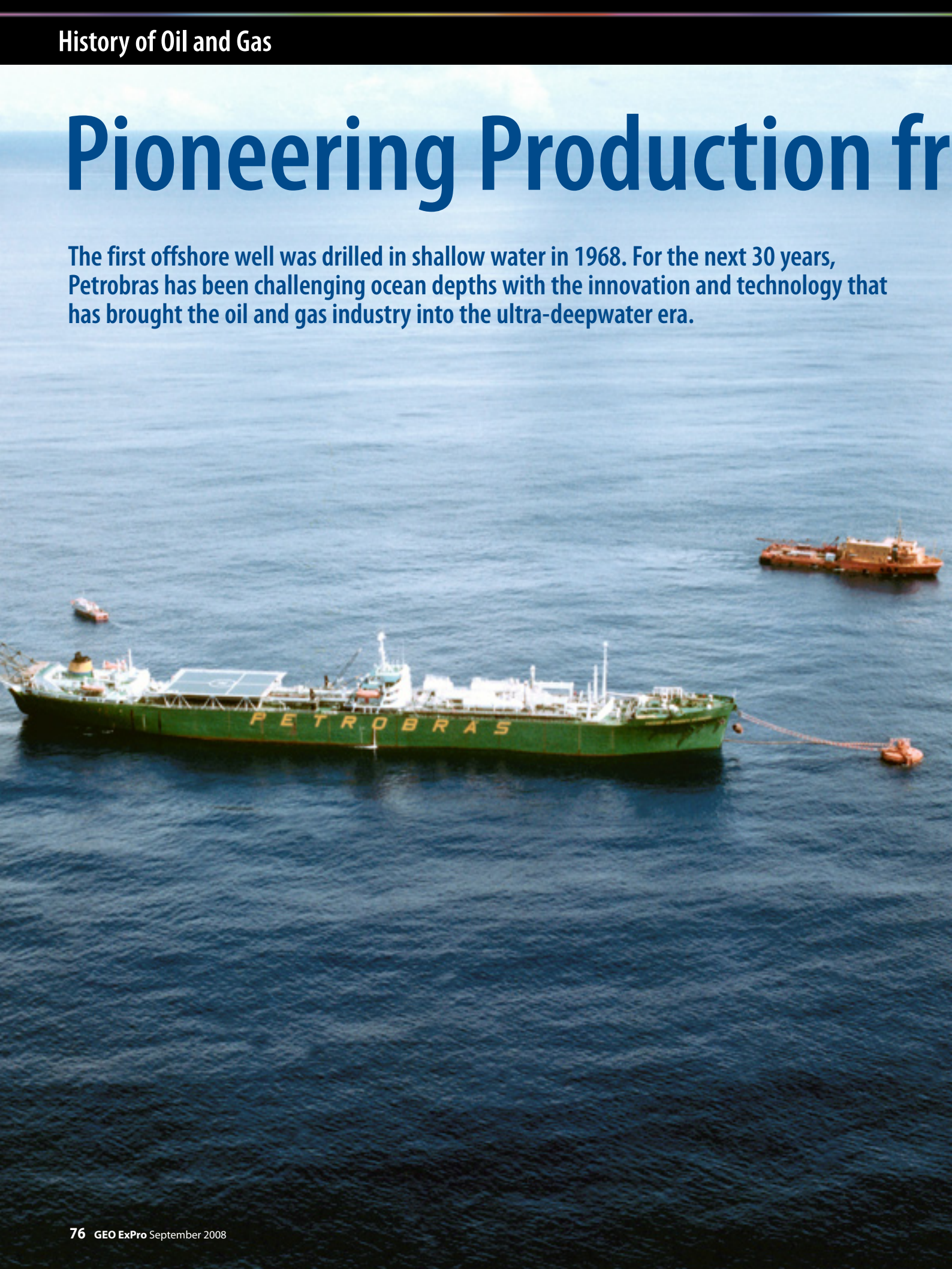
hvilken annonse er dette?

Pioneering Production fr

The first offshore well was drilled in shallow water in 1968. For the next 30 years, Petrobras has been challenging ocean depths with the innovation and technology that has brought the oil and gas industry into the ultra-deepwater era.



om the Deep Sea

Thomas Smith, Associate Editor

Most of the earth is covered by water. The oceans have thus provided us with plenty of exploration opportunities and challenges, while pioneering efforts in the Gulf of Mexico and off the California coast have led the way to the first offshore oil and gas production.

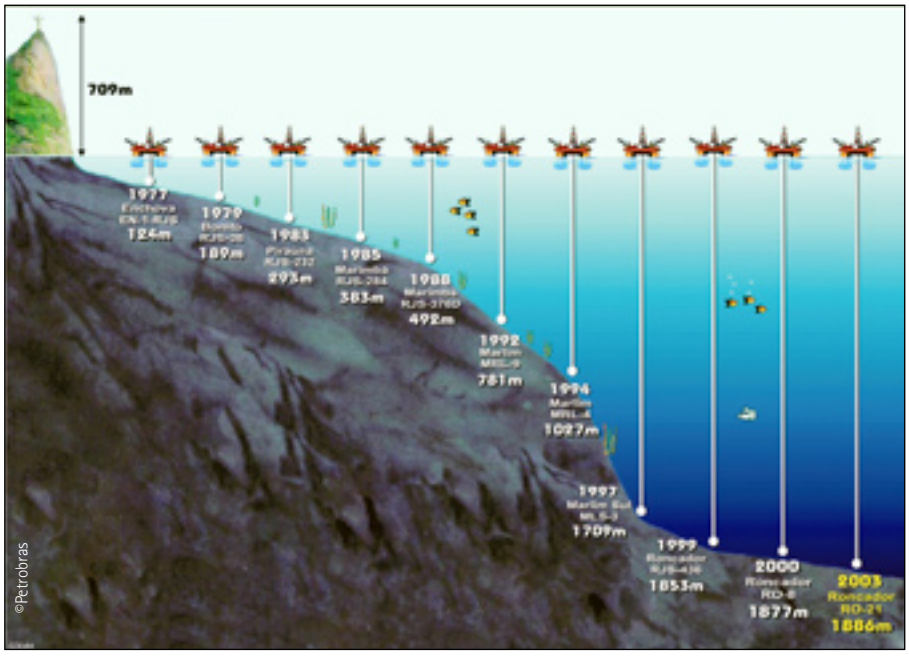
The first wells were drilled from piers that extended into the ocean waters at Summerland, California, in 1896, while Gulf Oil drilled the first offshore well detached from shore in Caddo Lake, Louisiana, in 1911. From these early beginnings, oil exploration and production has been progressing further offshore and into deeper water, and in 1947, Kerr McGee made history by completing the first offshore well out of sight of land.

Relative newcomer to offshore exploration and production, Petrobras is now the world's leader in subsea completions and has a very aggressive plan to play a dominant role in the production from the ultra-deep ocean depths in the future. Not only are they actively researching new technologies and engineering solutions to produce oil from the 3,000 m depths, they have leased 80% of the world's deep water drilling rigs and plan to spend over 5 billion US dollars to develop and hire deep water vessels over the next 9 to 10 years.

The First Steps Offshore

Brazil's first oil discovery was not made until 1939 and the first commercial field in 1942, both onshore in the Reconcavo basin in the northeastern part of the country.

"Still, little was known about the oil potential here through World War II and production remained low," says Giuseppe Bacoccoli, retired chief geologist of the Petrobras basin interpretation division,



Since 1977, Petrobras has steadily pushed production into deeper and deeper water setting records and accomplishing many "firsts" along the way. Operating in increasingly hostile exploration and production environments drove the innovation and solutions critical for efficiently exploiting the ocean's depths. (It should be noted that recent drilling activity in the Gulf of Mexico has surpassed Petrobras's water depth records. New water depth records: Anadarko's Cheyenne project is the deepest commercial field at 2,731 m; Union Oil's Trident project in 2,965 m of water is now the deepest discovery; and the deepest well was Chevron's Toledo project in 3,051 m of water.)

Ever deeper

The last issue of GEO ExPro started a new feature, The History of Oil. It happened to be the 1901 discovery of oil at Spindletop, Beaumont, Texas that was known as the Lucas Gusher. This started a very visible and exciting chapter in our history and changed the way we use, find, and produce hydrocarbons. We went from the days of the wildcatter to geoscientists and engineers playing key roles in finding and extracting oil. It is through their innovative ideas and technological solutions that have led to the successes the industry has seen through the years.

This issue's History of Oil features a stage that is invisible to most of us and certainly not as exciting as the 1901 gusher, but may be just as historic. This chapter looks at the past 30 years of offshore production (and a little into the future) of one company, the Brazilian state owned, Petrobras, a true pioneer in deepwater oil and gas production. Their deepwater production records were made possible not only through innovation and new technologies but pioneer thinking of their exploration geoscientists. They brought new ideas into the offshore exploration theater that makes this story truly remarkable.

Along with producing needed oil for Brazil, Petrobras has helped lead the world into the ultra-deepwater frontier. For all the new seismic innovation to image ultra-deep, sub-salt targets, new geologic thinking about preserving oil at such depths would be just ideas and images on paper if it were not for a delivery system to bring it to market.

While records are to be broken and the production has gone deeper (Anadarko now has the deepest commercial field in 2,731 m water depth) the engineers and geoscientists at Petrobras and their collaboration with other companies and universities have helped make the deep ocean basins accessible.

While the chapter is still being written, the contribution to the world's energy supply from the ocean depths continues to rise and recent new discoveries off the Brazilian coastline highlight the potential of this frontier (see separate article). This issue also features other areas around the Atlantic margin once thought too deep, but are now targeted for exploration.

technical assistant to the exploration manager, and member of the working team responsible for the geological interpretation that led to the first commercial discovery in the Campos basin in the early 1970's. "Petrobras was founded in 1953 through a Federal Law. An American geologist and former exploration manager for Standard Oil, Walter Link, was contracted as the exploration manager. He left in 1961 after the now famous report recommending Petrobras explore in other more favorable countries. The onshore basins were considered to have low prospectivity and the offshore was not analyzed."

"Until 1965, Petrobras was successful in the exploration of the small coastal onshore basins in the Bahia state, yet oil output was only one third of what the country needed," continues Bacoccoli. "At this time, it was decided to start exploration of the offshore basins. Two geological priorities were established, first to look for the offshore continuity of the onshore coastal producing basins, and then to explore new offshore basins using world analogues such as salt dome provinces and large Tertiary deltaic provinces."

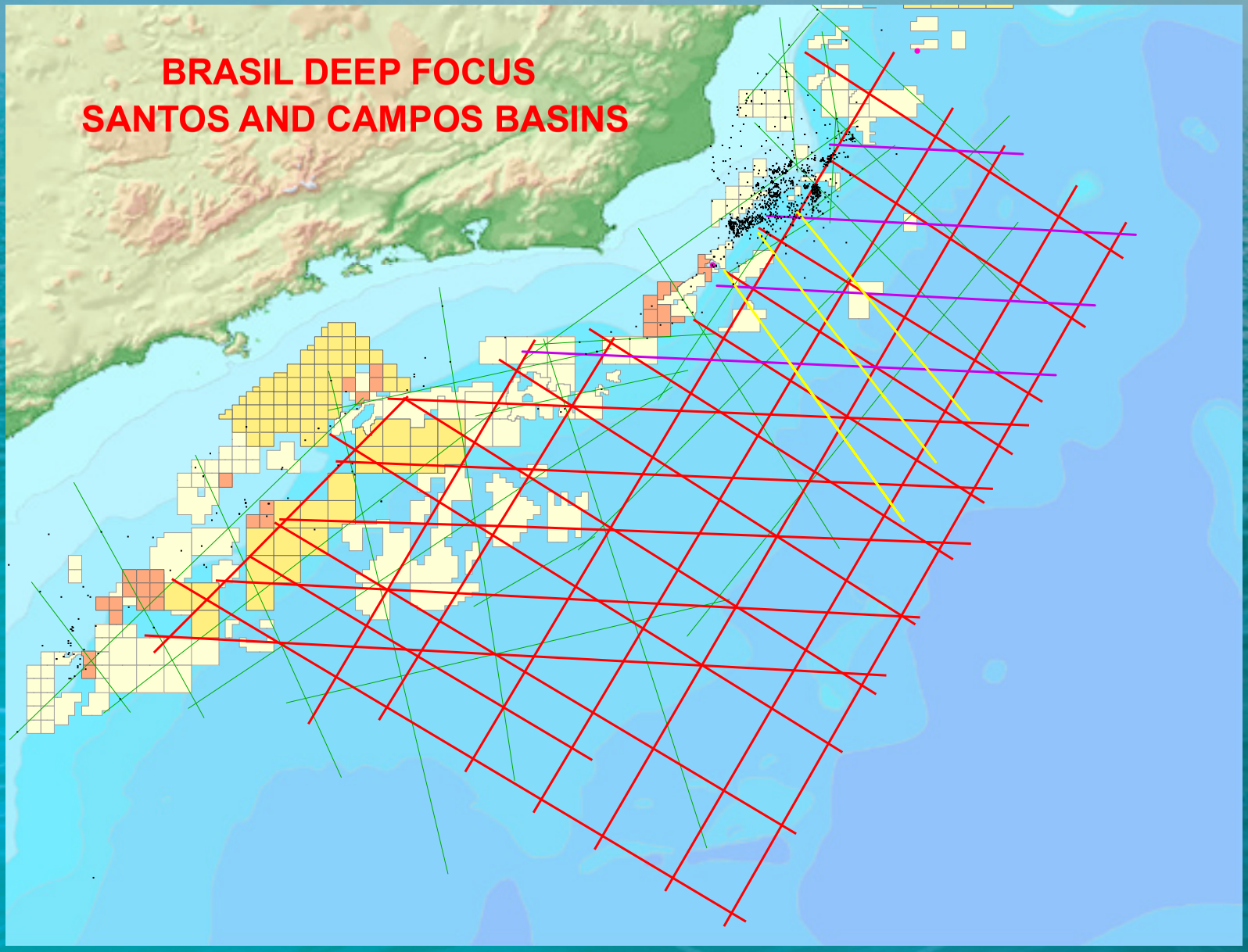
In order to expand their exploration opportunities into deeper water, the drill ship P-II was used and drilled their first discovery, the Garoupa field, in 1974.

"Exploration into the offshore basins was marked by three technical turning points," recalls Dr. Webster Mohriak, Petrobras exploration geologist. "The first came in the late 60's when plate tectonics were not well understood and the correlation between basins across the Atlantic had not been established, but the explorationists were aware of oil discoveries in salt basins along other continental margins in the world"

Seismic and gravity data were obtained ▶

The historic first offshore discovery out of sight of land was completed in 1947 by Kerr McGee Rig 16, a new concept using a mobile drilling 'tender'. Off southeast Louisiana, the Ship Shoal 32 well was drilled to a total depth of 770 m in 4 m of water 14 km from shore. The field produced oil until 1984.

Jack-up platforms were used for the first offshore exploration offshore Brazil and account for the first discoveries. Campos basin drilling started in 1971 and the early wells were also drilled from jack-up platforms.



Brasil Deep Focus

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15,000 km

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Guilherme Estrella, Exploration and Production Manager for Petrobras, do not look upon water depth as the biggest technological challenge any more.

in 1967 and the first offshore well was drilled the next year in the Espirito Santo basin on a 'plug like' feature. "There were heated debates about the origin of the 'plug like' features imaged on the oil vintage seismic data," says Dr. Mohriak. "Some geologists interpreted them as igneous intrusions while others envisaged them as huge salt diapirs."

The well drilled in 1968 from the jack-up rig Vinegarroon in 50 m of water turned out to be dry but did settle what those features actually were; it drilled into the side of a large salt dome. "This well paved the way towards more offshore drilling operations, however, the deep offshore was still considered too expensive and risky by some people," adds Dr. Mohriak.

The first offshore discovery was made when a second well that year tested the continuity of production in the Sergipe-Alagoas basin in northeastern Brazil.

Uncharted Waters

Moving into new, little explored offshore basins proved to be challenging. Exploration drilling in the Campos basin started in 1971. "We received each package of seismic sections (processing was done in Houston at the time) with a lot of expectation. For the first time, we were looking at seismic data of unknown basins. There were fantastic structures, salt domes, salt pillows, growth faults, and on and on," Bacoccoli remembers.

"After drilling 6 to 7 dry wells in the Campos basin, I was invited by our exploration manager to explain to the staff the absence of oil," says Giuseppe. "Then we finally drilled the 1-RJS-9 but had mechanical problems at around 3,000 m. After large discussions, a new well was drilled near the original location (1-RJS-9A) and oil was discovered in limestone reservoirs at about 3,100 m total depth."

This discovery would not only provide the economic boost Petrobras needed to keep exploring the basin but would lead to a "second turning point". That would be the geologic evaluation and a petroleum model for what Giuseppe calls the "Three Sisters" or from south to north, the Santos, Campos, and Espirito Santo basins, and to date, the three most important petroleum basins in Brazil.

"The evaluation that began in the late 70's used regional seismic profiles for the recognition of major structures along the continental margin, and the interpretation groups analyzed in detail the ultra-deep water region of the Campos basin," says Dr. Mohriak. "Regional mapping identified a sigmoidal progradational wedge in Tertiary sequences that was suggestive of a turbidite body. It was observed in very deep waters (more than 600 m) and beyond the current drilling technology, and this delayed drilling until 1984. It would be the first giant oil accumulation offshore Brazil, the Marlim field, discovered by borehole RJS-219A in early 1985."

"The third turning point was based on regional projects evaluating the Santos basin in the late 80's and early 90's," says Dr. Mohriak. "The geological evolution of the Cabo Frio fault zone, a major structure between the Campos and Santos basins, was interpreted as a detachment fault separating the pre-salt sequence from the massive prograding wedges corresponding to Cretaceous sequences. Some years later, the regional mapping of the rift structures observed from the platform towards the continental-oceanic crust boundary led to the identification of major structural highs sealed by a very thick salt layer in deep waters. This led to the drilling and recent discovery of the large, sub-salt hydrocarbon accumulations".

The Future

Petrobras, along with industry partners and universities, are developing numerous innovative tools and strategies critical for efficient operations as the deepwater frontiers continue to expand.

Guilherme Estrella, Exploration and Production Manager for Petrobras, sees a bright future in the deep water realms and coordinated efforts between engineers and geoscientists, "We can certainly say water depth is no longer the biggest technological challenge involved in oil production. We already have an exploratory frontier that extends beyond 3,000 m, and the major technological challenge in this frontier, particularly in the well-drilling projects, will be boreholes drilled at great depths and high temperatures, which will require special well projects and equipment to deal with such temperatures and pressures. There are also hurdles in the reservoir analysis projects. We have discovered oil in reservoirs composed of rocks geologists don't know very well, as for example, the microbiolites in the recent Santos basin sub-salt discoveries, whose electric log characteristics are rather complex. We are developing a training and qualification program to learn more about these carbonate rocks and about submarine production too."

"The major operators are slowly abandoning the use of large floating systems. So we have to develop systems, and are already doing so, to be installed in the bottom of the sea. This will be the next great step. We will slowly eliminate floating units. Everything will be installed on the sea floor and go from there to the main land or to platforms installed in shallow waters, for example, to be produced there. This is the next major technological advancement that is certain to take place in the upcoming years," says Guilherme Estrella.

The challenges are big, but Petrobras is confident on having good results, supported by the history of success on several unique subsea systems configuration that has allowed the steep progress towards ultra deep waters.

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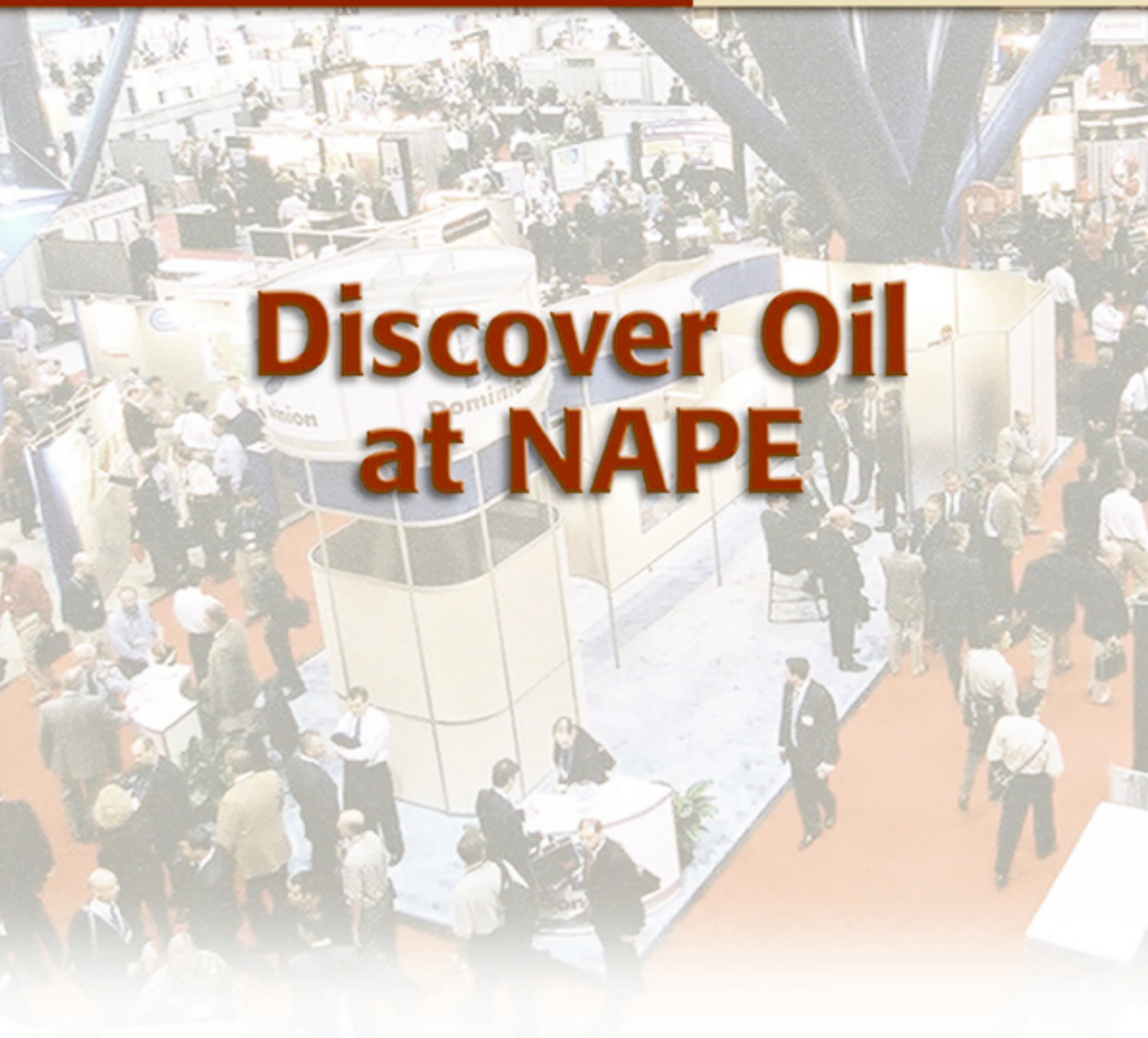

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Marvelous Vistas

Gateway to huge offshore oil reserves, Rio de Janeiro and southeast Brazil offers stunning scenery and geologic evidence of ancient mountains and the forces that spawned two continents.

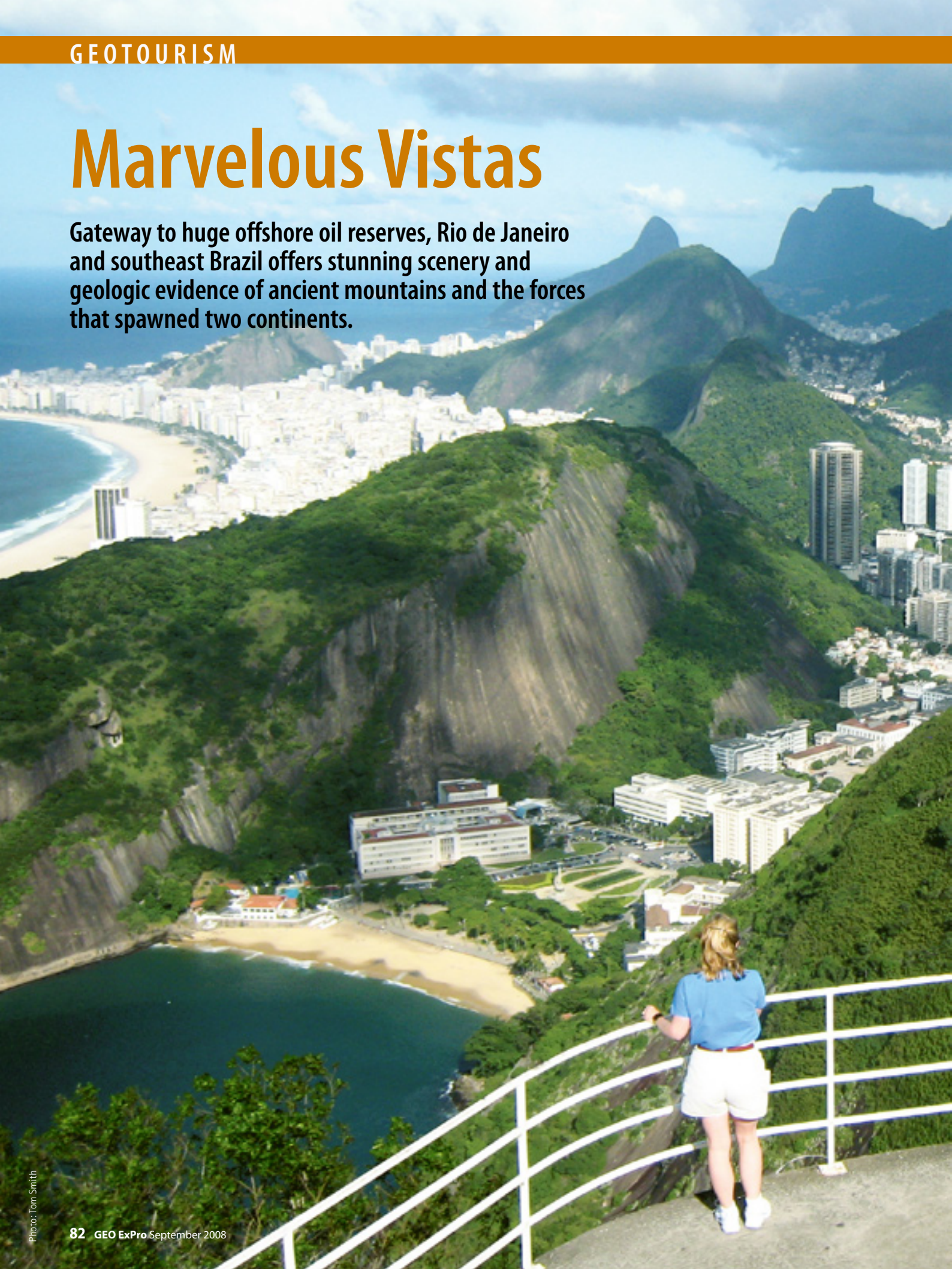

Photo: Tom Smith

Rio de Janeiro viewed from Pão de Açúcar (Sugarloaf Mountain). Copacabana Beach is on the left of the photo and Corcovado Mountain, with the statue of Cristo Redentor, is in the clouds on the right of the photo.

Bays along the southeast Brazil coast near Rio de Janiero have been redeveloped to act as service centers and ship yards for offshore operations.

Thomas Smith and Deborah Bertossa

Magnificent beaches, Carnaval, and the impressive Christ figure on a mountain top all come to mind when thinking of Rio de Janeiro, Brazil. However, this enchanting city is anchoring Brazil's emergence as a major player in the world energy picture. Beyond its gleaming shores lie recent deepwater oil and gas discoveries that could be some of the largest ever. It is a city surrounded by the endless beauty of its people (Cariocas), its dramatic setting, and promising frontier hydrocarbon basins.

Also known as the Cidade Maravilhosa (Marvelous City), Rio is now Brazil's second largest city and was its capital until 1960 when it was moved north to Brazilia. It has grown around the mountainous landscape; the various 'neighborhoods' that make up the urban area have been interconnected by tunnels that bore through the base of the steep mountains. Rio is known for its sparkling white beaches, in particular Copacabana and Ipanema, each separated by granite headlands. Made up of the weathered native granite, these long stretches of sand form beautiful crescents framed by mountains and sea.

Rio serves as the headquarters for the enormous state-owned oil company, Petrobras, and a growing number of oil and service companies. Offshore oil discoveries have prompted a serious expansion of the company (now the 6th largest in the world) with plans to modernize and enlarge their fleet of deep water drilling and production rigs. Production of biofuels has also contributed to the success of Brazil's diverse economy as Petrobras is a worldwide leader in research, development, and production of this alternative fuel.

Granites form the backbone of the beautiful scenery in and around Rio and materials for many of its buildings and walls.

Climbers ascend Morro da Babliônia in the neighborhood of Urca, which can be seen from the Sugarloaf tramway, and is a very popular route to climb in Rio.

Many Brazilians run on the less expensive 'Álcool', or alcohol fuel, that has helped them be nearly energy self sufficient.

European Colonists

When Gaspar de Lemos of Portugal sailed into Guanabara Bay in January, 1502, he mistook the large bay for a river and named it Rio de Janeiro (River of January). It would be years before the area was actually settled, first by the French and finally taken over by the Portuguese. By the 17th century, the native Tamoio people had been wiped out and Rio became an important European settlement in Brazil. African slaves were brought in to work the sugar and coffee plantations, and later, the gold mines. The King of Portugal, fleeing Napoleon's army and Lisbon, fell in love with Rio. From there he continued to rule his kingdom, Brazil, and the Algarve, making it the only New World colony to ever have a European monarch ruling on its soil.

By the end of the 19th Century, Rio was approaching a million people due to European immigration, along with the migration of ex-slaves from the declining sugar and coffee regions. This mix of cultures and people all add interest and life to the city. Development during the 1960s gave rise to many of Rio's modern skyscrapers but loss to some of its most beautiful colonial buildings. This period also saw immigration from outlying poverty-stricken areas, giving Rio its growing favelas (shantytowns).

A turnaround came when Rio hosted Eco 92, the UN Conference on Environment and Development. The government pumped more than a billion US dollars into the city for infrastructure upgrades. Now, the city buzzes with energy and new projects in an attempt to integrate the favelas into the city.

Signature Mountains

The area's captivating scenery is underlined by its unusual geography shaped by mountains that rise sharply from the sea and

The art deco sidewalks or Portuguese pavement, like this one along Copacabana beach are prevalent throughout the city.

Corcovado Mountain forms the background of many views across the city.

form an irregular coastline. Most notable of these large protrusions are Sugarloaf and Corcovado. Both features are composed of gneissic granite formed 570 million years ago and are evidence to the massive convergence of land masses and consequent Atlantic rifting which plays an important role in interpreting the formation of South America and its oil reserves.

Uplift and erosion has left what we see today – the hard, banded gneissic masses that not only form Sugarloaf and Corcovado, but underlay most of Rio. The shape of the rocks is determined by its resistance to erosion; the brecciated metasedimentary material located near fault zones weathered much faster and produced the rich soil of the densely forested lowlands along with the Rio Carioca (from which the term 'Carioca' was derived meaning Rio dwellers), supplying Rio de Janeiro with fresh water for centuries. The more resistant augen gneiss, characterized by its pink eye-shaped feldspars, caps the ridges of Sugarloaf and Corcovado.

A second type of granitic rock present in this southern region of Brazil is the leptinitic gneiss which contains beautiful tiny garnet crystals. Since the 16th century, the very prevalent augen gneiss has been used to build forts, castles, monuments, walls, and houses and can be seen in structures throughout the city.

Sugarloaf Mountain

Located at the tip of a peninsula, Sugarloaf Mountain is an ascent all tourists must make when visiting Rio de Janeiro. Beautiful views of Guanabara Bay, Cristo Redentor, and of course, the city. Two cable cars are taken to reach the top of the mountain. The first heads up 220 m to Morro da Urca which in itself offers beautiful views from stone terraces and various trails. The second cable car ascends to the top 396 m above Rio and offers unparalleled views of the bay, coastline, and outer islands.

As you ascend these summits, look directly across to see ambitious rock climbers scaling a gigantic granite rock face. Rio's setting offers numerous outdoor activities including jogging, hiking, walking, cycling, and surfing. These mountains are also attractive to hang-gliders and climbers. Rio de Janeiro is the center of rock climbing in Brazil with about 350 established climbs available locally.

Corcovado Mountain

High on Corcovado Mountain, 710 m above the city floor, stands the most notable of Rio's landmarks, the statue of Cristo Redentor (Christ the Redeemer). This enormous statue looms over Rio de Janeiro with outstretched hands. At 38 m tall and carved completely out of the local granite (1,038.5 metric tons), the statue can be seen from almost all parts of the city. The mountain is within the Parque Nacional da Tijuca, a lush 120 km² tropical urban forest and all that is left of the Atlantic rain forest around Rio and many parts of southeast Brazil.

The panoramic view from Corcovado is breathtaking. There are two ways to reach this steep summit: a small cog train which leaves from the base of the mountain every 30 minutes, or by road which winds its way up through the Tijuca rain forest. Both culminate at an escalator which will take you to the summit of this spectacular mountain.

Located at the base of Corcovado, and also within the Parque Nacional da Tijuca, is the Jardim Botânico (Botanical Gardens), a lovely park designed and established in 1808 by Dom João VI who was then the prince regent of the United Kingdom of Brazil and Portugal. Considered by UNESCO in 1992 as a biosphere reserve, it is one of the great tropical botanical gardens of the world. Some of the park's highlights include an entire greenhouse of beautiful rare orchids, a Japanese garden, and gigantic royal palm trees that line the pathways and squares. Many plant species native to Brazil, including the Amazon region, can be found in the park. Cariocas and their families make this a special place to visit during the weekends and holidays as it is located only minutes from the beaches of Copacabana and Ipanema.

Excursions from the City

Escape from the bustling and lively city life is not far away. Easy day trips to outlying towns are available to find that 'perfect beach' or take a boat to visit the islands. Tour operators are located throughout Rio to arrange tour excursions and lodging at numerous destinations.

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No 5. SEG 78th Annual Meeting,
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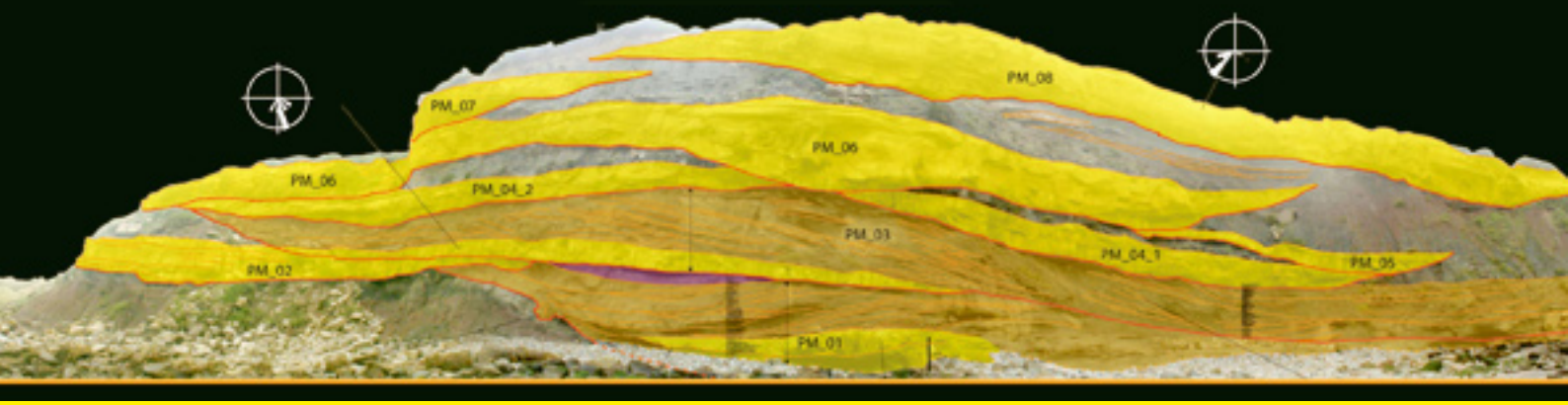

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GEO EXPRO, TOGETHER WITH IHS, PRESENTS SOME OF THE MOST SIGNIFICANT DISCOVERIES MADE THROUGHOUT THE WORLD IN RECENT MONTHS.

Jane Whaley, Associate Editor

"Significant Discovery" Off Sicily

Sicily is not somewhere that springs immediately to mind when thinking of hydrocarbons, but with current concerns about the security of supplies from the Middle East and West Africa, a number of companies have been looking harder at their own back yards, often with an intriguing level of success. Italian company ENI and the Pelagian Basin, south of the Italian island of Sicily, is one such example.

In July ENI made what it termed a 'new and significant' gas discovery in the Sicilian Strait, in relatively deep water of 560 m, about 20 km south of the south-western coastal town of Agrigentos. This new field wildcat, Cassiopea-1, tested gas at 6,710 Mcfpd (190 Mmcpd) and has reported estimated gas reserves of about 565 Bcf (16 Mcm or 100Bboe). It lies roughly midway between the 2005 Argo discovery to the south-east and the Panda gas discovery, made in 2002, about 10 km to the north-west. Argo has an estimated 100 Bcf of recoverable reserves, while Panda's 2P reserve estimate is 350 Bcf, with some evidence that the field could eventually prove to contain over 1 Tcfg (180MMboe). The Cassiopea field will be integrated with these two discoveries in an accelerated development programme.

In the Late Tertiary and Quaternary Italy rotated as the Tyrrhenian Sea to the west opened, giving rise to deep grabens which then filled with sands and shales which act as hydrocarbon reservoirs. The reservoir in the Panda gas field, for example, is a Pliocene turbidite formation. The Eocene Bou Dabbous shale formation is expected to source these hydrocarbons.

South-east Sicily is already a prolific oil producing province with about 1 Bb of recoverable oil from four principal fields, Ragusa, Gela, Vega and Perla, producing from Triassic dolomites and Liassic shelf edge carbonates. Across the boundary the trend continues with discoveries in Tunisian waters. Companies exploring off south-west Sicily believe that modern 3D seismic and reprocessing of old seismic will lead to the uncovering of further major prospects and fields.

Photo: Gill Leliot

The beautiful volcanic Aeolian Islands lie off the north-east coast of Sicily. The Calabrian arc, where the African and Eurasian plate meet around the toe of Italy and through Sicily, is one of the most seismically active areas in Europe.

Italy had proven oil reserves of 780 Mmbo and 3.14 Tcfg in 2007, (BP Statistical Review of World Energy, 2008). It has an attractive fiscal regime, and activity levels in exploration licensing have seen a marked increase over the last few years.

Western Australian LNG Project boosted

The Wheatstone and Iago discoveries are close to the Gorgon gas fields, which contain an estimated 40Tcfg, representing about 25% of Australia's known gas resources.

The Iago Field in Western Australia, discovered in 2000, was thought to contain about 5 Tcfg (142 MMcmg/890 Bboe), but the results of a recent second well on the field are expected to significantly boost the recoverable reserves. Iago 2 was drilled to investigate an extension of the field into a previously unexplored reservoir compartment and tested 53 MMcfg (1.5 MMcmg) per day.

The Iago Field is in the Barrow sub-basin, 150 km north-west of the north-west Australian town of Karratha, in relatively shallow water of approximately 117 m. The supergiant Gorgon gas field, which has reserves of about 40 Tcfg, (1,133 Bcm/7 Bboe) lies about 100 km to the south-west. Iago 1 found gas in a simple horst trap in the Triassic Mungaroo Formation, sealed by overlying Mungaroo shales, while Iago 2 discovered 47 m net pay in sands from the same formation, extending the field to the south.

The principal source rocks in the Barrow sub-basin are Upper Jurassic anoxic marine shales, which are usually within the oil window on the basin margins and the gas window in the centre of the basin.

The main significance of this discovery is its proximity to the Wheatstone gas field, which was discovered in 2004 and has reserves of over 4 Tcf (113 Bcm/710 Bboe) of gas. In March this year, Chevron announced plans to develop a new multi-train LNG export facility to be supplied by the Wheatstone Field. The additional reserves discovered in the Iago field means that Chevron will multiply the size of the planned project to 15 million tons (130 MMboe) per year, using three processing plants. The FEED stage will be launched in 2009.

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The Barrow Sub-Basin is part of the Carnarvon Basin, which extends north-westwards up the Australian coast, possibly though the Westralian Basin and the Timor Sea, to Irian Jaya and Papua New Guinea. This has lead a number of companies to believe that the Papuan Basin is seriously under explored.

Success in Underexplored PNG Basin

Although current reserves are put at 650 MMbo and 14 Tcf (2.3 Bboe), many observers believe that the potential of the Papuan Basin in Papua New Guinea is much greater.

This belief was boosted recently with the success of a new field wildcat, **Puk Puk**-1, on licence PPL 235 in the onshore Fly River Platform area. The well, drilled by Rift Oil in July this year, targeted the Lower Cretaceous Toro and Hedinia formations, and found a gross gas column of 159 m (48.5 m net) in good quality sandstone reservoirs.

Original estimates for Puk Puk were 226 Bcfg (38 MMboe), but the hydrocarbon column was larger than anticipated and as a result Rift Oil's estimate of the potential mid-case reserve size for the field has doubled to 439 Bcf (79 MMboe) of gas and 8.5 MMb of condensate. In addition, oil shows encountered during drilling may indicate the presence of oil elsewhere in the structure.

Puk Puk lies about 25 km north-west of a previous gas discovery on the same licence, Douglas 1, found in 2006. Seismic indicates a number of promising prospects and structural highs in the same area. An earlier well on the southern edge of PPL 235, Langia-1, encountered oil shows in Tertiary sediments as well as the Upper Jurassic-Lower Cretaceous reservoir objectives. Rift Oil consider that the block, which covers 7,000 km^2, is very promising, and estimate that the total upside potential of the permit may be in excess of 1 Tcf (180 MMboe).

Much of Papua New Guinea is covered in pristine rain forest, including the Fly River Platform. The river rises in the Central Mountains of New Guinea and drains for 700 km south-eastward to the flat, alluvial Fly Platform, before disgorging into the sea through a 70 km wide delta mouth.

PPL 235 lies approximately 50 km south-west of the main Papuan New Guinea hydrocarbon trend, the Central Highlands, where at least 12 fields have been found in sandstones of the Late Jurassic or Early Cretaceous. The Fly River Platform is less well explored, but almost all wells drilled in this area have shown evidence of hydrocarbons.

For a more detailed description of the petroleum geology of Papua New Guinea, see GEO ExPro 02/2007.

SPE Encourages Global Membership

Dr. Leo Roodhart, the 2009 President of the Society of Petroleum Engineers (SPE), hopes to enthuse a younger generation of oil industry experts by encouraging membership and active participation in the society throughout the world.

A physicist by training, Dr. Leo Roodhart has spent his working life with Shell in positions in R&D, production engineering, business development and innovation, before heading up Shell's Innovation Group, "GameChanger".

What ambitions have you for the SPE during your year as President?

These centre around globalizing SPE further, making it a truly international society where every member, wherever they live, regards it as their own. We now have 170 local sections worldwide, with regional offices in London, Kuala Lumpur, Dubai, and Moscow. A few years ago I convinced the SPE International Board to start holding the Annual Technical Conference and Exhibition where their members lived - internationally, not just in the US - so the 2010 annual meeting will be held in Florence, Italy. Language is obviously a impediment to globalization, but we will soon issue a Russian-language regional periodical and we will do similar publications in other languages if there is demand.

How has the membership changed in recent years?

Over the last 5 years, SPE's main growth in professional membership has been in Russia, the Middle East, India, Northern Asia, and South America, with membership split roughly 50–50 between US and non-US citizens. However, more than 70% of our 18,000 student members are non-US nationals. I want to find ways to address these students and keep them on board when they are ready to find a job. We need to enthuse young people and help them choose our industry for a career.

What prompted you to stand for office with SPE?

As with many things, I just fell into it. I have been a member of SPE all my working life. I wrote a few papers, presented them at conferences and, without realizing it, started to build a network across the industry. When I returned to The Hague from Canada, I became program chair of the local SPE section. Later I was elected chairman of The Hague Section and also was invited to serve on a few industry committees, before being elected to the Board of SPE International. Once on the board I was quite active, particularly in making SPE a truly global society, and was then nominated for the President's position for 2009 and was elected by the nominating committee last year.

You have a background in science and mathematics. Can you tell us why the hydrocarbon industry appealed to you?

After finishing my PhD, I applied for a job with Shell Research, as did many scientists with my background. They suggested I approach the research people in Shell E&P laboratories in Rijswijk, and I really liked the atmosphere of down-to-earth applied research. I also liked the enormous freedom researchers were given in those days. I was intrigued by the flow of so-called 'non-Newtonian' fluids ('silly-putty' type liquids), so flow dynamics became my research topic, and I was given great support by Shell.

Do you have an optimistic or a pessimistic view of the future of the energy industry?

As SPE President, my message to the young is that the world is not running out of oil. There is plenty for the next 100 years, but it is increasingly difficult to extract and we will need the best and brightest minds to do that. Now there's a technology challenge that should appeal to young people! So my view is optimistic, though our industry will have to face huge hurdles in the coming decades. These can only be tackled by working together on a global scale, as individual companies cannot solve them, requiring knowledge sharing on an unprecedented scale. SPE has a role to play here.

If you could change one single thing in the industry, what would it be?

Global cooperation instead of global competition and nationalism. I would also like to see all relevant engineers from the National Oil Companies becoming members of SPE.

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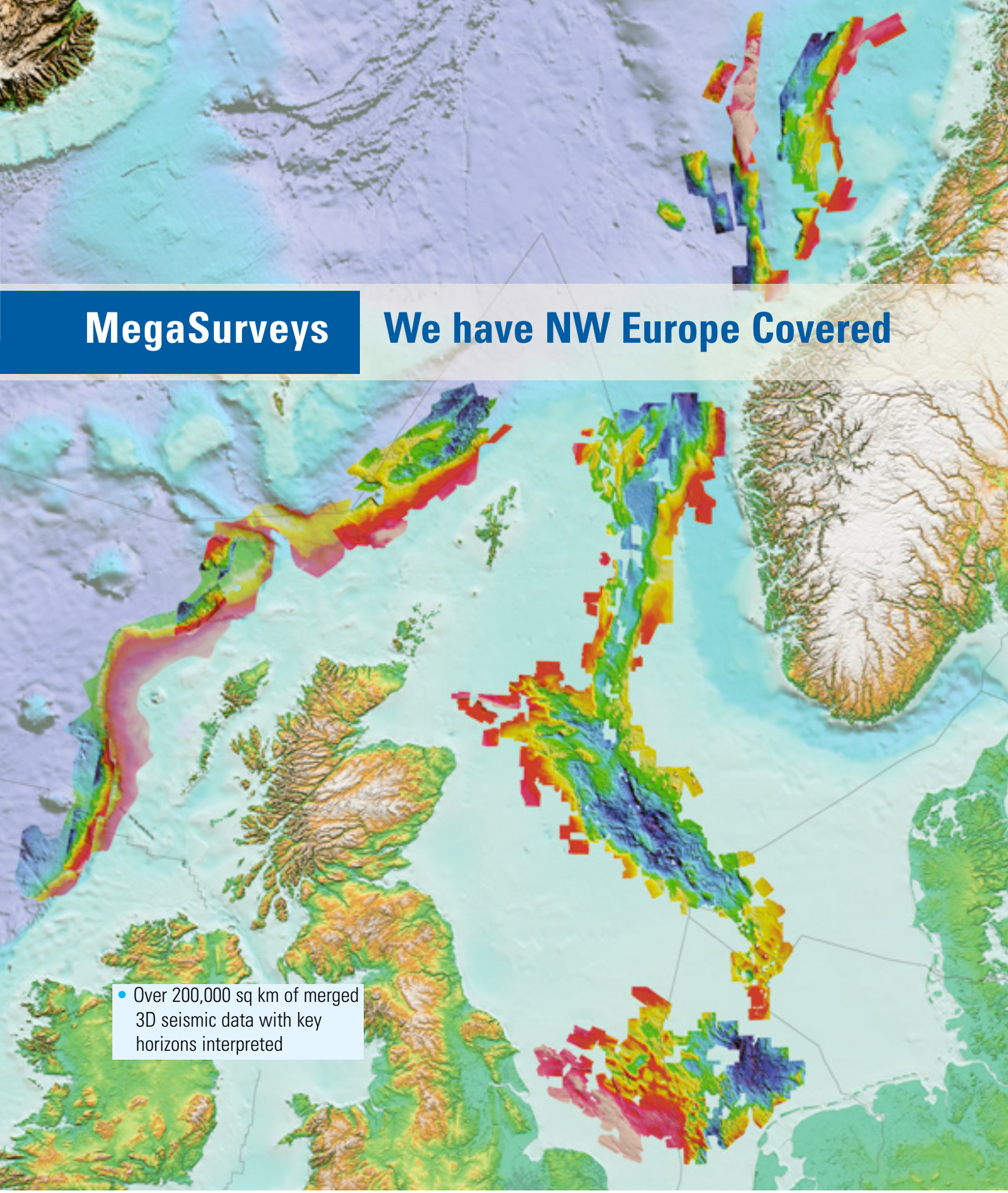

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A Significant Discovery

Ghana has four offshore sedimentary basins: Tano, Cape Three Points, Saltpond and Accra-Keta, all of which have experienced some degree of exploration. The potential of the onshore area, which includes the small landward extensions of the Tano and Keta Basins and the vast inland Voltaian Basin, is largely unexplored.

Photo: Paul Archer

The twin city of Sekondi Takoradi is the main town in western Ghana and the nearest port to the Jubilee and Odum discoveries.

Interest in the West African country has increased with the success of a recent appraisal well. It suggests that the Jubilee field may contain over one billion barrels of oil.

Until recently, few major international companies took any notice of Ghana. In recent years, however, interest has risen exponentially with the discovery of large reserves in the deep waters of the Atlantic. Eleven oil companies now have agreements with the Ghana National Petroleum Corporation (GNPC), and as many as 40 companies have expressed interest in the country.

Exploration offshore Ghana actually began in the 1970's but with only moderate success. The South and North Tano fields, in Ghana's western waters, and the central Saltpond field were discovered at this time, but being predominantly gas, they were deemed semi-commercial. Only Saltpond was put into production, producing 3.5 MMbo before it was shut-in in 1985.

Then, at the beginning of the 21st century, Aberdeen-based Dana Petroleum began looking at the western part of the Tano Basin and encountered good accumulations of heavy oil in Cretaceous reservoirs, as well as identifying interesting prospects from 3D seismic in the deeper water parts of the Tano Basin.

A real giant

Finally, in June 2007, a consortium of oil companies including Tullow and Kosmos hit the jackpot with Mahogany-1, located 132 km south-west of the port city of Takoradi, in water depths of over 1,000 m. The oil is trapped in an Upper Cretaceous (Turonian) turbidite fan system. This was followed a few months later by the Hyedua discovery, only 5 km south-west of Mahogany and part of the same field, which has been named Jubilee as it was discovered in Ghana's Golden Jubilee year.

A recent appraisal well, Mahogany-2, further tested the potential of the field and suggested production could be as high as 20,000 bopd. According to Tullow, the results of this well allowed geologists to revise their estimates of the field, with the P90 reserves rising to over 500 MMbo and the ultimate upside upgraded to 1.8 Bbo. Two more appraisal wells are planned for 2008 and a further four in 2009.

In February this year came further encouragement for the industry, with the success of Odum-1, approximately 13 km east of the Jubilee Field and 117 km south-west of Takoradi. This discovery is at a different Upper Cretaceous level (Campanian) and opens a new play fairway in the Tano Basin. Further interesting prospects have been identified in this region, several of which are thought to hold more than 500 MMbo.

Seventh largest producer

The Government of Ghana is now keen to start production in early 2010, aiming to pump 200,000 bopd by 2015, which would make it the seventh largest producer in Africa. Ghana's economy, which relies mainly on gold, timber, cocoa and a budding IT sector, is already doing well without the money that oil will provide. Many Ghanaians, while welcoming the promise of the wealth which should come with oil, are wary of the pitfalls which its discovery has brought their West African neighbours, and are working hard to ensure that the whole country can benefit.

Jane Whaley, Associate Editor

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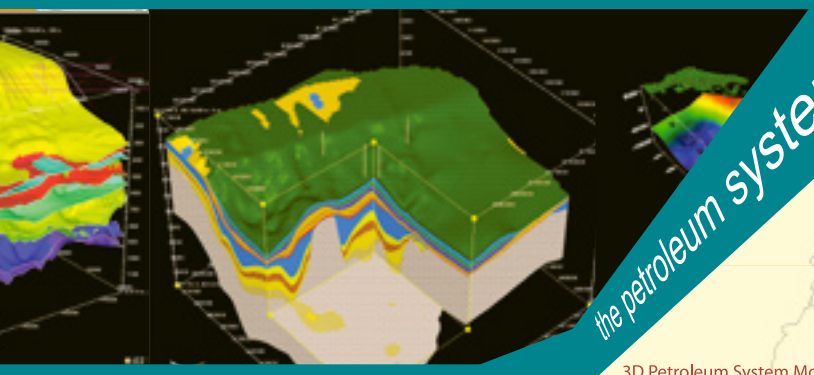


CONVERSION FACTORS

Crude oil
1 m^3 = 6.29 barrels
1 barrel = 0.159 m^3
1 tonne = 7,49 barrels

Natural gas
1 m^3 = 35.3 ft^3
1 ft^3 = 0.028 m^3

Energy
1000 m^3 gas = 1 m^3 o.e
1 tonne NGL = 1.9 m^3 o.e.

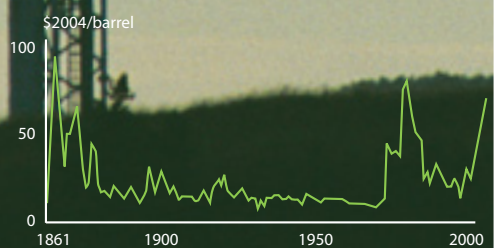
Numbers
Million = 1 x 10^6
Billion = 1 x 10^9
Trillion = 1 x 10^{12}

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

Giant field
Recoverable reserves > 500 million barrels (80 million Sm^3) of oil equivalents

Major field
Recoverable reserves > 100 million barrels (16 million Sm^3) of oil equivalents

Historic oil price



Success in a High Cost World

As the price of oil shoots up towards $150 a barrel, high costs and high expectations follow. So what is the best route to financial success – exploration, enhanced recovery or acquisition?


Photo: Jane Whaley

Dr. Andrew Latham started his career in 1990 as a new ventures geologist with Ranger Oil. As Vice President for Wood Mackenzie's Exploration Service, he provides analysis of exploration economics, strategies and industry trends.

"With oil at such a high price, can explorers go wrong? Obviously, it's not that simple. Exploration companies are under huge pressures which are pushing costs upwards, so that the total technical cost for finding and developing oil and gas has increased from about $7 a barrel in 2000 to $25 in 2007."

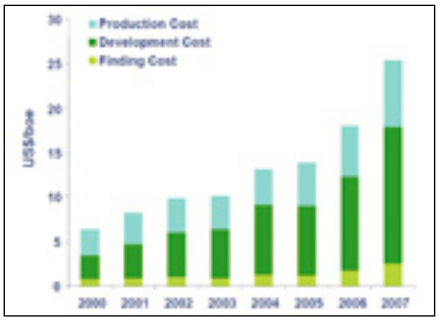
Andrew Latham, Vice President, Exploration Service with industry analysts Wood Mackenzie, posed this question at a recent meeting of the Petroleum Society of Great Britain in London. In answer, he reviewed a number of factors affecting success, ranging from price and cost trends, investment and reserves changes, and alternative resource capture options.

Cost-driving factors

Latham identifies three fundamental drivers affecting costs. "Firstly, the industry is developing more difficult reserves, in remote locations, deeper water and greater target depth. Reservoirs are tighter and more complex fluids are being exploited. Secondly, **labour and raw material costs have risen** – the price of steel has increased by nearly 100% in three years, and the high price of fuel affects us all - so exploration and appraisal spend has doubled over the last two years. Thirdly, **demand in the service sector exceeds supply,** so margins have risen dramatically, from around 5% in 2004 to 20% in 2008."

Exploration returns are also under pressure from fiscal changes in many countries, as government take has been increased by countries watching the rise in oil prices. Signature bonuses have risen more sharply than the oil price, resulting in a massive increase in the price of new exploration acreage. As a consequence, some of the industry is moving from highly-taxed areas to newer, more fiscally attractive regions.

Source: Wood MacKenzie company reports



Total technical costs have risen sharply in recent years, particularly development costs.

The best route

What is the best route to increasing the resource base and financial success of an oil company? "Not all oil companies rely on new field exploration to the same degree, some preferring to negotiate discovered resource opportunities," Latham explains. "However, this does not seem to be as attractive as it once was, as project returns have been decreasing. The extent to which companies invest in exploration is a strategic choice, but to find more they need to invest more."

So is it possible to be successful in this high cost, high price world? Andrew Latham suggests that "discovery trends indicate vast resources remain to be found. This means that although cost, access and fiscal factors have offset much of explorers' upside from high prices, exploration economics still compare favourably with mergers and acquisitions and other routes to financial success."

Plenty of reserves waiting

Andrew Latham of Wood Mackenzie reveals that analysis of the volumes of hydrocarbons found over the last 10 years uncovers some surprising trends. With the exception of 2000, when the giant Kashagan field was discovered, the volume of oil found in new fields has remained about 15Bboe annually (compared to about 30Bbo consumed). The number of large discoveries each year - about 40 - has also been consistent over the last ten years. *"The interesting thing about this," Latham says, "is that one might expect a 'creaming curve' effect, with volumes of discovered reserves falling, rather than the consistency that we are seeing.* What this is actually telling us is that there is still plenty out there, waiting to be discovered."

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