VOL. 7, NO. 2 – 2010

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

Geotourism: Cornwall, UK

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Bakken Shale:
Source Rock Becomes Reservoir

Seismic foldout:
Australia's Bight Basin

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COLUMNS

5 Editorial
8 ExPro Update
16 A Minute to Read
32 Recent Advances in Technology
44 History of oil: Sarawak
50 Geotourism: Cornwall
56 Energy Statistics: Provided by Rystad Energy
58 Global Exploration Update
60 Q&A
62 Hot Spot
64 Global Resource Management: Iraq

FEATURES

20 Sourcing an Oil Boom
26 Kurdistan: Safe and Secure, with Billion Barrel Prospects
36 SEISMIC FOLDOUT: Australia's Bight Basin
39 Hidden assets in South Australia

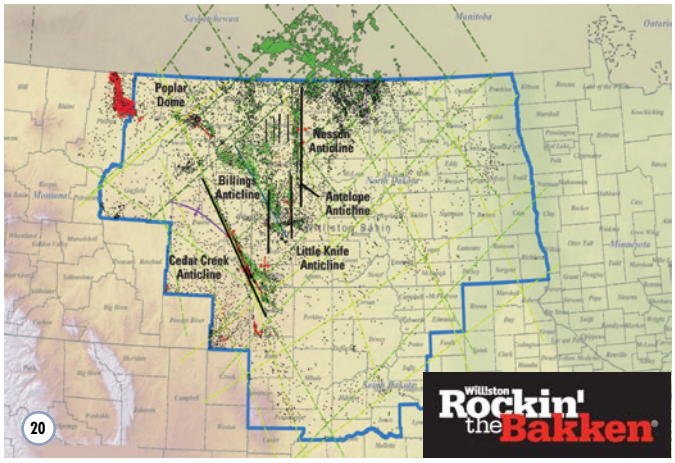


Illustration: IHS Energy

The Bakken Shale - Source Rock Becomes Reservoir Rock
Underlying an area approximately the size of France, the Bakken Formation oil reservoir keeps expanding into what has become North America's hottest onshore oil play.

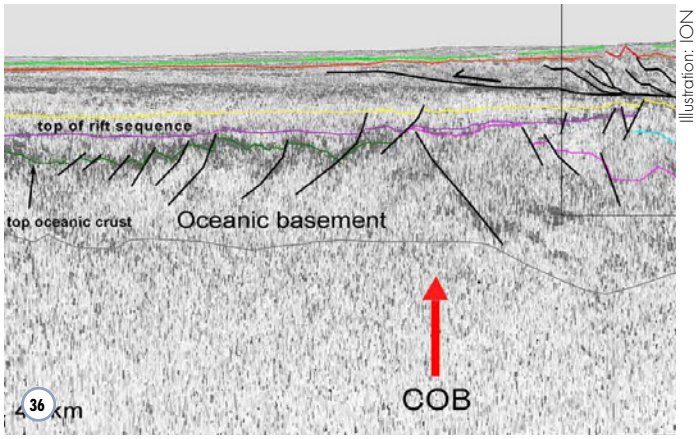


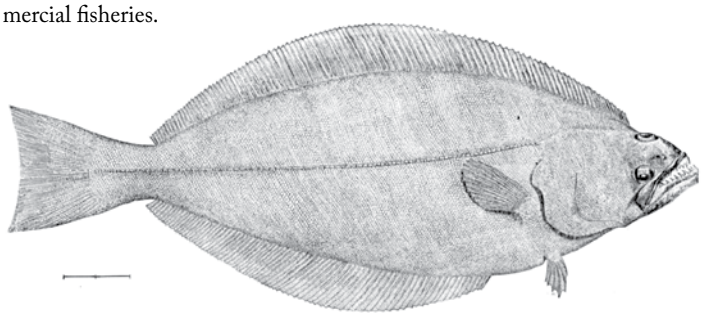
Illustration: ION

Geoscience Explained: Seismic Fold-out
A largely untested 15,000 m succession of Middle Jurassic to Upper Cretaceous sediments in the offshore Ceduna Sub-basin has turned the planned offering of six exploration areas into a favoured frontier exploration area.

SHOOTING SEISMIC DOES NOT KILL FISH

"Sound waves from seismic data acquisition resulted in increased catches for some species and smaller catches for others." To me, that sounds a bit inconclusive, but it is still the main result from research done on an important fishing ground and a frontier exploration province offshore Norway during the summer of 2009.

After having acquired seismic offshore Norway for almost 50 years (the very first survey was shot in 1962, in Skagerrak), including major 2D surveys and huge 3D lay outs, a large research programme was conducted last year aimed at improving the understanding of how seismic campaigns affect fish distribution and the commercial fisheries.



Net catches of Greenland halibut (*Reinhardtius hippoglossoides*), a deepwater fish found between 200 and 1600 m in waters with temperatures from 1-4 °C, were higher during and after seismic operations than they were before them. Line catches of Greenland halibut, however, declined during seismic work, but increased afterwards.

The research programme was undertaken in conjunction with the acquisition of a 3D survey within the highly prospective Nordland VII (Vesterålen) area north of the Arctic Circle. The acquisition overlapped some of the best traditional offshore fishing grounds in Norway.

The Institute of Marine Research was given responsibility for carrying out the project, which was financed by the Norwegian Petroleum Directorate (NPD). According to NPD, it is one of the largest such research projects ever conducted.

The project revealed that the sound of the air-guns affected the fisheries in the study area off Vesterålen "in a number of ways". These "ways" included both increased and reduced catches of individual fish species, made by different types of gear, and the fact that some species withdrew from the area, while others remained.

The details we leave to those who are particularly interested. The overall conclusion, however, is that the research programme failed to prove that seismic acquisition has a devastating effect on fish and fishing, contrary to statements often made by fishermen, and their allies in "environmentally friendly" organizations, whose main goal is to make oil and gas exploration more difficult. It is in fact no secret that the reason why Norwegian fishermen make a lot of noise (!) about seismic acquisition is to get compensation for reduced catchments.

The outcome of the USD 4 million research programme will not change this. Certainly not. Even though the conclusions are not accepted by the fishermen. First, they ask for research, and when the results are not in their favour, they are not willing to face the truth.

Halfdan Carstens
Editor in Chief

THE BAKKEN SHALE

It has been ten years since the first horizontal well was completed in the Bakken Formation at Montana's Elm Coulee Field. Thanks to research, technological advancements, and sound geological work, this oil play is reversing declining area production. Bakken exploration and production has now expanded from Montana into North Dakota and the Canadian provinces of Saskatchewan and Manitoba. The US Geological Survey (USGS) recently estimated the mean undiscovered resources to exceed 3.8 Bbo.

Richard Findley, the Billings, Montana independent who originated the Bakken play, greatly underestimated the size of the discovery field and now believes the USGS "assessment is greatly understated". The play is evolving rapidly; the story starts on page 20.

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Halfdan Carstens

Huge Blocks Offered in the Baffin Bay

New data shows the existence of large sedimentary basins offshore West Greenland. To exploit the potential, The Government of Greenland has made a plan for licensing.

A licensing round is now carried out in the Baffin Bay followed by licensing rounds in the Greenland Sea in 2012 and 2013.

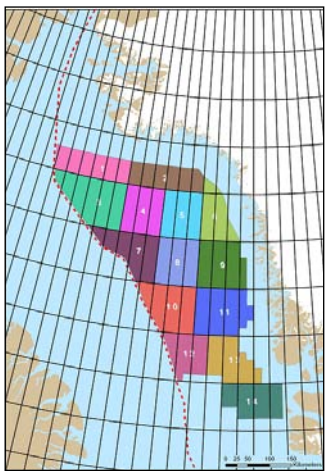
The deadline for submission of applications for the Baffin Bay licensing round is 1 May 2010. Applicants may apply for licences in 14 predefined blocks varying in size between 8,000 km^2 and 15,000 km^2. The total licensing area in Baffin Bay covers approximately 151,000 km^2, equivalent to 25 North Sea quadrants.

Exploration for hydrocarbons offshore West Greenland was initiated in the beginning of the 1970s, and in the following years five exploration wells were drilled, of which only one showed traces of hydrocarbons.

In 1992 The Geological Survey of Denmark and Greenland (GEUS) registered oil seeps on the Disko Island in Northwest Greenland. In the following years the seeps were recorded over a wide area, extending from northern Disko through Nuussuaq peninsula to the southern part of Svartenhuk peninsula. In 1996, a Canadian company drilled an exploration well on Nuussuaq, which showed the existence of hydrocarbons.

In 2000, a group led by Statoil drilled a dry exploration well, Qulleq-1, offshore central West Greenland.

New seismic data have revealed the existence of large sedimentary basins offshore West Greenland. An integrated evaluation of seismic, gravity, magnetic and satellite data – primarily collected trough the latest five years – confirms the possible existence of a very large interconnected basin system with petroleum deposits along the so-called Ungava Fault Zone. Thus, this basin system links the petroleum deposits in the Labrador-sea south of 60°N, with the collected oil seeps on Disko-Nuussuaq, all the way up to 71°N.



GEUS, TGS-Nopec and the Bureau of Minerals and Petroleum has made a comprehensive GIS compilation of information from the Baffin Bay region. The study has been carried out by GEUS and is based on all TGS data and on public domain data and includes seismic interpretation, mapping and evaluation of prospectivity, petroleum systems and geohazards.

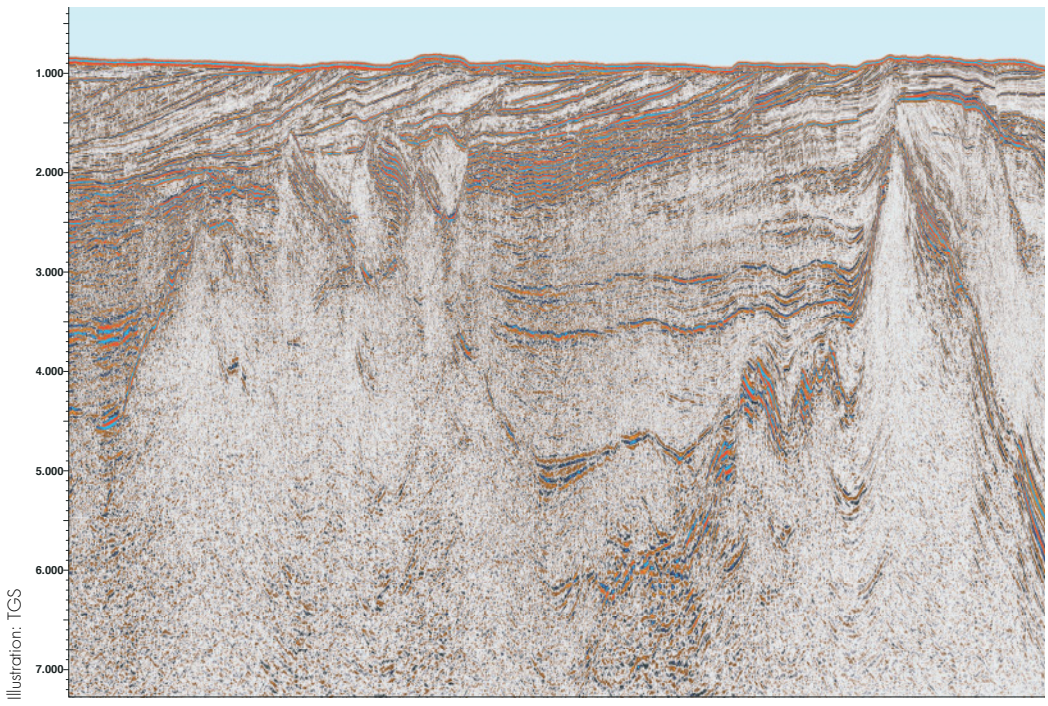


Illustration: TGS

Line running northeast-southwest across the Melville Ridge and the Kivioq Basin.

ABBREVIATIONS

Numbers
(U.S. and scientific community)

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

Liquids

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

Gas

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

Ma: Million years ago

LNG

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

NGL

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

Reserves and resources

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

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

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

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

The World's Deepest Exploration Well

In 2009, BP drilled what they said was "one of the deepest wells ever drilled by the oil and gas industry".

The well, located in Keathley Canyon, approximately 400 kilometres south east of Houston, was in 1,259 meters of water. The well found oil in multiple Lower Tertiary reservoirs and is considered to be a giant discovery with possibly several billion barrels to be recovered (see also Hot Spot, page 62). The well was drilled to 10,683 meters, meaning that it drilled through 9424 meters of sedimentary rocks.

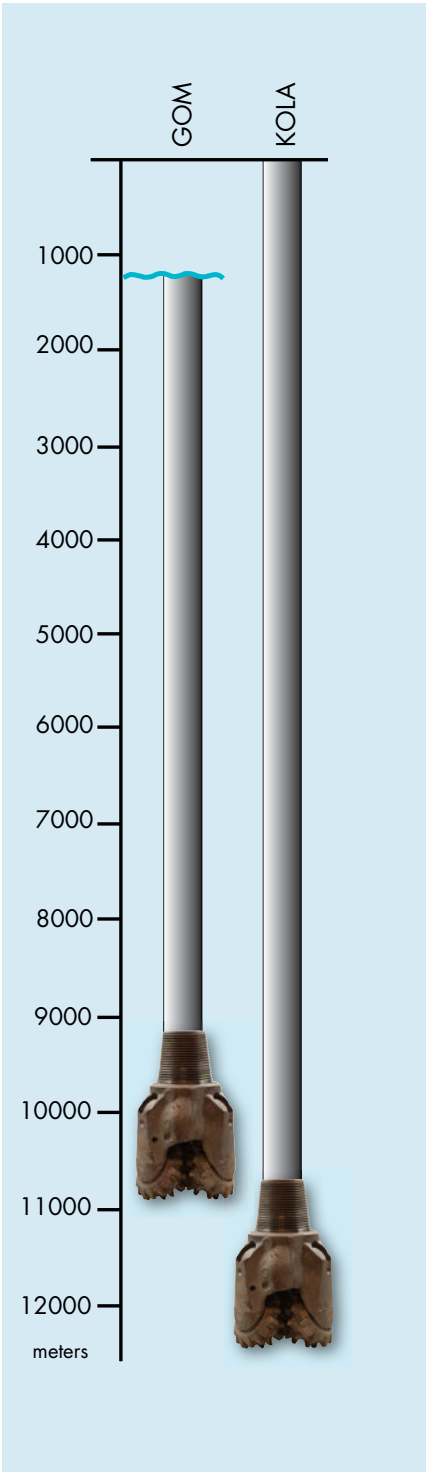
The **longest** holes ever drilled by the petroleum industry, however, are horizontal, meaning that the lower part is drilled parallel to the sedimentary layers within a reservoir.

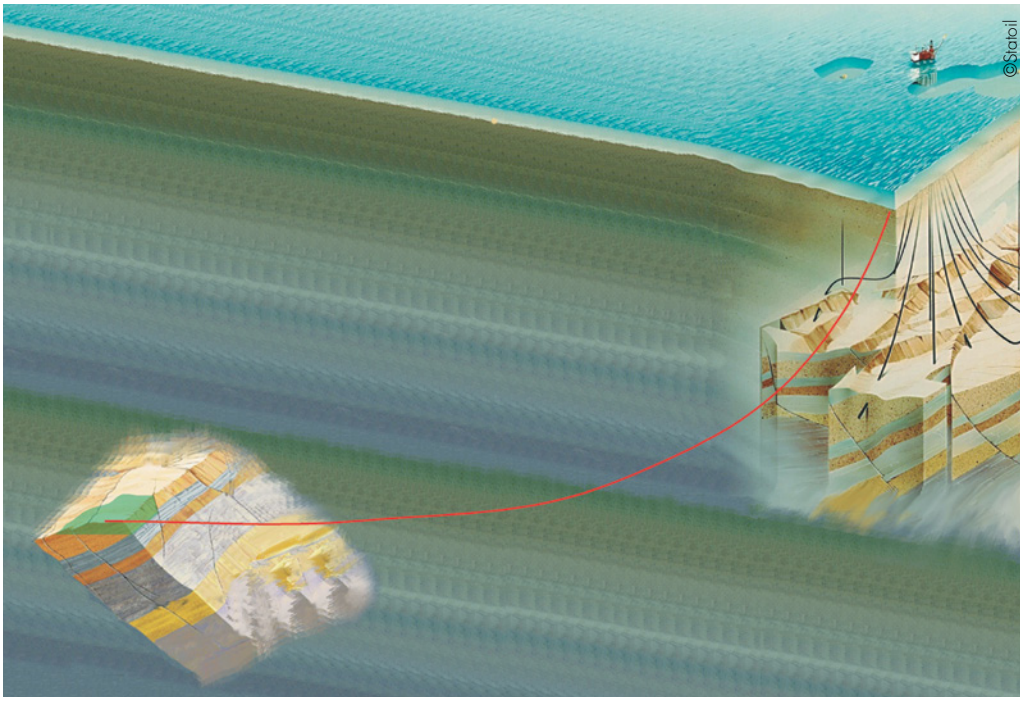
At Wytch Farm oil field in southern England, BP in 1997 pushed drilling technology to new limits when drilling a horizontal departure that reached 10,658 meters total measured depth.

The "world record" now belongs to the Al Shaheen Field offshore Qatar. A 2008 well reached a total length of 12,289 meters, while the total step-out distance from the surface location was 10,902 meters. In all, the well set 10 records including the longest reservoir contact (10,804 m) and the longest open hole (slb.com). The well was drilled in 36 days from a jackup. The well surpasses by approximately 600 m the prior extended-reach record of 11,680 m measured depth with a land rig drilling at Sakhalin Island, also in 2008.

In 2003, Transocean Inc. and ChevronTexaco with the Transocean drillship Discoverer Deep Seas set a new world **water-depth drilling record** by spudding a well in 3,051 meter of water in the U.S. Gulf of Mexico. It was the first time in the offshore drilling industry's history that a drilling rig explored for oil and natural gas in more than 10,000 feet (3,048 meter) of water.

The **deepest** drilling ever done took place on the Kola Peninsula in Russia, almost next to Nikel and the Norwegian border. Drilling of the Kola Superdeep Borehole started in 1970 and had reached a depth of 12,262 meters 19 years (!) later. In comparison, the thickness of the earth's crust is some 40-50 km (compare seismic section offshore Australia on pp. 36-38). This well, different from oil exploration wells, was done in crystalline rocks up to 2.7 billion years old.





In 2006, Statoil drilled an extended reach well – up to 85° from the vertical – from the Gullfaks field into the comparatively small field Gulltopp some 9 km to the west with approximately 25 million barrels of oil in reserves. With a total length of more than 10,000m (planned vertical depth was 2,450m), it was the longest "extended reach well" ever drilled from a fixed production platform.

Training based on competency

We have read all too often in recent years about the oil and gas industry's skills shortage. Known so familiarly as the "great crew change," our expertise shortage today is due mainly to the industry's poor or non-existent recruiting in industry-periodic downturns, particularly during the late 1980s.

The age demographics of petro-technical professionals in different operating companies vary enormously, but three factors are usually present. **First**, the mid-career range tends to be depleted everywhere. Thus, companies are under huge pressure to develop their young people faster than they are accustomed. **Second**, companies have been very actively recruiting in recent years, at least until the global recession and associated oil and gas price fall, and therefore the number of young recruits requiring professional development is larger than ever before. **Third**, companies cannot ignore the development of personnel of any age and experience as new technology continually comes into play and must be learned.

So how to get the most bang for our buck when it comes to professional development?

Numerous studies have sought to understand the return on investment in training. Time and again, it has been shown that training based on a competency model provides the surest route to spending training money wisely. Competency models provide a firm baseline for assessing skill levels and ensuring training is fit for purpose. It has been shown that training based on a competency model shortens time to professionalism, or time to autonomy, as it is also referred to, by at least two years.

Studies also point to the advantage of using a mix of learning methods rather than relying on just one method such as class-room learning. The traditional class-room environment has its place, but so does e-learning, on-the-job learning, case-study learning, and for disciplines such as geoscience instructional seminars in the field. Finding the right combination at the right time in the development cycle is what counts.

Finally, it is recognized that coaching and mentoring remains an essential requirement in any training program. Training must develop both discipline knowledge and the experience to apply that knowledge. Gaining experience takes time, but it can be dramatically accelerated if a coach is present to provide guidance and a helping hand.

Given these truths, every company faces the challenge of finding the right development program to suit its needs. For example, competency models do not necessarily translate from one company to another. Like every other component of the training program, they must be fine-tuned to the specific company, its culture, and its discipline needs. The fact is that no one-size fits all. The question is "how to proceed?"

The traditional answer for some companies, particularly the larger operators, has been to create their own development culture and internal training resources. Other companies, such as the independents, rely on outsourcing training providers. That said, the pressure on petro-technical professional expertise guarantees that E&P training remains big business and it continues to grow. Recently, three of the industry's leading training providers decided to pool their considerable resources and offer a truly comprehensive training and development offering to meet the industry's current needs.

The three companies are IHRDC, Nautilus and NExT. They continue to operate as independent companies, but for large workscopes they come together under the banner Plato Alliance to offer the industry's first truly comprehensive and integrated portfolio of training products and services, together with 40 years' worth of training and development expertise to create specific, customized solutions for their clients.

The full portfolio of the three companies combined include:

- Over 500 courses and programs in all the geosciences and petroleum engineering domains taught by more than 300 quality instructors;
- Over 80 geoscience field seminars in a wide variety of geological environments;
- The industry's largest e-learning library, including 1000 hours of technical learning in all geosciences and engineering domains, an overview of the entire value chain of oil and gas industry, and key business essentials;
- Management programs covering all aspects of the oil and gas industry including challenging digital business games;
- Competency management design, consultation and the CMS online system.

The full value of these Plato Alliance offerings is only realized when these products are integrated in customized programs based on a firm competency model and then tailored specifically to client needs using the right mix of classroom training, field seminars, blended learning programs, learning-by-doing and technical coaching/mentoring. Plato Alliance companies work together to build such programs by combining their vast resources and unrivaled experience. It is truly the first one-stop shop in E&P training.

Henry Edmundson
Founder, Plato Alliance


Photo: Nautilus

Participants on a Nautilus field course identify flow units in a Jurassic sandstone with carbonate cemented zones, an outcrop from a nearby producing oilfield in the UK.

Jane Whaley

Choice in E&P Data Provision

"We intend changing the E&P data and information business by providing the client with choice and an excellent, accurate and timely product," states Dr. Nick Robinson, CEO of the new kid on the data block, DI International.

Back in 1987, Nick was one of the founders of UK-based data provider IEDS, which was eventually acquired by IHS, as were a number of other data and information companies, including Petroleum Information, Erico and Petroconsultants. Nick continued to work for IHS for a few years before leaving to follow other interests in the oil industry. "Whenever I met my old clients, however, they would talk about the lack of competition in the data business," Nick says. "They were not complaining about quality or service, but merely the lack of choice. I talked to them about what they wanted from a data provider, and in June 2008 set up DI International. There were four of us then; just 18 months later the company has 31 employees, offices in seven countries – and is still growing."

Having spoken to potential clients, Nick was determined that the new service needed to be fast and immediate. "We realised that in today's market, rapid access to accurate data is key. Our database is instantly accessible on line - there is no need to install expensive software or undergo training. Just log on, and you have access to a variety of information on your chosen country or region."

DI International's WEB+ activity report spans the full range of E&P data, from overviews of exploration history and contracts, to details of exploration and appraisal wells, rig movements, production statistics and current and future geophysical surveys. Information is geographically linked via colour-coded maps and data can be downloaded in MS office formats, as well as GIS shape files. Records are continually updated with data not previously available to the industry, and new information is highlighted so the reader can see it immediately.

"From inception, DI International has been client-driven, and we work closely with our customers, to refine and develop our products," Nick says. "For example, they suggested that it would be good to be informed when something new had occurred in their area of interest, even if they were not close to their computer at that time. We have therefore recently introduced our DII Scout service, which delivers a summary of new information direct to the client's Blackberry or similar hand-held device. From the initial discussions with clients to the launch of the service in January this year took two weeks, showing how much we value our client feedback."

But now matter how fast and attractively packaged a database is, its main value lies in the quality of the data it contains. DI International spent its first year accumulating data and developing contacts, so that now it believes that it can provide the most accurate and up to date information available through a unique network of in-country agents and correspondents. "Our expert regional managers all have many years experience monitoring and researching E&P activity in their area, and can provide in-depth analysis and opinion on any new developments," Nick explains. "Harnessing this expertise, and again following client suggestions, the company will soon launch a strategic upstream management analysis service, giving an expert political and future interpretation of trends and developments in each region."

"Feedback from our clients has been excellent on all aspects of our service, so we hope we are achieving our main aim of transforming the E&P data business," says Nick Robinson. A company aiming high.

Image: DI International

Dr Nick Robinson, a founder member of IEDS and former Head of International Operations with IHS, is CEO of new E&P data company DI International.

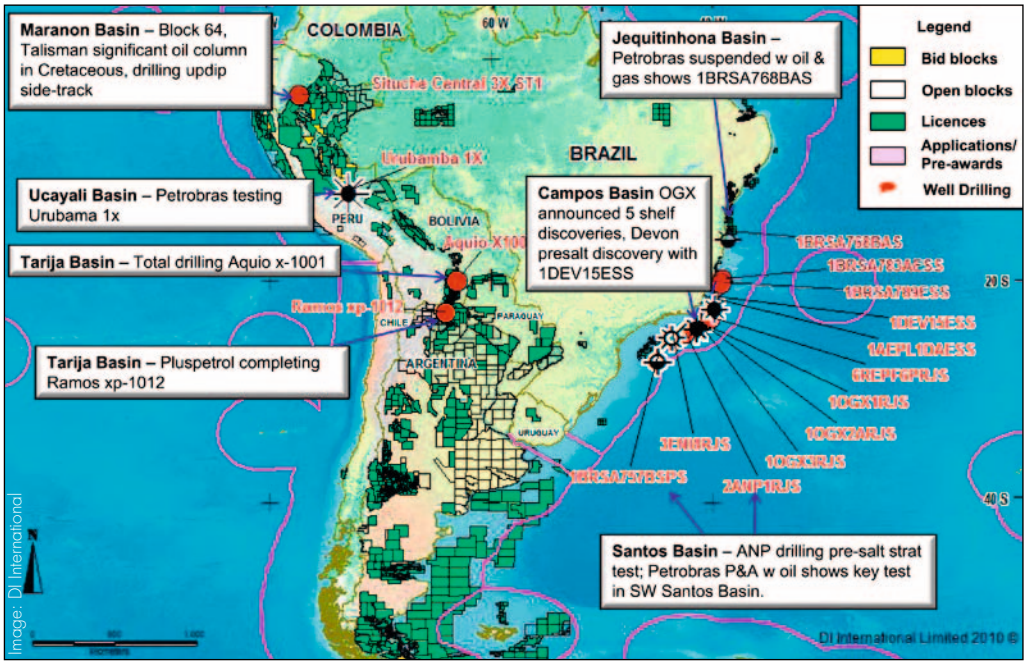


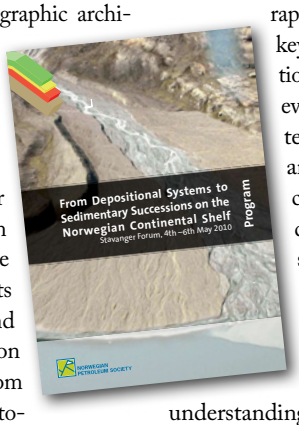
Image: DI International

Downloads include regional powerpoint maps showing a summary of key regional activity, ready to be inserted into the client's own presentation.

From Source to Sink

From Depositional Systems to Sedimentary Sucessions on the Norwegian Continental Shelf

The Norwegian Petroleum Society hosts a three day conference on the sequence stratigraphy of the Norwegian Margin to in Stavanger in May 2010. This meeting follows on from previous successful NPF events on this subject, building further on advances in our understanding of the role of climate and tectonics in controlling sediment delivery from source to sink, and its impact on stratigraphic architecture and petroleum exploration offshore Norway.

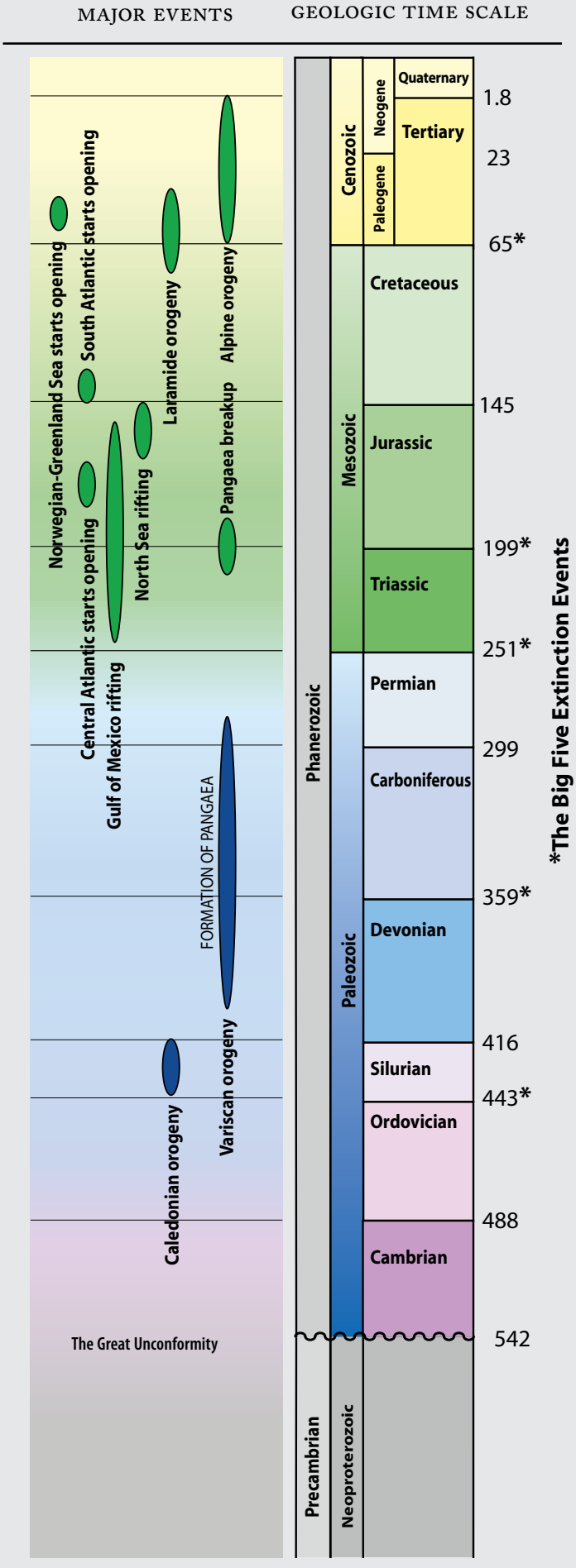


The Norwegian Continental margin stretches for ca. 2500 km from the North Sea in the south to the Barents Sea in the north and includes hydrocarbon plays ranging from Devonian to Pleistocene in age. Reservoir types vary from alluvial fans to deepwater fans, in almost every climate type from arid through humid to glacial, in tectonic settings ranging from intramontane through compressional/transpressional to extensional/ transtensional basins, and passive margins. The Norwegian margin has it all, with a huge remaining potential and a high quality database of seismic and well log information available.

This range of depositional systems and tectonic settings provides an exciting challenge for petroleum geologists trying to understand and predict stratigraphy and lithological properties. The initial focus of sequence stratigraphy on eustasy as the key control on depositional architecture has evolved to encompass tectonic, climatic and geomorphologic controls on sediment delivery and preserved stratal architecture. The development of this understanding and its impact on our understanding of the Norwegian Continental shelf is the focus of this meeting. Special attention will be given to the integration of both analogue studies and processed based models with the insights gained from the interpretation and visualization of high quality subsurface case studies.

STAVANGER, MAY 4-6, 2010

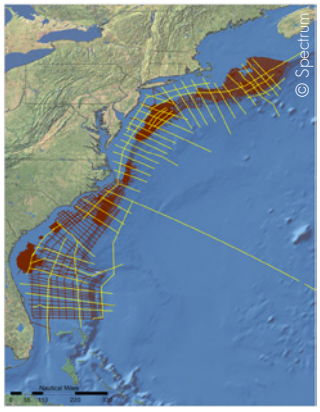
While in Stavanger, take advantage of the fabulous landscape close to the city.



Seismic off the U.S East Coast

Upon receiving permit approvals, Spectrum plans to actively pursue a comprehensive program to acquire seismic and other geophysical data over the U.S Atlantic offshore continental shelf and deepwater areas focusing its activities with the knowledge gained from the reprocessed data.

As Spectrum says they committed to preserving the environment, three marine mammal observers would be on duty during the seismic survey process to ensure that the vessel's operations conform to governmental regulations. In addition to observing operations, the three man team would also actively collect data during the survey process to aid research into marine mammal populations and migration patterns.



New software from Blueback

Bridge is a Petrel plug-in which expands the exploration workflows in Petrel developed by Blueback Reservoir. This facilitates unique integration of electromagnetics with seismic and other subsurface data. Bridge is developed using the same standards for the user interface as in Petrel, and intuitive menus and buttons make it easy for Petrel users to learn to use the functionality. Tool-tip help systems on all Bridge windows together with the Bridge Getting Started manual and the Bridge training course, makes it straight-forward to get started using the software.

Blueback Reservoir's goal is to offer a complete workflow for geophysicists and explorationists to model, visualize, interpret and integrate electromagnetic data. With the inclusion of EM forward modeling, you it is possible to model the EM response based on resistivity understanding of the subsurface. The Bridge interpretation loop then sets up a workflow for comparing modeled EM data and measured EM data.

RMS 2010 - new release

Emerson Process Management has launched RMS 2010, the latest release of the reservoir modeling system RMS™ which comes with major improvements across the entire workflow.

Within the Roxar modeling suite, users can build models for any reservoir. They can also estimate reserves, plan wells and simulate past and future production. In this way, they can do everything they need to produce maximum performance from their reservoirs, regardless of geology, location or complexity.
Key features of RMS 2010 include:

- *The New Well Correlation System* makes well picking and tracking the geology simpler, faster and more adaptable, thereby providing a smooth start to the modeling workflow.
- *The Enhanced Structural Modeling Tool* comes with an improved workflow for well correlation, isochore generation and horizon modeling. Structural modeling in RMS is easy-to-use and has all the functionality needed for generating high quality models for any reservoir - from the simplest to the most complicated.
- *The RMS 3D Gridder* has been made even more robust with the result far closer to geological reality than previous techniques have managed.
- The *Property Modeling Tools* in RMS have also been further extended in RMS 2010 to include Multipoint Statistics and improved methods for combining seismic interpretations with the advanced modeling algorithms in RMS to achieve unique data-matched models.

Roxar's flagship reservoir modeling solution, RMS comprises 13 fully integrated software modules, including mapping, reservoir modeling, well planning, reservoir simulation and uncertainty modeling tools. RMS 2010 will continue to operate on Linux 64-bit, Windows XP and the Vista 32 and 64-bit platforms, as well as Windows 7 64-bit.

Sysdrill - new release

Paradigm™ recently released of Paradigm™ Sysdrill® 2009.1, at the 2010 IADC/SPE Drilling Conference and Exhibition in New Orleans.

"The Chinese and Russian energy markets are rapidly growing, both in size and importance," said Robert Innes, Paradigm director of well planning and drilling. "Sysdrill 2009.1 effectively eliminates previous language-based usage limitations, providing Chinese- and Russian-speaking users with access to one of the industry's most advanced well planning and drilling engineering applications," he claimed.

The Sysdrill 2009.1 update extends the range and accessibility of the Sysdrill suite, which offers well planning, survey management, anti-collision, torque and drag, hydraulics, casing design, cementing, and well control in a single application. Further integration with Epos system offers Sysdrill users quick and more reliable access to E&P data for collaborative work on large multi-disciplinary projects. Epos 4, released in 2009, is an open data integration platform scalable from a laptop to a full enterprise solution.

Egypt - onshore seismic

Spectraseis has completed a Low Frequency (LF) seismic survey for Shell Egypt N.V in the North East Abu Gharadig (NEAG) Basin, Western Desert, Egypt.

The survey objective was to introduce LF technology in the Western Desert of Egypt. The project is the largest ever LF seismic synchronous survey, with 110 data points recorded over four days.

The project took place with the logistical support of Ardiseis, a regional joint venture between CGGVeritas and TAQA in the Middle East region, and covered a 60 square kilometer area in one week using a team of 17 crew members.

It also saw the mobilization of 120 recording stations - the largest equipment shipment for a single LF seismic survey by Spectraseis, and featured Spectraseis' recently launched field acquisition system, Field Office 2.0 and its innovative numerical technique Time Reverse Imaging (TRI). TRI spatially localizes the source of hydrocarbon microtremors, allowing operators to directly image hydrocarbon reservoirs at depth.

The completion of this survey represents a number of major milestones for Spectraseis - it is the first survey with Shell in the North African region, it marks our first collaboration through Ardiseis, and it is the largest synchronous survey we have ever completed, says Karim Lassel, Spectraseis director.


© Spectrum

Closing Sale

Petroleum Geo-Services has closed the sale of PGS' Onshore seismic data acquisition business and related MultiClient library to Geokinetics. The consideration in the transaction consisted of a combination of approximately USD 184 million in cash and 2.15 million shares of Geokinetics common stock. The 2.15 million shares issued to PGS represent approximately 12% of the current outstanding common shares of Geokinetics. Following the closing of the transaction, PGS is expected to be the second largest shareholder of Geokinetics. The combination of Geokinetics and the onshore business of PGS will create the second largest onshore seismic acquisition company in the world in terms of crew count and the largest based in the Western Hemisphere. The company will have the assets and technical capabilities for up to 38 crews and carry in excess of 207,000 equipment channels, more than 150 vibroseis units and possess in excess of 6,240 square miles of MultiClient library data upon completion of current projects in progress.

Sale of Nodal System

Fairfield Industries has sold their Z Land® Nodal System to Long Beach, California-based Signal Hill Petroleum, Inc. Z Land® nodal seismic data acquisition system has been designed and manufactured by Fairfield Industries. Signal Hill's purchase of the entirely cable-free Z Land nodal system closely followed the company's successful completion of a 2-D seismic survey using Z Land in the congested urban locale of the Long Beach/ Signal Hill oilfield, where Signal Hill currently is the principle operator. Z Land nodes are especially suited for deployment in both rugged terrain and densely-populated urban environments.

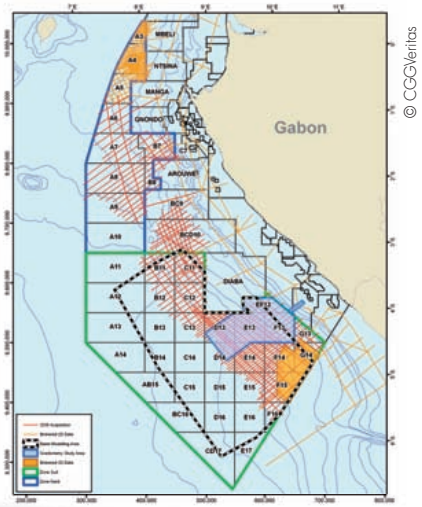
Z Land is one of three entirely cable-free nodal seismic data acquisition systems developed by Fairfield. The three systems, including two Z marine systems, have attained a high-profile in the industry where they are considered to be at the forefront of nodal technology.

Offshore Gravity

ARKeX has recently completed a BlueQube Marine gravity gradiometry survey on behalf of CGGVeritas over 9,000 sq km of the Zone Sud area offshore Gabon. The survey was performed as part of a comprehensive work program undertaken by CGGVeritas to improve understanding of untapped potential in the pre-salt province of Gabon to coincide with the recently announced 10th Gabonese Licensing Round.

The BlueQube Marine data was acquired to better constrain the extent of individual salt bodies, improve the geologic modelling and identify prospective areas where future 3D seismic acquisition should be performed.

For a detailed review of the pre-salt potential, see GEO ExPro No. 6, 2009, pp. 36-41.



© CGGVeritas

The 10th Gabonese Licensing Round opens in May 2010 and covers 42 blocks from two of the deepwater basins.

Jim Halverson, geologist with the Montana Board of Oil and Gas, examines a very 'oily' Bakken Core.

Photo: Tom Smith

TOM SMITH

Sourcing an Oil Boom

Underlying an area approximately the size of France, the Bakken Formation oil reservoir keeps expanding into what has become North America's hottest onshore oil play.

While the recent U.S. Geological Survey's 2008 assessment of the U.S. portion of the Williston Basin did not start this oil boom, they certainly added fuel to the fire. Their report estimated mean undiscovered resources of 3.844 Bbo and 3.705 Tcfg (0.68 BBoe) for the Williston Basin Province. This estimate does not even account for a large portion of the play that lies to the north in Canada.

While the Bakken has long been viewed as an excellent hydrocarbon source rock, it was slow to become a legitimate drilling target. In the 1980s and 1990s, wells drilled into the upper shale member produced some marginal results. The real breakthrough came ten years ago, in May 2000, when a horizontal well was completed in Montana's **Elm Coulee** Field, first discovered in 1996. The play has since been expanding rapidly into North Dakota, Saskatchewan, and Manitoba as well as into the underlying and overlying formations.

HOW IT ALL STARTED

Prior to discovery of the Elm Coulee Field, the primary Bakken target was the upper shale member of the Bakken Formation. **Richard Findley**, an independent geologist in Billings, studied the Bakken Formation in detail. While many wells had penetrated the formation, only minor amounts of oil had been produced. Reviewing the old drilling records, Mr. Findley found that good porosity had developed in the middle member that had largely been ignored by the oil industry. He found this porosity across a large area in Richfield County, Montana, and concluded a sizeable field of high-quality crude resided in this middle layer and started leasing. With the prospect simply too big for his one man company, he had to seek out a partnership.

"I sold the original idea to Lyco as a completely defined development opportunity," says Richard Findley. "I mapped what I originally called Sleeping Giant (later named Elm Coulee) as a possible continuous accumulation over 64 km long and 7 km wide. As it turns out, I was actually conservative in my cutoffs as the field has expanded beyond my original limits."

"Originally, independent geologist Dick Findley came to Lyco Energy Corporation in Dallas, Texas, selling an idea to reenter old plugged and abandoned Red River wells (the Ordovician Red River Formation is one of the primary producing horizons in the Williston Basin) and proposed a simple frac job in the middle Bakken horizon. He estimated a cost of about $85,000 per well and the company would benefit in new and relatively cheap

oil production," recalls **Bob Larson**, formerly with Lyco at the start of Bakken project, now a Senior Geologic Engineer with Enerplus in Denver, Colorado.

"The reentries were an inexpensive and prudent way to begin to prove my concept of a very large oil field," explains Mr. Findley. "This was the beginning of the very long learning curve which we are still on today."

"We entered 9 wells. Three had junk in the way, two came out pretty good, two were ok, and two were not so good," says Bob. "We were not overwhelmed with the results and felt the program was not working the way it was designed to work. We knew there was oil in the middle Bakken but the low rates were not economic at the time. We needed a way to extract this oil commercially."

"We made an agreement with Halliburton to support some of the costs and design a frac program for a horizontal well in the middle Bakken," says Bob. "We all agreed that with Halliburton's expertise in horizontal technology, coupled with being able to frac more of the reservoir, the program may become commercial."

Their first horizontal well, Burning Tree State well, spudded in March 2000, drilled 500 m laterally along the middle Bakken member. Then the Halliburton trucks moved in with sand, water, and a lot of diesel horsepower and the fracing process began. The well, which had an initial production of 196 bopd, 85 mcfpd gas, and only 7 bwpd, started a boom that is still going strong.

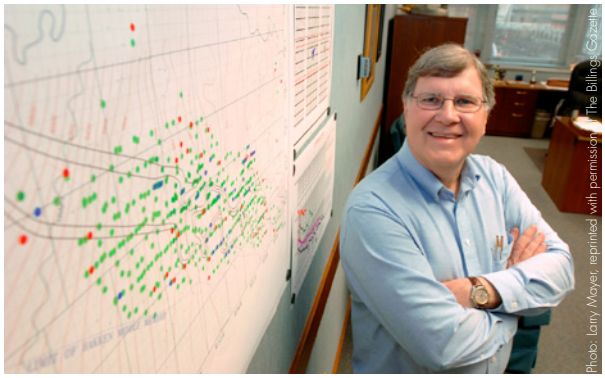


Photo: Larry Mayer, reprinted with permission of The Billings Gazette

A geology graduate from Texas A&M University, Richard Findley started Prospector Oil, Inc. in 1983. His exploration focus has been in the Williston Basin. "I had to take off the blinders and expand my vision to identify a field as large as what I had mapped (Elm Coulee)," says Mr. Findley. "You need to think big to see big."

CHALLENGING VARIABILITY

"The Bakken is the most complicated system I have encountered in my 42 years in this business," says Bob Larson.

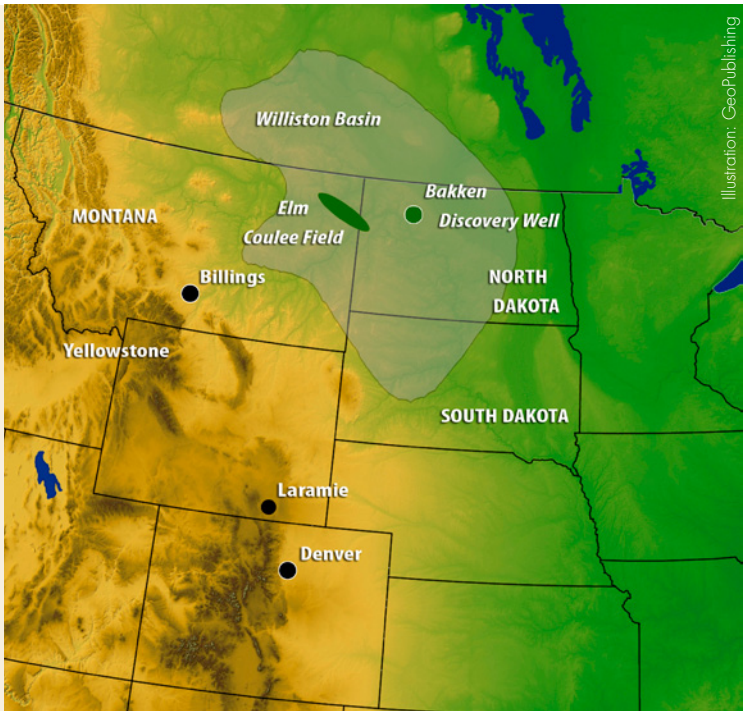
The Elm Coulee Field that started this play may be an exception rather than the rule for Bakken production. The producing field is in a relatively confined area (800 to 1,300 km^2) when compared to the formation's areal extent in Montana and North Dakota of over 65,000 km^2.

The Bakken Formation is fairly homogeneous across the field where the middle member is a clean dolomite 1.5 to 5 m thick with an average porosity of about 8.5%. Down dip from the accumulation, the middle member becomes thinner and matrix porosity is nearly absent. The accumulation is bound up dip to the southwest where the formation pinches out against older strata.

Outside the Elm Coulee area, the middle member thickens toward the basin center to over 22 m but is much more heterogeneous. Scattered porous dolomite stringers and natural fractures hold a lot of reserves. The challenge has been to connect these porosity stringers. Operators in North Dakota are using advanced geosteering with the aid of structural maps to keep the well bore near the top of the middle member. Some recent well production tests in North Dakota have shown the Bakken to be as productive there as wells drilled in the Elm Coulee Field.

According to **Scott Norrid**, SAS Region Asset Manager, Northern U.S. for Halliburton, "Each part of the basin is different but if the right technology is applied, commercial completions can be achieved."

"*The drilling, completing and stimulating of wells is still evolving*



The Williston Basin covers an area the size of France in three western states and two Canadian provinces.

THE PLAY CONTINUES IN CANADA

Further north in Saskatchewan, the Bakken has been fueling an exploration boom since 2005. Their first middle Bakken discovery was in southeastern Saskatchewan in 1956. The first modern commercially successful Bakken wells were drilled by Bison Resources Ltd. at the Viewfield in 2004.

According to **Erik Nickel**, the Senior Research Petroleum Geologist with the Saskatchewan Ministry of Energy and Resources, "There are over 1,506 wells currently producing from the Bakken, most drilled since 2005. Prior to 2005, there were between 10 and 50 Bakken wells active since 1956. Total Bakken production through May, 2009, is nearly 40 MMb. The boom has also affected the sale of Crown Mineral Leases, jumping nearly 3-fold in 2008 from the previous year which also showed record sales."

Ed Dancsok, Director of the Geology and Petroleum Lands Branch for the Saskatchewan Ministry of Energy and Resources, says "there could be between 25 and 100 Bb of Bakken oil in place in the province." Com-


Photo: Williston Economic Development

The Williston Basin landscape is flat and rolling.

panies there expect to achieve a 15 to 19% recovery using infill drilling at eight wells per section. As much as 20 Bbo may be ultimately recovered and that is a lot of oil.

OTHER PRODUCING HORIZONS AND PLAYS

While the Bakken continuous reservoir play has spread from the Elm Coulee Field in Montana east into North Dakota and north into Saskatchewan, new discoveries fueled by Bakken sourced oil are springing up in adjacent horizons as well.

Most researchers believe that the oil sourced from the Bakken Formation did not travel very far, at least vertically. Being over-pressured, Bakken oil has travelled into both the underlying and overlying formations as well as up dip out from the areas of oil generation. Erik Nickel and other Canadian geologists "believe that the oil in the Viewfield area migrated northward from the basin center in North Dakota, a distance of at least 200 km."

The Devonian Three Forks/Sanish sand that underlies the Bakken Formation is seeing plenty of action in North Dakota and Manitoba as well as the equivalent Torquay Formation in southeastern Saskatchewan.

According to **Michelle Nicolas**, a Petroleum and Phanerozoic Geologist with the Manitoba Geological Survey, "While the Bakken play in the U.S. and Saskatchewan is a big one, in Manitoba it is more of a Three Forks play. Located on the eastern edge of the Williston Basin, the lower Bakken Shale is absent except for some local preservation in salt collapse features. This leaves the middle Bakken sand in direct contact with the underlying Three Forks siltstones. Manitoba has some production from the Bakken sand, most modern production is from the commingled middle Bakken and Three Forks formations. The Three Forks is the dominant oil producer."

"As a new exploration target discovered in the Sinclair Field in 2004, future potential exists north and east of the field," Nicolas adds. "Over 1,050 wells in four fields are now producing from the Three Forks. The largest, the Sinclair Field, has proven and probable reserves estimated at 6.8 MMm^3 (43 MMb) with the current production at 11,067 bopd or about 48% of Manitoba's total production."

The Three Forks/Sanish sand play in North Dakota could "eventually equal the Bakken," according to Lynn Helms, Director of the State Department of Mineral Resources.

In North Dakota, near the basin center, the

Running out of ideas?

University of Tulsa Petroleum Geology Professor Parke A. Dickey possibly had the Bakken discovery in mind when, in September, 1958, he wrote "We usually find oil in a new place with old ideas. Sometimes, we find oil in an old place with an old idea. Several times in the past we have thought that we were running out of oil, when actually we were running out of ideas."


Photo: BJ Services Company

A simultaneous frac of three wells in the Bakken Formation in Montana. The wells are separated by 400 m and the horizontal bores are perpendicular to the section line road. The length of the view down the road to the horizon is roughly half the distance traversed by the horizontal well bores. The 2,700 m distance more than doubles the lateral lengths of the early wells. Stimulation size has increased as well, from 136 metric tons of sand to as high as 635 metric tons.

Three Forks Formation is made up of sand and porous dolomites that are conformably overlain by the Bakken. While still very early in this play, researchers are still trying to find out if the Three Forks is a separate oil-producing formation from the Bakken. Recent production show these producing horizons can act as two separate reservoirs with Three Forks testing as good, or better, than some of the Bakken wells.

A REAL OIL-FINDER

Oil flowing from the Bakken Formation has reversed declining production from an onshore basin that has seen exploration for nearly 100 years and 60 years of production.

To many explorationists, the basin had been almost completely explored. At any rate, the area was one of the most heavily explored in the U. S. Then, through one person's ideas and the cooperation between a service company and an independent oil company, the basin hosts the highest-producing (Elm Coulee alone produced over 15 MMbo in 2008) onshore field found in the lower 48 states in the past 56 years, according to the U.S. Energy Department. North Dakota's oil production is now at the highest levels in their history (62.8 MMbo in 2008 and over 50 MMbo through August, 2009) due to the success of the Bakken.

"The Bakken play is a great example of how, through research, technological advancements, and sound geological work, reserves can be increased," says Erik Nickel. "This happened in an area thought to be 'drilled out'. Many had written southeast Saskatchewan off as a mature Mississippian oil play before the Bakken was re-worked."

"While I really appreciate the awards and recognition for the discovery of Elm Coulee, it is important to note the team effort of the scientists and engineers at Lyco and Halliburton that made the Bakken economic," says Richard Findley, the Billings, Montana independent that started the Bakken play.

"More importantly, Elm Coulee appears to be a sweet spot within a much larger continuous oil accumulation that the USGS reevaluated. Since that evaluation, frac technology has advanced and, combined with the potential of the Three Forks Formation, I believe their assessment is greatly understated."

"Now we need to look beyond the Williston Basin. Elm Coulee is a good analogy for other continuous oil plays throughout the world," concludes Richard Findley, a true oil-finder.

The Williston Basin - playground for stratigraphers

Developed on the North American Craton during the Ordovician, the Williston Basin is a roughly circular depression containing more than 4,800 m of sedimentary section. The thickest section is near the center of the basin at Williston, North Dakota. Strata generally thin and become shallower toward the basin margins. The basin covers about 780,000 km^2 across North and South Dakota, Montana, and the Canadian provinces of Manitoba and Saskatchewan.

After 23 serious attempts starting in 1924, the 1951 Clarence Iverson Farm well struck oil. This would be the first major discovery in a new geologic basin in the continental U.S. since WWII. Now, the basin hosts what could become one of the largest onshore oil finds (Bakken Formation) in the continental U.S. The Department of Energy ranks the Elm Coulee Field as the 23rd largest in the entire U.S.

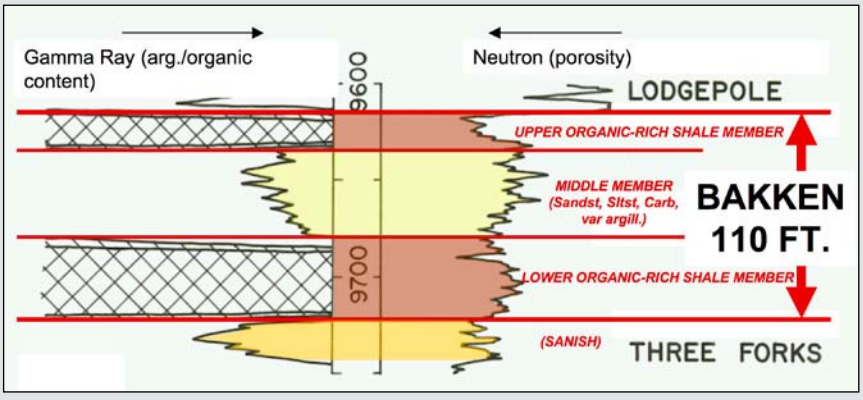
The basin records a nearly continuous sedimentation separated by periods of erosion. Several cycles of marine transgressions that filled the basin are separated by marine regressions. In the 1940s, Northwestern University's **Lawrence Sloss** used the Williston Basin as an example area when he first proposed his cratonic sequence concept demonstrating a series of rising and falling sea levels. This concept eventually grew into the depositional sequences on seismic data that Vail, Mitchum, and Thompson proposed, or better known as seismic stratigraphy, and is a major tool in hydrocarbon exploration.

Sloss divided the Phanerozoic strata into 6 sequences, the oldest being the Cambrian to Lower Ordovician Sauk Sequence. The Bakken Formation and the reservoirs associated with this source fall in the third sequence, the Devonian to Mississippian Kaskaskia Sequence.

The Williston Basin tilted northward during the Devonian, the marine communication from the Cordilleran shelf to the Elk Point Basin of western Canada. This shift caused more restricted conditions in the Williston Basin during the deposition of the organic-rich Bakken shales. The shift also explains the connection and stratigraphic similarities between the Bakken Formation and the Devonian rocks in Canada rather than the Devonian rocks deposited on the Cordilleran shelf.

The USGS contends that, of the three Bakken Formation members, the middle sandstone is a major contributor to the composite continuous reservoir. Since the discovery of the Elm Coulee Field, it has also been the most sought after drilling target in the basin. This member varies considerably across the basin in thickness, lithology, and petrophyscial properties.

The structure of the basin is relatively simple and probably resulted from basin subsidence initiated by two Archean shear systems. Folding and faulting are the main evidences of structural deformation. Some of these structures such as the Nesson, Cedar Creek, Little Knife, Antelope, and Billings anticlines produce oil.



Courtesy: Bill Walker

The Bakken Formation is divided into three informal members, a lower shale, middle sandstone, and upper shale. The shale members are excellent petroleum source rocks. All three Bakken members and the surrounding formations that are exploration targets (Sanish sand, Devonian Three Forks, and the Mississippian Lodgepole) make up the interval evaluated by the USGS referred to as the "Bakken composite continuous reservoir." The Bakken Formation conformably overlies the Three Forks in the basin center but unconformably overlies it elsewhere.

KURDISTAN:

Safe and Secure, with Billion

JANE WHALEY

Photo: Heritage Oil

"Kurdistan is an exciting and very safe place to explore," exclaims Steve Curd, Chief Geophysicist with Heritage Oil, one of the first foreign companies to move into this region of Iraq after the second Gulf war, back in 2004. "It is a beautiful country, and the scenery is spectacular - from our Miran Block the Zagros Mountains can be seen rising in the distance, giving a wonderful backdrop. And of course, it was the collision of the Arabian and Asian plates in the Late Cretaceous and Early Tertiary which formed not only these mountains, but also the structural traps we are exploring, which have the same north-west to south-east trend as all the major accumulations in the area."

"Many of these structures can be seen at the surface, which helps in the design and cost-effectiveness of our seismic work," he continues. "It also means we can look at our reservoirs at outcrop, and come across oil seeps which prove what promising acreage we hold."

BILLION BARREL PROSPECTS

According to CFO Paul Atherton, Heritage Oil has been interested in Iraq for over a decade. "We decided to concentrate on Kurdistan for political and security reasons, but also for prospectivity, as the undiscovered potential of the region is estimated by the USGS to be about 40 Bbo and 60 Tcfg (11.4Bboe)," he explains.

Having built up an extensive database on the area, and with the help of expert advisers, the geologists at Heritage knew exactly the area they wanted, and the company was one of the first to be awarded a Production Sharing Contract by the Kurdistan Regional Government. "First mover advantage meant that we were able to cherry-pick a prized block," Paul continues. "Our 1,015 km^2 Miran block is just 55 km east of the giant Kirkuk field, which

Barrel Prospects

Where in the world can you still find undrilled billion barrel prospects? Iraqi Kurdistan is one answer. But what is it like to work in an area thought by many to be a war zone?

The Miran West Field is 55 km east of the giant Kirkuk field and is thought to have more than 1 Bbo recoverable.

The Kurdistan Region of Iraq is in the north-east corner of the country and is bordered by Syria, Iran and Turkey, all of which have indigenous Kurdish populations

has remaining reserves in excess of 10 Bbo. We were awarded it in October 2007 and just 15 months later, in December 2008, we spudded our first well."

"Our initial seismic survey, conducted in the second quarter of 2008 – the first ever on the block – enabled us to identify two large and very promising anticlinal structures, Miran West and Miran East, together covering 330 km^2," explains Steve. "Initial estimates, reinforced through an independent study by RPS Energy, suggest that the block contains in-place reserves of 3.4 billion barrels of oil. Where else in the world nowadays have you a chance of discovering giants like this?"

FRACTURED LIMESTONE RESERVOIRS

As reported last year (*GEO ExPro*, vol. 6, no. 4, p.74), the first well, Miran West-1, drilled to a depth of nearly 3,000m, found a gross oil-bearing column of 710m with three Cretaceous reservoir zones. Estimates for the field suggest that it has in excess of one billion barrels recoverable, and although testing was incomplete, Miran West-1 flowed at a maximum rate of 3,640 bopd from a single upper reservoir interval.

"As the seismic revealed structures with substantial vertical relief, possibly trapping a significant column of hydrocarbons, and we had no other knowledge of the prospect, standard industry practice meant that we drilled with high mud weights, in case we encountered a high pressure gas column," Steve explains. "However, we found oil, under much less pressure, so our high mud weights tended to invade and contaminate the reservoirs in the vicinity of the well. This is not a major issue, but it meant that we were not able to properly test the lower horizons. The second well, Miran West-2, is being drilled with the knowledge gained from the first well and therefore with appropriate drilling parameters and equipment to gain maximum information."

The main targets in this part of Iraq are all Cretaceous in age, although in northern Kurdistan the Triassic is also hydrocarbon bearing, and in other parts the Jurassic may be prospective. The principal reservoir horizons in this structure are the Late Cretaceous Shiranish and Kometan Formations, and the Early Cretaceous Qamchuqua. These are all carbonates, principally limestones, extensively

Image: Heritage Oil

Kurdistan – the other Iraq!

Nestling between with the Tigris and Euphrates Rivers, Kurdistan is known as the Cradle of Civilisation', as it was here that agriculture, metal work, pottery and weaving all first appeared. In fact, the Citadel in Erbil dates from 6,000 BC and is said to be the longest continually inhabited city in the world.

Covering about 30,000 km^2 of the north-east corner of Iraq, with a population of nearly 4 million, the Kurdistan Region of Iraq was initially established in 1970 to stop continual fighting between Iraq and Kurdistan separatists. During the regime of Saddam Hussein, however, much of Kurdish self-rule was lost, culminating in the chemical gas genocide of the 1980's and oppression by Saddam's forces after the Kurdish uprising of 1991, when hundreds of thousands of Iraqi Kurds were killed or displaced.

The new post-Saddam constitution, which was ratified in 2005, established the Kurdistan Region of Iraq as a federal entity recognized by Iraq and the United Nations – effectively an autonomous region within a federal state. It is ruled by the democratically elected Kurdistan National Assembly, which has the right to issue production sharing contracts and exploration rights over new acreage, although not existing fields. Proceeds from the sale of oil goes to the Iraqi government and then is redistributed, with 17% of the total Iraqi budget, the vast majority of which stems from oil sales, going to Kurdistan.

As a result of its relative stability, the Kurdistan Region of Iraq has the fastest growing economy with the highest standard of living in Iraq, with many modern hotels and offices in the capital, Erbil. As a more secular society, Kurdistan has managed to avoid much of the religious and sectarian violence that has affected other areas in the country.

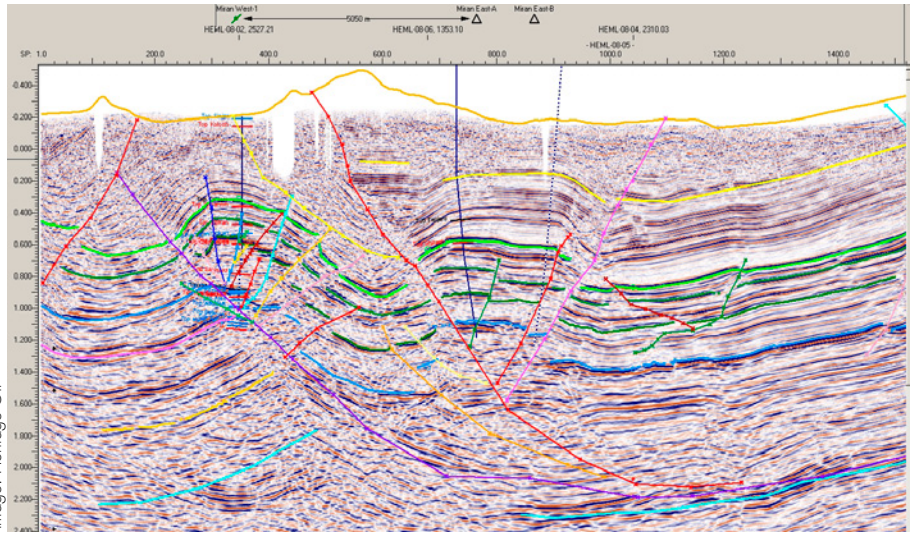


Image: Heritage Oil

A seismic line across the Miran block clearly shows the two structures of Miran West and Miran East

cracked as a result of folding and therefore exhibiting excellent fracture porosities. "The highly fractured nature of the rock means that we expect recovery rates of between 50 and 70%," says Steve. "Data gathered from the initial test indicates that a production rate of 10,000 bopd per well should be achievable."

SECURE AND SAFE

Miran West-2 was spudded in November 2009, about four kilometres north-west of the first well, and is expected to take four months to drill, so the field is already well on the road to development, with first oil expected as early as this summer. "Initially, we expect to produce about 5,000 bopd for local consumption," explains Paul. "We will eventually export much larger quantities via the Iraq-Turkey pipeline, which has a capacity of 1.6 MMbopd. At the moment the export payment mechanism via Iraq has not been clarified, but we are confident that this will be resolved, as the money from exports from this area will benefit the whole country, not just Kurdistan. As soon as that happens, we will look to begin exports from Miran."

Which brings us to the inevitable question: bearing in mind everything we read about Iraq, what is it like to work in Iraqi Kurdistan? "It's great," says Steve. "It's very stable and very safe. Since March 2003, there has only been one bomb in the areas administered by the Kurdistan Regional Government, no foreigners have been kidnapped and not a single coalition soldier has died. The local Kurdistan security force is excellent and we have very few fears for our safety. The main towns have comfortable western-style hotels and the locals throughout the State are welcoming and hospitable. It is also very interesting historically, so there are plenty of places to explore in my time off."

Heritage has a Chinese crew working on the drill site, but uses and trains local staff wherever possible. "Our drivers, security and labourers are all local, and we also have Kurdistan geoscientists, administrators and logistics people," says Paul. "This is a very important policy for us. We are also involved at the community level, working with schools and mosques in the Miran area. Heritage's objective is to support development in local communities. We recognise the importance of engaging with local stakeholders and believe that by working closely with host communities we are better enabled to meet the challenges facing us."

"There are now about 25 international oil companies working in the Kurdistan Region of Iraq, and flights come to Erbil from all over the world," adds Steve. "There are no issues – basically, it's not the Iraq you hear about in the news!"

Heritage Oil

Tony Buckingham, CEO and founder of Heritage Oil, has more than 30 years experience in the oil industry, but comes from a very different background to that of most senior managers in the business. He started out as a deep sea diver, working on rigs in the North Sea, before moving into the security business, acting, among other things, as an adviser to large independent companies like Premier Oil and Ranger. Having worked for many years in Africa, in 1992 he set up Heritage Oil, specifically to concentrate on exploration in Africa and the Middle East.

Heritage acquired pioneering assets in the Albert Basin in Uganda in 1997 – the first company to do so. After the initial seismic in the area showed promise, it farmed out 50% to Africa Energy, (later purchased by Tullow) and together they went on to discover over 700 MMbo in the Albert Graben. Since then, Heritage has been awarded or acquired exploration acreage in Mali, Tanzania, Pakistan, the Democratic Republic of Congo and Malta, and producing fields in Russia and Oman.

Since acquiring its first assets six exploration wells have been drilled on Heritage acreage, and all of them have found hydrocarbons, a remarkable success rate. Late in 2009 the company decided to sell its Ugandan assets, in order to concentrate resources on the development of Kurdistan, while diversifying further elsewhere. In total Heritage spent about US$150 million in Uganda and is selling the assets for about US$ 1.5 billion – not a bad return on investment, as Paul points out.

Interested in Iraq, the company strategically chose to float on the Toronto Stock Exchange in 1999, taking advantage of Canada's politically neutral status. At the time it had a market capitalisation of less than US$20 million. In 2008 it moved to the London Stock Exchange, where Heritage Oil is listed on the Main Board, is a member of the FTSE 250 group of companies and is now valued at US$ 2.2 billion.

Photo: Heritage Oil

Marine Seismic Sources

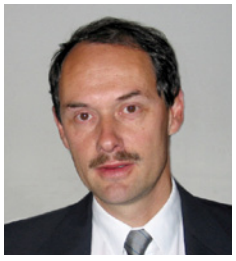
PART II: AIR-GUN ARRAYS FOR NON EXPERTS

This second article on marine seismic sources summarises salient points on marine air-gun arrays and their radiation characteristics.

"Every wave, regardless of how high and forceful it crests, must eventually collapse within itself."

Stefan Zweig

Lasse Amundsen is Chief Scientist, Geophysics, at Statoil.



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

In the first article in this series (GEO ExPro Vol. 7, No. 1), we showed that air-gun arrays produce high-energy, low-frequency sound in the form of sharp, short-duration pulses. Key parameters of source signatures are peak-to-peak (P-P) pressure amplitude in bar-m and peak-to-bubble ratio (PBR). The nominal output levels of most seismic arrays tend to be 10-100 bar-m

Figure 1 shows a seismic vessel with two air-gun arrays towed 365 m behind (measured from the navigation reference point). An example of an air-gun array configuration with 28 active guns in three strings is shown in plan view in Figure 2a. The individual gun volumes in this example range from 20 in^3 (0.3 l) to 250 in^3 (4.1 l). The total volume is 3,090 in^3 (50.7 l). The array contains a number of 'cluster guns', where two guns sit so close together that their air bubbles coalesce after the guns have fired.

Cluster guns produce sound more efficiently than a single large gun with the same volume as the cluster.

The source array dimension is 15 m (inline) x 20 m (cross-line). Inline and cross-line refer to the direction the ship sails and the perpendicular to the sail direction, respectively.

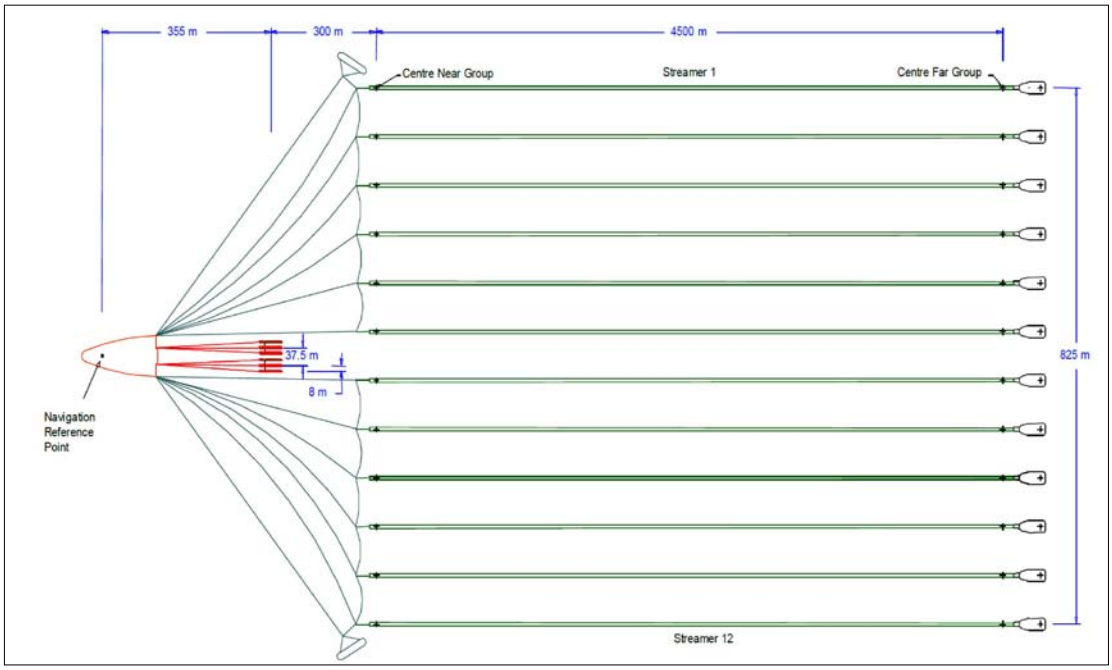
The source signature from the array at 5 m depth is displayed in Figure 2b. Observe that the bubble oscillations are strongly damped. The primary-to-bubble ratio is PBR=35.6. The amplitude spectrum is shown in Figure 2c. The notches at frequencies 0, 150, 300 and 450 Hz are caused by the source ghost. Note that the primary-to-bubble ratio is frequency dependent.

SOURCE DIRECTIVITY

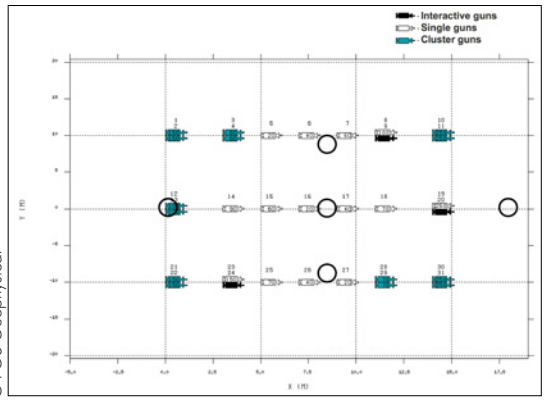
In seismic surveying, air-gun arrays are designed to direct a large proportion of the sound energy downwards. Despite this downward focusing effect of the array, relatively strong sound pulses will propagate in all directions. The radiation from an array will depend on the angle from the vertical, so that the radiated source signature is directional. This effect is called directivity.

Each array has its own specific radiation pattern. This pattern, which will be different for different frequencies, varies relatively slowly from low to high frequencies. The radiation pattern will also be different for different array tow depths.

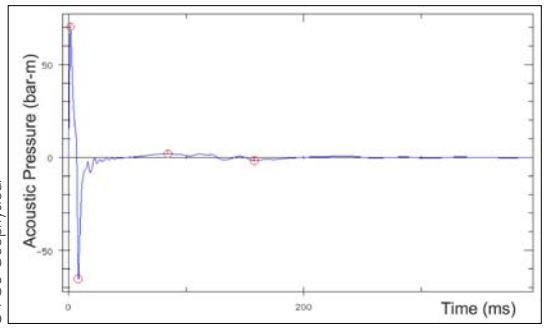
For the gun array in Figure 2a, source directivity can be modelled. Figure 3 shows the radiation pattern for



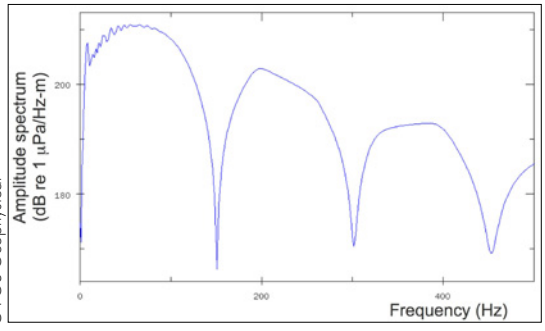
Seismic vessel with two seismic sources (two air-gun arrays) and 12 hydrophone cables equipped for a 3D investigation.



Configuration (top view) of an air-gun array of total chamber volume 3090 in3 (50.7 l).



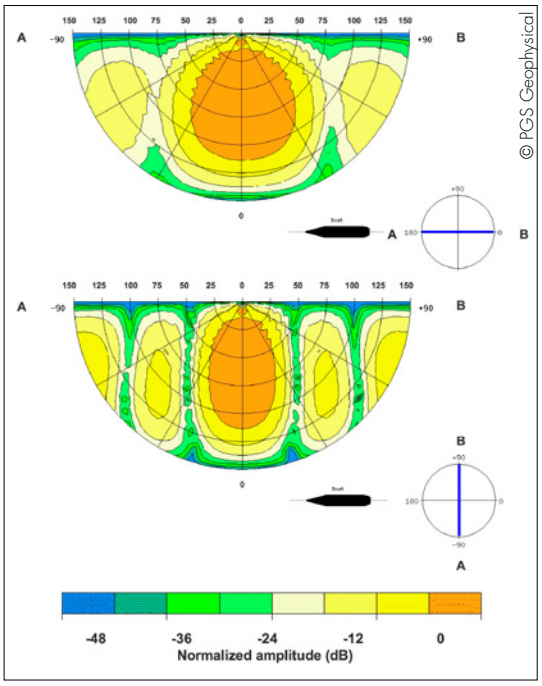
Modeled farfield pressure signature of the sound pulse referred to 1 m distance from the source centre. The source depth is 5 m. The gun pressure is 2000 psi. The strength (peak-to-peak amplitude) is 135.6 bar-m. The primary-to-bubble ratio (PBR) is 35.6. The water velocity Is 1506.9 m/s.



Frequency spectrum of the modeled farfield pressure signature.

frequencies 0-150 Hz, in in-line (top) and cross-line (bottom) directions. Vertical direction is 0 degrees. 90 degrees, at the edge of each circle, corresponds to horizontally propagating energy. Observe that the radiation pattern is concentrated downwards, and that the source pulse gets attenuated for angles that differ from the vertical. The amplitude levels emitted horizontally tend to be 18-29 dB lower than the vertical. Note that the sound produced by the array is not distributed evenly across the frequency spectrum.

The amplitude is largest in the 20-100 Hz interval but some energy will be present up to 500-1000 Hz. The high-frequency components are weak when compared to the low-frequency components, but strong when compared to ambient noise levels.



In-line (upper panel) and cross-line (lower panel) directivity plots for the air-gun array, at 60 m deep point of observation. Colors indicate different energy levels in dB.

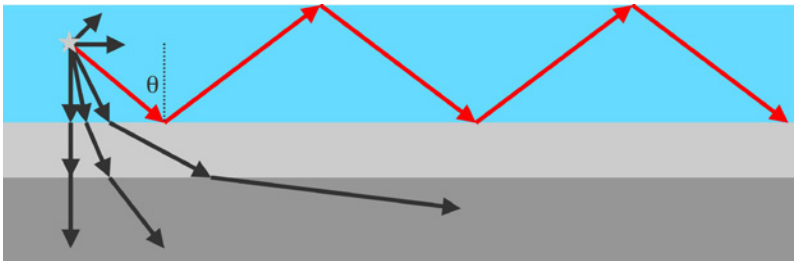
THE EFFECT OF THE WATER LAYER AND SEABOTTOM

The seismic signal from the air-gun array will be affected by the physical properties of the water layer and the sea bottom.

The sound travelling with small to moderate angles to the vertical axis will reflect at and refract into the water bottom. The reflection strength is given by the reflection coefficient for the interface between the water layer and the layered bottom. For small angles, the reflection coefficient is small, typically 0.2, so that most (~80%) of the sound enters the subsurface.

However, sound hitting the sea bottom at angles larger than a critical angle to the vertical, determined by the ratio of sound velocity in water and sea bottom, will be reflected back into the water layer (Figure 4). The water layer, bounded above by the sea surface and below by the water bottom, then forms an acoustic wave guide where the sound propagates with significantly less attenuation than sound in an infinite water pool. The transmission properties of this wave guide depend on the geology of the water bottom and variation of sound velocity with depth and distance.

For a soft sea bottom, the critical angle is typically 60-70 degrees; for a hard sea bottom the critical angle can become 30 degrees. More sound enters the wave-



Graphic picture of sound propagation in a water layer over a layered sea bottom. A large part of the sound travels downwards. Sound that hits the sea bottom at an angle greater than the critical angle (θ) will be totally reflected. This sound is trapped within the sea layer that then channels or guides the sound. This phenomenon is known as waveguide or normal-mode propagation.

guide for hard sea bottoms than soft ones, producing a higher level of sound at large range from the source.

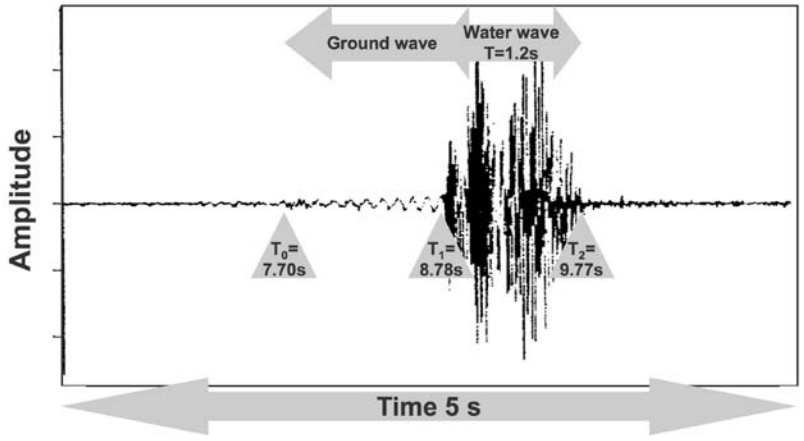
SOUND PROPAGATION WITH HORIZONTAL DISTANCE

The signals from marine air-gun arrays can be detected in the water column many kilometres away from the seismic vessel, sometimes 100 km and more. The sound levels from air-gun arrays at long horizontal distances from the seismic vessel are determined not only by the acoustic power output but equally important by the local sound transmission conditions.

In a later GEO ExPro article we will address this effect in more detail. Here (Figure 5), we show the sound recorded 13 km away from an airgun array in water depth of 70 m. The signal has three important features at times T_0=7.70 s, T_1=8.78 s and T_2=9.77 s. These are the arrival times of three 'wavelets' travelling with apparent velocities c_0=1687 m/s, c_1=1480 m/s and c_2=1330 m/s, respectively. The low-amplitude, low-frequency wave starting at T_0=7.70 s is called the *ground wave* because it is closely related to the sediment sound velocity. The lowest frequency component arrives first (at T_0 with velocity c_0), followed by progressively higher frequency components travelling at progressively lower velocities. The highest frequency component of the ground wave arrives at time T_2 with velocity c_2. The high-amplitude, high-frequency wave which is superimposed on the ground wave at time T_1=8.78 s is called the *water wave* because it is mainly a function of the water sound velocity. In the water wave, with duration T=1.2 s, higher frequencies travel fastest and arrive before lower frequencies. At time T_2 the frequencies of the ground wave and the water wave merge, at which point they form a single wave called the *Airy phase*. At this abrupt end of the wave train, energy has been transported in the water layer waveguide with the minimum group velocity.

The onset of the water wave is sometimes used in marine refraction work to determine the source-receiver range (since the water speed is well known).

We conclude that with increasing horizontal distance from air-guns, the signal decreases in strength but increases in time duration during guiding of the sound. The initially-short air-gun array signal, some 10 milliseconds in length, can become quite long. In the water wave, higher frequencies arrive before lower frequencies. This geometrical dispersion effect will be sensed as a frequency modulated tone or 'hooting' by anyone listening down there in the water column.



Seismic signal recorded in the water layer a distance 13 km away from a source vessel. The water depth is 70 m. The initial source signal some 10 milliseconds long is much broadened in time since the signal frequencies travel with different velocities. See text for more details.

The **decibel (dB)** is a logarithmic unit of measurement that expresses the magnitude of a physical quantity relative to a specified *reference level*. Decibel is most widely known as a measure of sound pressure level. Decibels are measured on a base-10 logarithmic scale – an increase of 3 dB doubles the intensity of sound, 10 dB represents a ten-fold increase, 20 dB represents a one hundred-fold increase, and so on.

The seismic survey literature refers to peak-to-peak (P-P) pressure amplitude in bar-m. P-P can be converted to source level L_s in dB re 1 µPa-m as follows: L_s (dB re 1 µPa-m) = 20 $\log_{10}$(P-P)+220.

Levels from continuous sources (like noise) are normally expressed on a 'root-mean-square' (rms) pressure basis. For an ideal sinusoid, the rms level is 9 dB lower than the P-P value. It is difficult to compare levels from air-guns with continuous sources, but a guide is to set the rms level 18 dB lower than the P-P value.

It is difficult to compare underwater sound to that in air because of pressure differences, but by subtracting 61.5 dB from the underwater measurement one roughly obtains the in-air equivalent of the sound intensity measured in dB. In air, a short exposure to 140 dB is seen as the approximate threshold for permanent hearing loss for humans.

To set seismic signal levels in perspective, the pressure of low-level background noise from gentle wave action/little wind is above 60 dB re 1 µPa (spectral level, 10-100 Hz). In bad weather, low-frequency background noise increases to 90-100 dB re 1 µPa. Marine vessels generate significant noise. Supertankers may have a source level of 170 dB re 1 µPa-m (spectral level); similarly the source level of active trawlers will be in the order of 150-160 dB re 1 µPa-m. Whales can generate signal levels exceeding 180 dB re 1 µPa at 1 meter.

Signals from air guns range from 240-260 dB re 1µPa-m_{P-P} . Chemical explosives detonating in the sea will have peak pressure levels in excess of 270 dB re 1 µPa-m, for charge sizes of 1 kg. However, chemical explosives are not used in marine seismic operations today.

The computed source level depends on the frequency range over which the acoustic pulse is measured. Seismic arrays are frequently measured over 0-125 Hz or 0-250 Hz. There may be a slight underestimation of total energy by these bandwidths, but the error is small because output above 250 Hz is limited. It is known, however, that the output from air-guns extends well into the kHz band but with much-reduced pressure level.

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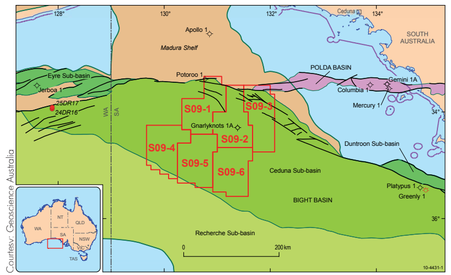
Landrø, 2007, Attenuation of seismic water column noise – tested on data from the Grane Field: Geophysics, 72, V87-V95.

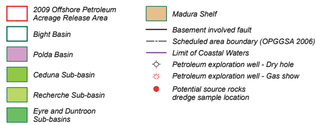
New Insights into Australia's Bight Basin

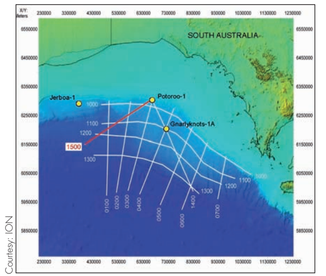
The first regional seismic program designed to collect data through the crustal section in the Ceduna Sub-basin of the Bight Basin is providing key information and the first seismic images of untested petroleum systems.

See full story starting on page 39.

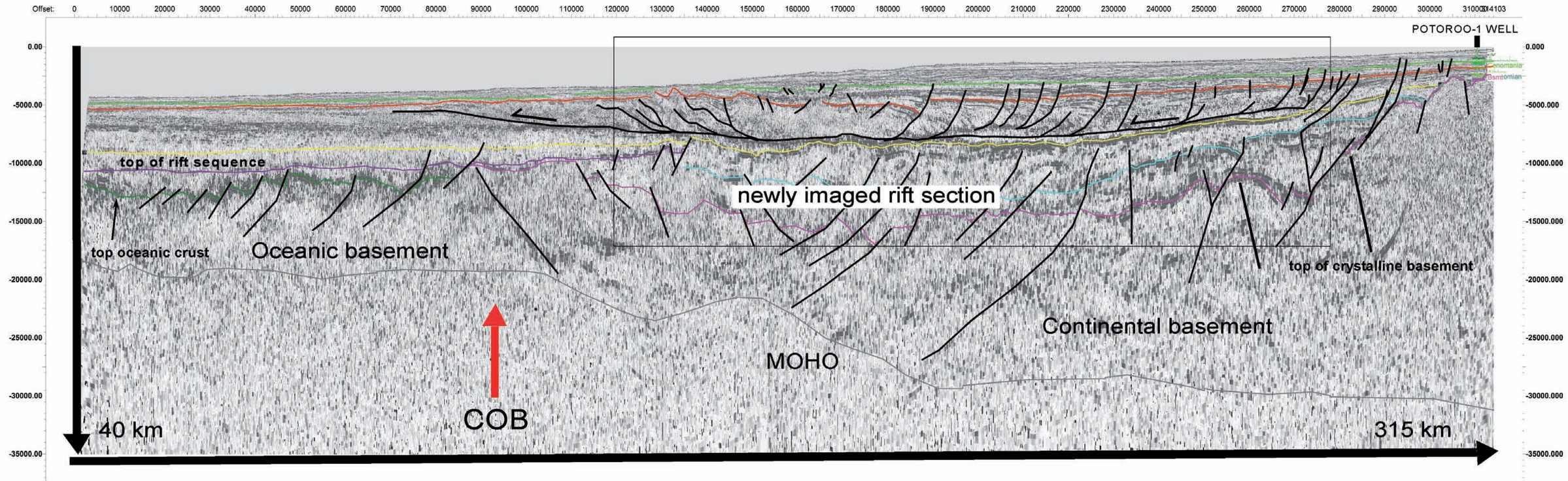


The eastern Bight Basin showing the 2009 acreage release area, sub-basins, wells, and 2007 dredge sample locations.





Index map of the 315 km long foldout line shown in red and the remainder of the 5,000 km regional data acquired by ION Geophysical Corporation in 2009. The program utilized 10 km offsets with a record length of 18 seconds to image the deep reaches of the basin.



Hidden Assets:
South Australia

A largely untested 15,000 m of syn-rift and post-rift succession of Middle Jurassic to Late Cretaceous sediments in the offshore Ceduna Sub-basin beckons exploration.

THOMAS SMITH

This year the Australian Government is offering six exploration areas in the frontier Ceduna Sub-basin of the Bight Basin. Prior exploration focused mainly on the margins of the Ceduna Sub-basin where nine unsuccessful wells were drilled. The only well that attempted to test the deep basin was drilled in 2003; the Gnarlyknots 1A well targeted an untested petroleum system but failed to reach the planned horizons.

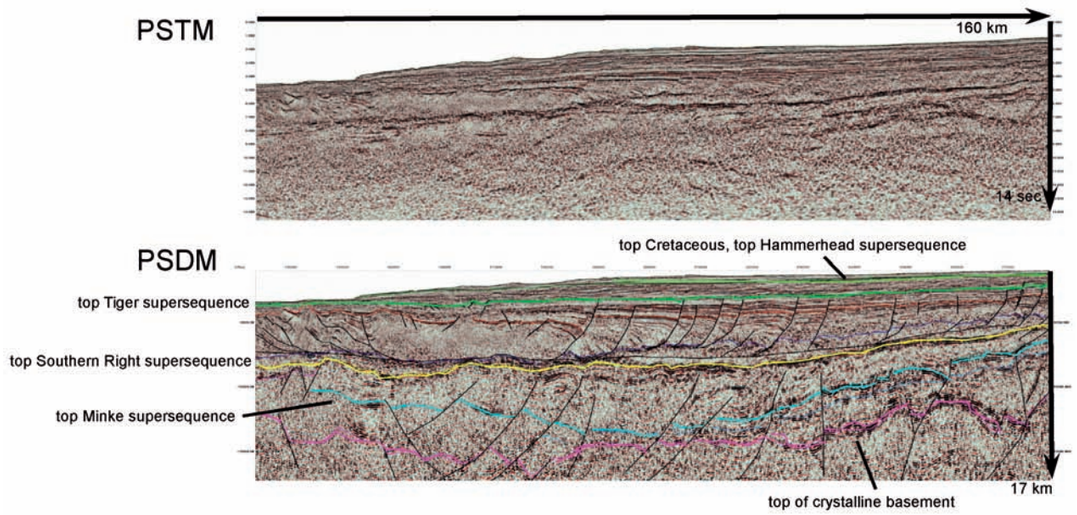
In 2007, after the first wave of unsuccessful exploration, and to address questions concerning the area's petroleum prospectivity, Geoscience Australia conducted a marine sampling survey. This survey identified rich Late Cretaceous source rocks in the basin. A recently completed seismic survey, BightSPAN™, conducted by ION Geophysical, was able to image an early rift section much more clearly than previous datasets. The deep imaging, regional survey shows untested potential petroleum systems to underlie most of the basin.

BASIN EXPECTATIONS

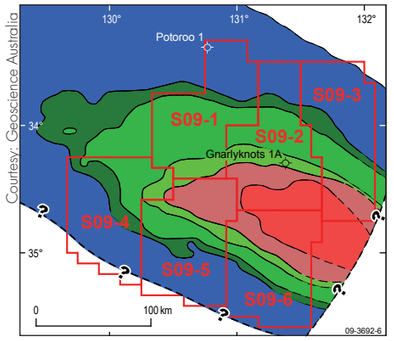
A series of Mesozoic to Cenozoic depocenters developed along Australia's southern margin during the breakup of eastern Gondwana. Prior to and following the commencement of seafloor spreading between Australia and Antarctica, basin development evolved through a series of extensional and thermal subsidence episodes. The result is the east-southeast trending Ceduna Sub-basin, the major depocenter in the Bight Basin. The Sub-basin extends over an area of 126,000 km² in water depths to 4,600 m.

"After the first round of exploration, one of our biggest concerns about the Ceduna Sub-basin was the existence and extent of source rocks," says Jennifer Totterdell, Project Leader for the Southern Frontiers Project, Geoscience Australia. "Negative perceptions regarding the prospectivity of the Bight Basin followed the disappointment of Gnarlyknots 1A, and one of the perceived exploration risks in the basin continued to be hydrocarbon charge."

"Previous work based on wells that intersect the proximal basin margins identified a range of potential source rock intervals across the basin, with the most prospective section predicted to be the more distal, marine facies of the Albian-Santonian section," says Jennifer. "In 2007, we successfully sampled more distal rocks along submarine canyons and fault exposures. We found the best source rocks to date, a suite of organic-rich, oil-prone shales of Cenomanian-Turonian boundary age."



Time-Depth Comparison:
The sections displayed above are taken from the boxed portion of the foldout line. These lines are the first to image the lower rift sequence below the detachment zone. The lower line is a pre-stack depth migration (PSDM) of the time line shown. The PSDM greatly improved the structural fidelity of the seismic image. The time migration gives the impression that the section is much more faulted than in fact it is. Therefore, traps are not as serious a risk as was previously associated with this section. In addition, the improved imaging at depth adds new perspective on additional targets. The depth migrated line also shows better resolution of layered packages possibly indicating pockets of reservoir sandstones along with seals and good source rocks.



Maturity map for Cenomanian-Turonian marine shale at the base of the Tiger Supersequence showing mature source rocks throughout most of the basin depocenter.

2009 Offshore Petroleum Acreage Release Area
Immature
Early Oil
Main Oil
Late Oil
Wet Gas
Dry Gas
Petroleum exploration well - Dry hole

According to Geoscience Australia, subsequent petroleum systems modeling showed that generation and expulsion from the Cenomanian–Turonian (Late Cretaceous) source rock occurred during the mid-Campanian to Recent, resulting in potentially significant accumulations of both liquid and gaseous hydrocarbons within overlying deltaic sandstones of the Turonian–Santonian Tiger and/or latest Santonian–Maastrichtian Hammerhead supersequences.

KEY SURVEY

The BightSPAN program covers a portion of the Bight Basin and particularly the Ceduna Sub-basin where Australia is offering tracts for leasing. The acquisition is typical of other ION BasinSPAN (SPAN) programs. The seismic data are interpreted together with simultaneously collected gravity-magnetic data to regionally map the crustal continent-ocean boundary (COB) and the top of the MOHO discontinuity.

Line 1500 extends from the outer continental shelf from the Potoroo-1 well, across the COB, and out over the ocean crust. Oceanic crust (top shown in green) lies in about 5,000 m water depth, is characterized by about 6 or 7 km of crystalline crustal thickness and a MOHO at about 15 km depth. The COB lies near the base of the continental slope, where MOHO begins to deepen from the base of oceanic crust to beneath the continental shelf.

The placement of the continental basement (top shown in pink) and MOHO picks is crucial to understanding the petroleum systems of this margin as it controls not only the thickness of rift-related sedimentary rocks but also the age of the critical points in the petroleum history. The Potoroo well bottomed in basement and helps anchor that pick. ION's interpretation is further controlled by modeling of the gravity profile taken during acquisition and verified by two seismic refraction experiments reported by Hayes in the 1991 AGU Circum-Antarctic Atlas.

The sedimentary section of the line consists of a thin Tertiary section above a Cretaceous section that has been previously imaged in seismic data, down to about the top of the Southern Right supersequence (shown in yellow) which has, in some previous surveys, been interpreted as the basement. A rather typical continental margin growth fault system balanced by a toe thrust lies just above the yellow horizon.

Below the Southern Right supersequence, or prior to the Berriasian, is a section at least 5 km in thickness above basement that developed during the early rifting phase between Antarctica and Australia. In previous datasets, this has only been poorly imaged if imaged at all.

UNTESTED PETROLEUM SYSTEMS

The petroleum system identified by Geoscience Australia from seafloor dredge samples lies in the upper portions of line 1500. The marine source rocks identified to be the best found to date lie below the bright green horizon (top Tiger supersequence or top Santonian) and above the red horizon (Blue Whale supersequence). Potential hydrocarbon accumulations are predicted to occur in the deltaic sandstones near the top of the Tiger supersequence. Reservoir sandstones are also found in the overlying Hammerhead supersequence located below the top Cretaceous pick (dark green horizon).

The older rift section (between top Basement shown in pink and Southern Right shown in yellow on the time-depth line) that is imaged on the inboard BightSPAN data is interpreted to be equivalent to the fluvial-lacustrine Middle Jurassic-Early Cretaceous section intersected in the Eyre Sub-basin to the west (Sea Lion and Minke supersequences). It is overlain by an Early Cretaceous succession that is largely non-marine and which is interpreted to include thick lacustrine shales. In the Eyre Sub-basin, the early rift succession is interpreted to contain lacustrine source rocks that have sourced the breached oil accumulation at Jerboa 1, the only well in the Eyre Sub-basin.

"New seismic data, including the BightSPAN survey and reprocessed data available from Geoscience Australia and Fugro MCS, provide clearer imaging of the Jurassic half graben along the eastern margin of the Ceduna Sub-basin and new insights into the half graben play in this part of the basin," says Jennifer Totterdell.

"In the past 10 years, the vast amount of new, high quality geophysical data available to explorers and identification of oil-prone source rocks has vastly advanced our understanding of the prospectivity of the Bight Basin," concludes Jennifer Totterdell. "Petroleum systems modeling suggest the basin has undergone multiple phases of generation and expulsion of oil and gas potentially resulting in major hydrocarbon accumulations."

BasinSPANS™

ION's seismic imaging subsidiary GX Technology group (GXT), offers a new approach in basin evaluation by acquiring and processing regional data designed to image down to the base of the earth's crust. According to Bob Peebler, ION's CEO, "SPAN originated from the idea that you're spanning a whole basin with data. …for explorationists to succeed, they must explore for hydrocarbons and not just prospect." These surveys are designed for deep imaging typically using 18 second records and 9,000 m cables. Each SPAN is custom designed to provide critical insight into the geologic evolution, deep basin architecture, deposition, and structural history of petroleum systems in a frontier basin.

FOLLOWING ON FROM THE REPORT ON THE PEAK OIL DEBATE HELD AT THE 7TH PETROLEUM GEOLOGY CONFERENCE LAST YEAR,

Are NOCs the Future of the

National Oil Companies (NOCs) have become increasingly important in the oil industry. Back in the 1970's the major oil companies controlled around 80% of the world's oil supplies: that figure is today much considerably with much of the remaining resource now in the hands of the NOCs of the main petroleum-producing nations.

The protagonists of this debate were **Marlan W. Downey**, former AAPG president, who spoke for the motion, and **Peter Gaffney**, Founder of Gaffney Cline, who spoke against it.

DOWN TO 10%

Marlan Downey, who spent 30 years with Shell before joining the Board of ARCO and then moving into academia, viewed the topic very much from the historical standpoint, comparing the past and present situations of the NOCs and international oil companies (IOCs). "Once, the international oil companies, and their clients, the great powers, imposed their will on the penniless, powerless countries where oil was found. The great powers, economically allied with the IOCs, divided much of the world up into 'Spheres of Influence' and agreed not to compete with one another," he said. He recalled the days when international oil companies boycotted oil producing countries which asked to retain a share of their oil through production sharing contracts.

In those days "the international oil companies controlled the production, transportation, refining, and marketing of nearly all the oil in the world, outside the USA. They provided all the capital, the technology, the project management skills - and took most of the oil. Now they control a mere 10%."

But as he pointed out, nearly 50 years have passed since the halcyon days of the IOCs, and more importantly, two generations of young people from these emerging states have benefitted from education and training to enable them to take control of their own resources. The modern NOC has well-qualified engineers, geologists, and geophysicists, as well as accountants and managers – and they know where to look for both the capital and the technology to ensure their forthcoming prominence.

IOCS AND NOCS INTERDEPENDENT

In Peter Gaffney's opinion, however, the future of the petroleum industry is simply a matter of economics, as the market is a more powerful influence than the National Oil Companies. He cited the inability of the NOCs to stem the recent price fall from the $150 heights of 2008. "I believe that, regardless of how important petroleum is to the world economy, it is still a commodity, and as such will continue to oscillate in price through its foreseeable life."

Gaffney agreed with Downey that the NOCs have matured and graduated into worthy competitors to the IOCs in their own right, but concludes that they are therefore both equally vulnerable to market forces. He sees them more as interdependent, rather than independent of one another, emphasised by the fact that for the first time in several years the NOCs are looking for partners on a broader front than previously, widening their nets to become international competitors and looking to work with others to mitigate their own risks.

WORKING WITH THE NOCS

Both speakers said that they thought that many larger companies are still worried about their ability to work with the NOCs. "It is important that the NOCs are accepted as they are now, so the deals available today need to be structured in today's real world, not that of the 1950's," said Gaffney. "But," Downey added, "the negotiating power, the control of oil, belongs to the national oil companies in oil producing countries." Many IOCs are wary of negotiating with NOCs, worried that they are not on a level playing field, with the NOCs of young oil producing nations, supported by their governments, likely to move the goal posts at will. "Forget the myth of contractual third party arbitration. Does anyone doubt that courts in the FSU will rule on petroleum contract disputes in a manner favourable to the FSU?"

In Marlon's view, the IOCs have only themselves to blame - when they cut their laboratories and research staffs in the 80's and 90's to save a few dollars, they lost their dominance in technology. The NOCs continued developing their expertise and now, as he said, "Petrobras

Photo: Guy Elliott/PESGB

Convener Julian Rush with Peter Gaffney, who co-founded Gaffney-cline Associates in 1962 and has worked as an advisor and senior manager in most of the world's petroleum provinces.

WE NOW LOOK AT THE SECOND GEOCONTROVERSY DEBATE:

Petroleum Industry?

doesn't need any help from Shell to develop in the deep water, and Aramco doesn't need any help from Chevron to manage large oil field projects in Saudi Arabia." Unlike Gaffney, he believes that the NOCs no longer need the independents and major oil companies. "It is their century!"

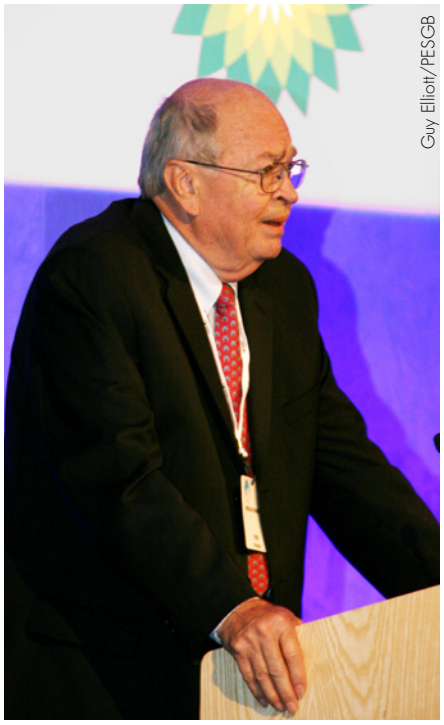
CONSUMER V SUPPLIER

But Peter Gaffney thinks that this argument ignores the realities of global economics. "The National Oil Companies themselves can be divided into two groups - producers and consumers," he explained. The exporting nations are facing the same problems as the rest of the industry, and can be seen to be curbing their plans for new plants and reducing production capacity. The NOCs of the consuming nations, however, are busy trying to ensure their long term supply from a range of countries, while actively reducing their import costs.

So which type of NOC has the upper hand? Neither, in Gaffney's opinion, as the driving forces of today's world economy are not the oil companies but growing nations such as India and China – producers, but more importantly, major consumers of energy supplies. "As such, they have a capability to influence the market from a very different perspective than that of exporting countries."

Photo: Petrobras

President Lula of Brazil holds up the first sub salt oil produced by Petrobras, Brazil's National Oil Company, which is the world's eighth biggest global company in market value, according to Ernst & Young.



Guy Elliott/PESGB

Marlan is former President of the AAPG, and has been honoured by the Houston Geological Society as "A Living Legend in the Oil and Gas Business". He was also knighted by President Biya of Cameroon for his service to that country.

Gaffney also pointed out that alternative hydrocarbons are set to have a major impact on the future of the petroleum industry. "Who could have imagined 10 years ago the huge new resources of natural gas that have become available in the United States through coal bed methane and the very successful shale gas developments?" he said. These are likely to materially change the energy dynamics of the whole world - another factor which is completely independent of the effects of the National Oil Companies.

WHAT FUTURE?

Julian Rush, the Channel 4 Science correspondent who acted as moderator for all the geocontroversy debates, agreed that the whole geopolitical system will change as the economies of China, India, Brazil and others grow to equal and surpass the Western economies. He expects to see the oil and gas industry evolving as it has over the last decades, to meet new global political realities as wealth, power and influence ebb and flow across the planet.

Summing up, Julian said that both speakers agreed that NOCs are now dominant. But will they survive to be the future of the petroleum industry, when they are so tied to the political ambitions of their countries, assuming that the politicians continue to see oil and gas as part of their plans for growth?

When it came to the vote, the attending delegates chose strongly in favour of the motion, declaring that NOCs are the future of the petroleum industry. But, as so often with this type of discussion, the title of the debate actually masked some crucial underlying questions: will all oil companies, both international and national, face extinction before the first half of the 21st century is out – and is the rise and dominance of the NOCs a threat or an opportunity? We leave it to you to decide.

What do you think?
Send your comments to
jane.whaley@geoexpro.com

Miri 1910:
The Centenary of Oil Discovery

In 1910, now 100 years ago, the Shell/Royal Dutch Group drilled the first discovery well in Miri, Sarawak. This oil discovery changed the face of Miri from a small fishery village into a modern city. But it took a lot more than luck to find and produce Sarawak's only onshore oil field.

Photo: spOt_ON

Sibu is a riverine town in Sarawak, an important gateway to the interior.

in Sarawak

Sarawak is located on the northwest coast of Borneo, the world's third largest island. It is rich in natural resources; indeed the word "serawak" is a Malay word for the mineral antimony. Paleolithic cavemen and hunter-gatherer tribes first settled in Sarawak; the oldest evidence includes a *Homo sapiens* skull in the Niah Caves near Miri estimated to be 35,000 years old. Then about 4,500 years ago waves of Austronesians, the ancestors of the present Dayak peoples, came to this region. Chinese and Malay traders visited Sarawak as early as 900 A.D., brining Buddhist, Hindu and Muslim traditions to Borneo. The Europeans came in the 16th century. In 1512, Antonio Pigafetta, an Italian companion and chronicler of Ferdinand Magellan, wrote an account of the region, or what he called "Cerava." In the 1820s, Dutch colonialists began to exert their influence in Kalimantan, the southern part of Borneo.

The modern history of Sarawak began in 1839 when James Brooke arrived in Sarawak. Brooke was born in 1803 in India and was an army officer of the British East India Company. Upon his father's death, James quit his job and used his inheritance to purchase a schooner, the *Royalist*, and sailed for Sarawak. There he met with Rajah Muda Hashim, who was governing the region on behalf of his nephew, Sultan Omar Ali Saifuddin II of Brunei. As Brooke's party left Sarawak for Singapore, Dayak pirates unsuccessfully attached his ship. In 1840, Rajah Muda Hashim requested Brooke's help to defeat a Dayak revolt in Kuching, promising in return to give him Kuching and enviros (later called the First Division of Sarawak). Following this success, Brooke was appointed the first White Rajah of Sarawak in 1841 in exchange for a small annual payment to the Sultan of Brunei. Initially the British were not supportive of Brooke, but after Brooke began to eradicate piracy in South China Sea, and in 1846 the Sultan of Brunei ceded the nearby island of Labuan to the British Royal Navy as a base for fighting the local pirates, relationships between Brooke and Britain were cemented.

MOTIVATED BY OIL SEEPS

The first geological survey of Sarawak was conducted by Hiram Williams in 1845. Sarawak was also part of Alfred Russel Wallace's natural history exploration from 1854-1862, which is recorded in his book *The Malay Archipelago* (1869). Wallace refers to coal mines in Sarawak: "These [coal mines] puzzle the natives exceedingly, as they cannot understand the extensive and costly preparations for working coal, and cannot believe it is to be

used only as fuel when wood is so abundant and so easily obtained." The Italian biologist Odoardo Beccari also explored Sarawak from 1865-68, documented in his *Nelle Foreste di Borneo* (1902; *Wanderings in the Great Forests of Borneo*, 1904).

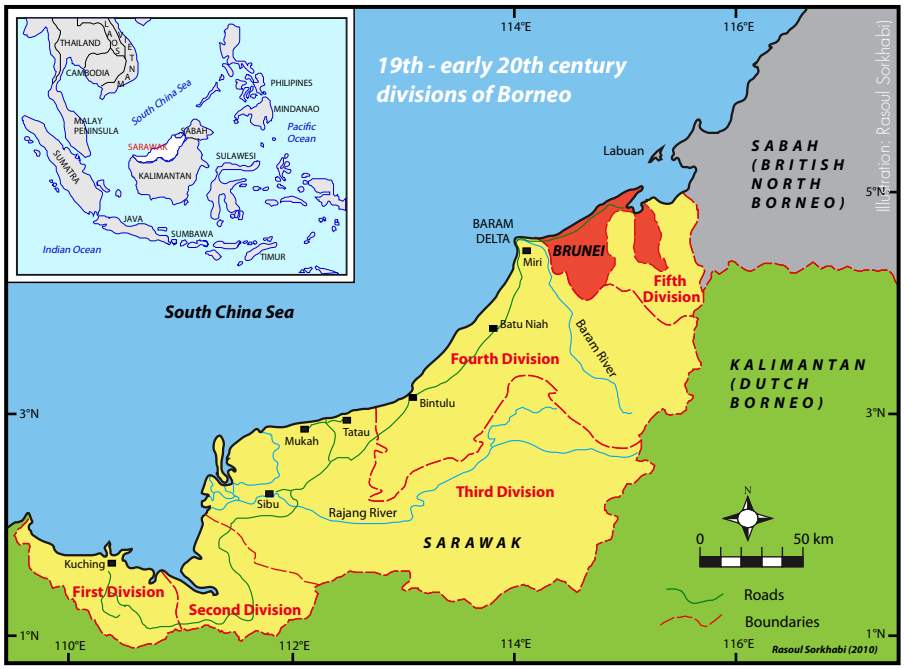
The Brooke administration was in business engagements with companies in Scotland and Singapore. To better facilitate trade between Sarawak and Britain, the Borneo Company Limited was founded in London in 1856. In the following decades, surveyors working for this company carried out extensive mapping of Sarawak for its mineral and natural resources. (Henry Longhurst details this history in his 1957 book, T*he Borneo Story: The First Hundred Years of the Borneo Company*.)

In 1864, Britain recognized Sarawak as an independent state. In 1868, James Brooke was succeeded by his nephew Charles Johnson (later renamed Brooke), who ruled Sarawak until 1917 and, over time, extended his domain to the present boundaries of Sarawak. In 1888, the White Rajah obtained British protection for Sarawak. During Sir Charles Brooke' period surveys and exploration in Sarawak increased. Dr. T. Posewitz published *Borneo: Its Geology and Mineral Resources* (London, 1892), and Henry Ling North produced a comprehensive description of *The Natives of Sarawak and British North Borneo* (London, 1896).

Like the other oil regions of the world, oil seeps provided the first motivation for drilling in Sarawak. Indeed, local inhabitants had extracted oil from hand-dug wells for centuries. The 11th century *Song Hui Yao*, a historical compilation of the Song Dynasty of China, mentions imports of Borneo-camphor and petroleum. In 1882, Claude Champion de Crespigni, Resident (chief officer) of the Fourth Division (Baram), listed in his report to the Brooke Government 18 hand-dug oil wells in the Miri area. Perhaps foreseeing the value of what the locals called "minyak tanah" or "earth oil," De Crespigni recommended in his 1884 journal that "the oil district near the mouth of the Miri River should be thoroughly searched and reported on." "Earth oil" was used by local people for lighting lamps, waterproofing boats, and medicinal purposes. But De Crespigni's words fell on deaf ears in the Brooke government.

ENTER CHARLES HOSE

Charles Hose was born in Hertfordshire, England in 1863. He entered Jesus College, Cambridge in 1884; but two years later without completing his studies, the young Hose (with help from his uncle, the Bishop of



A geographic map of Sarawak in Borneo showing the administrative divisions during the rule of the White Rajahs of Sarawak (1841-1946).

A view of Miri City from the Canada Hill.

A view of Miri coastal town and South China Sea.

Dr. Charles Hose (1863-1929), a British colonial officer at the service (1884-1907) of Rajah Charles Brooke in Sarawak and a pioneer explorer whose effort and vision led to the discovery of the Miri oil field in 1910. He was a member of the Supreme Council of Sarawak from 1904 and a member of the Sarawak State Advisory Council (based in Westminster, England) from 1919. A Fellow of the Royal Geographical Society, the Zoological Society, and Jesus College, Hose authored several important works on the natural history and ethnology of Sarawak, *including The Pagan Tribes of Borneo* (1912) and *The Field Book of a Jungle-Wallah* (1929). Illustration: Setsuko Yoshida

Singapore) took up an administrative cadetship in Sarawak. Hose resided at Claudetown (today's Marudi), and in 1888 he succeeded de Crespigny as Officer-in-Charge, and in 1890 as Resident of Baram.

Hose, a keen natural historian and explorer, picked up de Crespigny's oil idea and began mapping of oil seeps in and around Miri. He even offered awards to the locals who would show him an oil seep. Hose reported his findings to the Brooke government, but a consultant geologist from England gave a negative opinion of oil exploration in Sarawak because of poor logistic conditions.

Hose kept the oil idea in the back of his mind. After serving as Resident of Sibu (the Third Division of Sarawak) from 1904-07, he retired and returned to England, where the aging Rajah Sir Charles Brooke was then staying. Hose wrote to the Rajah seeking his permission to show his map of the oil seeps and the Miri oil samples to a petroleum company. After obtaining the Rajah's permission, Hose went to London to discuss his idea with the Anglo-Saxon Petroleum, a part of the Royal Dutch/Shell Group (formed in 1907). Mr. H.N. Benjamin and his colleagues at the company were interested in the idea, and the Rajah thus came to London to sign the first Sarawak Oil Mining Lease in 1909.

SHELL AND THE DISCOVERY WELL

Shell dispatched their senior geologist Dr. Josef Theodor Erb (a Swiss geologist who had joined the Royal Dutch in 1900) along with Hose to Miri. They traveled on the Trans-Siberian railway and by boat, arriving in Kuching and calling on the Rajah, before proceeding to Miri. Erb started an independent examination of the Miri area, mapping several anticlines including his favorite "Miri Hill," a northwest-dipping asymmetrical anticline, with nearby oil seeps. In July 1910, Erb reported to the company his final geological map of the Miri area, and located the first exploratory well at the crest of the Miri anticline about 150 m above sea level. This surprised people who had anticipated the well to be drilled in an oil seep like all the previous hand-dug wells. Before the drilling could begin, Erb and Hose had to convince the local people that the well would not open the underground cave that was, according to a local legend, home for two evil tigers.

The well was spudded in on 10 August 1910 using a rig composed of wooden derricks and the cable tool drilling (a technology that dates back to the Chinese in the fifth century for drilling for brine). The rig was engineered by a Canadian, Mr. McAlpine; therefore, the hill has been historically called the "Canada Hill." On 22 December 1910, the well struck light crude at 425 ft (130 m) depth. The reservoir was Upper Miocene deltaic sandstone beds deposited by the ancestral Baram River. Initial production was only 83 barrels oil oil per day (bopd); after total production had reached 111,322 tons or 82,650 barrels, the well was deepened to 1,096 ft (Miri-2 drilled in 1911 was dry, but over time, numerous other wells (many deeper) produced from various payzones in the field.

The Sarawak Oilfield Ltd., a subsidiary of the Shell/Royal Dutch Group, was established to run the Miri operations (this company is now called Sarawak Shell Berhard, located in Lutong, on the outskirts of Miri). Most of the labor force to work in Miri came from Singapore.

The 1910 discovery well was to change the face of Miri, or as Hose put it his 1927 book *Fifty Years of Romance and Research or a Jungle-Wallah at Large:* "An area which was almost uninhabited was now a center of bustling life."

THE RISE, FALL AND RISE OF THE MIRI FIELD

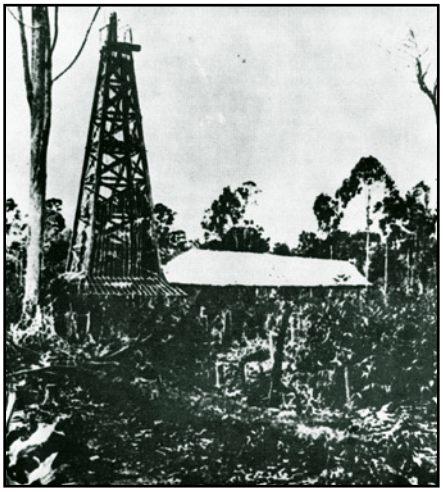
Oil production from the Miri field rose from 5 bopd on average in 1911 to 523 bopd in 1913 (from eight wells), when Shell also began to export the Miri oil. The following year oil production reached 1315 bopd and further increased to 11,210 bopd in 1923.

In 1914, Sarawak Shell built the first refinery in Miri (it was relocated two years later to Lutong). Also in the same year, Shell laid a submarine pipeline from Tanjong Lobang (south of Miri) to transport the crude to an offshore loading berth and tankers. The sealine was about 2.5 miles long and six-inches in diameter. During World War I (1914-18), the Miri field provided 5763 bopd averaged over the year for the British Navy.

In May 1917, Sir Charles Brooke died and his son Charles Vyner deWindt Brooke became the Third White Rajah of Sarawak (he was knighted in 1927). Hose, who lived in England, received a royalty on oil production from Miri, considerable revenue for the rest of his life. He also gave lectures and published works about the natural history and culture in Sarawak. (For his scholarly works, Cambridge awarded an honorary doctorate to Hose in 1900.) He died in 1929. Several species discovered from Borneo have been named after him. As for Dr. Josef Erb: After the Miri field discovery, he continued his work for Shell in other parts of the world; he died in 1934 at the age of 60. Another Shell geologist who made significant contributions in the late 1930s to the geology of the Miri field was P. von Schumacher.

Shell introduced rotary drilling in the Miri field in 1925. Peak production reached 15,211 bopd in 1929. By the end of 1940, the Miri field had produced 7 million barrels of oil and a total of 597 wells had been drilled in the field. And by then, Miri's population had grown to 11,000, of whom nearly two-thirds were of Chinese ethnicity.

In 1941, during the heyday of World War II, the Brooke government obtained military



Drilling Miri Well No. 1 in 1910.

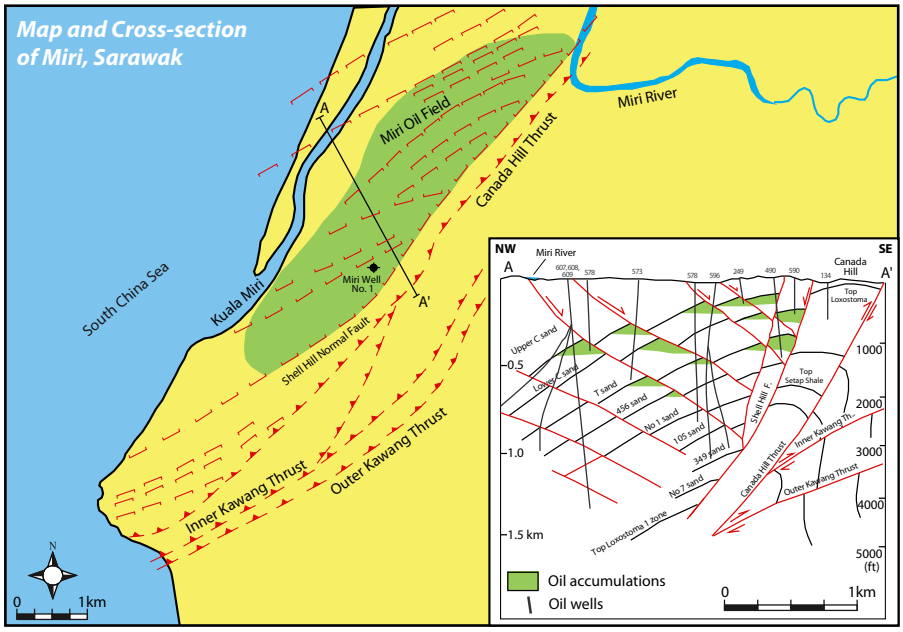


Illustration: Rasoul Sorkhabi

A map and geologic cross-section of the Miri field,originally drawn by the Sarawak Shell geologist P. von Schumacher in 1941 and revised by other geologists since then.

Photo: Rasoul Sorkhabi

An outcrop of the Upper Miocene Miri Formation in the town of Miri showing cross-bedding in the deltaic sandstone.

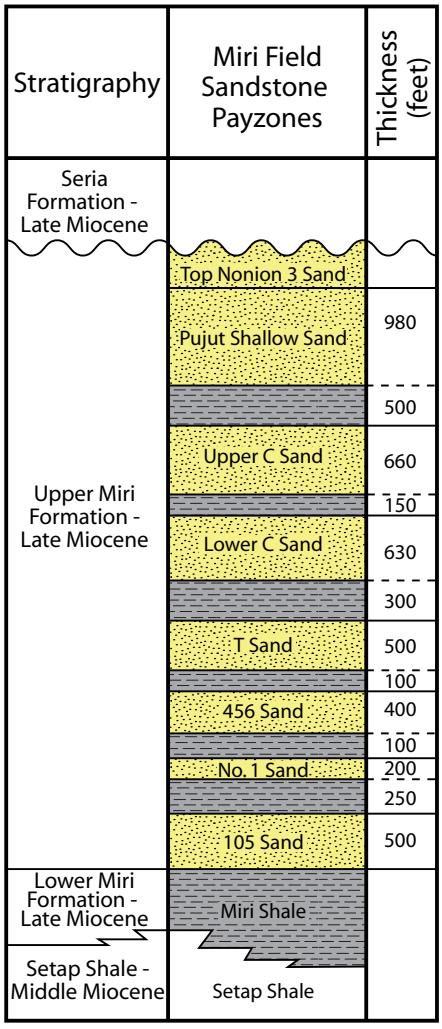


Illustration: Rasoul Sorkhabi

Stratigraphy of producing zones in the Miri oil field (modified from *The Petroleum Geology and Resources of Malaysia*, Petronas, 1999)

help from Britain: Over 1,000 soldiers (the so-called 2/15th Punjab) under the command of Major C.M. Lane were stationed in Miri to protect the oil field. Anticipating the Japanese invasion, they eventually shut in the Miri wells and the Lutong refinery, and sent the equipment, skilled workers, and documents to Singapore. This was part of the Allied forces' Denial Scheme. On 19 December 1941 (only nine days after the Perl Harbor attack), a ten-thousand-strong Japanese army occupied Sarawak following two days of fighting with a small garrison of Dutch troops. This virtually ended the Brooke dynasty's hold on the region.

Within two months of their occupation, the Japanese were able to retrace the equipments and men in Singapore and bring them back to Miri. Thus a new Japanese company, Nenryo Haikyu-sho ("Oil Supplying Services"), took over the operations in Miri and produced nearly 750,000 barrels of oil for the Japanese army during World War II. (Of this volume, Miri Well No. 1 produced 4,371 barrels.) When the war ended in September 1945, Miri had suffered severe damage and destruction, mainly from the Allied forces' bombings (part of the Denial Scheme). The Third White Rajah returned to Sarawak in 1946 but decided to give the country to the British Crown. In 1947, attempts were made to reconstruct and reproduce oil from the Miri field.

1960s: OFFSHORE SARAWAK AND JOINING MALAYSIA

In 1949, the Geological Survey Department of British Territories in Borneo was established in Kuching, and over the next 15 years its geologists produced valuable maps and reports on various areas of Sarawak and Sabah. (This organization was the forerunner of the Minerals and Geoscience Department of Malaysia).

Despite this progress, the Miri field remained unique because 46 onshore exploratory wells drilled in Sarawak Shell during the 1910s-50s did not yield commercial accumulations. (The sole exception was the Seria field located in Brunei and discovered in 1929.)

In 1955 Sarawak Shell began marine seismic surveys. In 1957, the company relinquished 75% of its land lease (about 36.650 square miles) in Sarawak, some eleven years earlier than the concession deadline. The company instead decided in 1960 to explore offshore Sarawak. Initial drilling by the *Orient Explorer* (a jack-up drilling rig) in the Temana field hit oil in 1962 but not in commercial quantities (this was to be materialized in 1972 for Temana). In 1963, Shell put in place Sarawak's first floating rig *Sidewinder,* and then two semi-submersible mobile rigs, *Alpha* in 1965 and *Echo* in 1968. Two wells drilled in the offshore Baram field during 1963-64 were dry, but Baram-3 drilled by the *Sidewinder* hit oil in May 1964. Two years later, *Alpha* drilled the first well in West Lutong; it struck oil too, and the field came onstream in 1968. By the end of 1969, the Tukau, Bokor, Betty, Baronia, and Bakau oil and gas fields had joined Sarawak Shell's offshore portfolio.

Meanwhile, the company had to live with new political realities. In 1957, Malaya

An outcrop of the Upper Miocene Miri Formation in the town of Miri deposited by the paleo-Baram Delta. The human scale in the photo is the author of this article.

obtained its independence from Britain, and in August 1963, the then-British crown colonies of Sabah (British North Borneo) and Sarawak joined Malaya forming the Federation of Malaysia. This took place just four months after the death of the last (third) White Rajah of Sarawak in London.

THE GRAND OLD LADY

On 31st October 1972, the Miri field was closed in. Since its beginning 61 years earlier, 624 wells (a close spacing of 8.5-11 m) had been drilled in the field and a total volume 80 million barrels of oil had been produced. In 1972, only 90 wells were producing at about 450 bopd. It was time for retirement. Although there are still oil seeps in Miri, urbanization has discouraged further drilling.

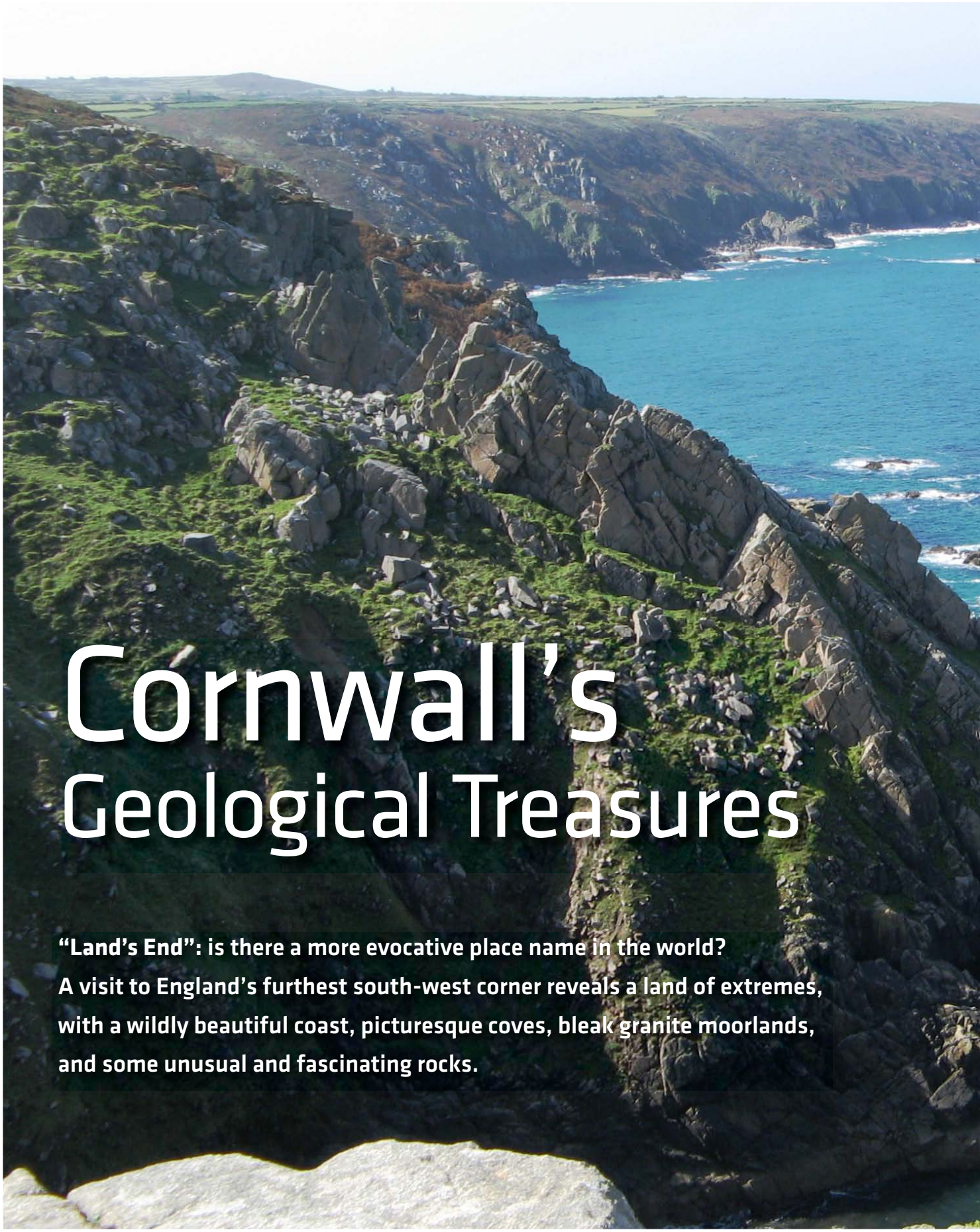
Today, the 30-m high Miri Well No. 1 derrick, affectionately called the Grand Old Lady, sits on top of the Canada Hill (renamed Bukit Telaga Minyak in Malay in 2005), next to the Petroleum Museum that was opened in 2005 and is funded by the Sarawak government, Shell Malaysia, and Petronas.

An attraction site for tourists and school students, the Grand Old Lady represents an important monument in the history of Sarawak as its first oil well that faithfully produced 658,650 barrels of oil over a period of six decades. (At the time of closing, it was still pumping out 7 bopd). The Grand Old Lady has also witnessed the growth of Miri from a sleepy village in the 19th century to a modern tourist city, with an airport, national parks, beaches, and a population of 280,000. ■

Bibliography

Three authors, Robert Payne (1960) Steven Runciman (1960), Cassandra Pybus (1996) have given the history of *The White Rajahs of Sarawak*, but none of these books touches on the Miri oil discovery. James Jackson's *Sarawak* (1968) provides some information on this subject. Sarawak Shell has published *The Miri Story* (Third edition, 1990). In the past, Petronas and Sarawak Shell have organized several field trips and guidebooks for Miri. The Petroleum Museum at Mir provides information to the visitors if you happen to be in town. Two geologists Mario Wannier and Philip Lesslar have produced a wonderful DVD, *Destination Miri: A Geological Tour* (2006) available at **www.ecomedia-software.com**

A view of Miri Oil Well No. 1's derrick, affectionately called the Grand Old Lady, now a historical monument of Miri City, located near the Petroleum Museum.



Cornwall's Geological Treasures

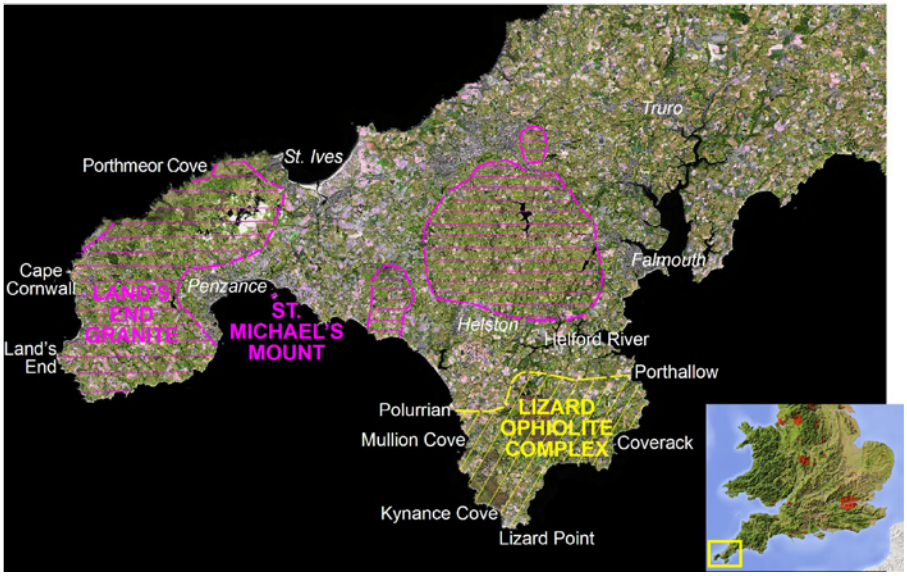
"Land's End": is there a more evocative place name in the world? A visit to England's furthest south-west corner reveals a land of extremes, with a wildly beautiful coast, picturesque coves, bleak granite moorlands, and some unusual and fascinating rocks.

The granite cliffs around Land's End, England's most westerly point, have many deep ravines and caves carved by the sea along joints, faults and zones of mineralisation.

Photo: Jane Whaley

The county of Cornwall, nearly 500km west of London, is a holiday playground with a stunning coastline, sandy beaches, picturesque villages, wild high moors and hundreds of great walks. For the geologist, however, south-west Cornwall, in particular Land's End and the Lizard Peninsula, holds particular fascination.

The greatest influence on both the geology and landscape of Cornwall was the Late Palaeozoic Variscan orogeny, when a granite batholith, which forms the deep core of the Cornish peninsula, was emplaced, crucially folding and metamorphosing the surrounding sediments. Almost simultaneously, a tectonic front advancing from the south produced the intriguingly named Lizard Peninsula.



THE LIZARD OPHIOLITE COMPLEX

Attractive though the idea is, the Lizard Peninsula is not named after some mythical giant reptile, but is probably derived from a Cornish word for a high area or headland. Bounded to the west, south and east by the sea and about 15 km wide and 10 km deep, to the north the peninsula is almost separated from the rest of Cornwall by the Helford River.

The Lizard is geologically different from the rest of Cornwall because it is an ophiolite complex. A section of oceanic crust was thrust over continental crust after a collision between two continents, overlying metamorphosed mostly sedimentary rocks, originally slates, sandstones and volcanics, now changed into mica-schists and quartzite. These original rocks, known as the Old Lizard Head Series, are rarely exposed, one of the only places where they can be clearly seen being at Lizard Point. The oldest rock in Cornwall is the 500 million year old Man of War gneiss, which forms small rock islets off Lizard Point.

A classic ophiolite has at the base ultramafic rocks (those with little silica), representing the mantle, overlain by layered intrusive gabbros and volcanic dykes, with at the top pillow lavas and sedimentary deposits formed on the ancient seafloor. The junction between the gabbros and peridotite represents the boundary between the mantle and oceanic crust, and is marked by a fundamental change in seismic velocities due to the density contrast. Subsequent movement and faulting means that these rocks are not always found in an ophiolite complex, but most do feature somewhere on the Lizard.

ORNAMENTAL SERPENTINITE

Much of the peninsula is dominated by originally deeply buried mantle material such as peridotite. This contains large amounts of minerals like olivine and pyroxene, which have been altered to create the rock serpeninite – a rare example of metamorphism resulting from a decrease, rather than an increase in temperature and pressure. This rock, so named because it resembles snake skin, is banded and streaked with veins, and polishes to a very attractive red, green and black rock. It was extremely popular for ornaments in Victorian times and is still quarried in small quantities for tourist souvenirs.

Drowned river valleys like Helford are oases of wooded tranquillity and make a very pleasant change from the dramatic and windswept coast.

Lizard Point, where some of the oldest sediments in Cornwall are exposed, metamorphosed by the overthrust Lizard ophiolite complex.

One of the best places to appreciate serpentinite is Kynance Cove on the south-west coast of the Lizard. A famous beauty spot for centuries, it is approached down a steep winding path which suddenly opens onto the small bay, where the wet cliffs and small shoreline rock islets shine red and green where they have been polished by the sea.

One of the many ways in which geology is responsible for the distinctive landscape of the Lizard is the characteristic flora of slow growing, low-lying heathland plants resulting from the toxic nature of serpentinite to vegetation.

PICTURESQUE MULLION COVE

The Lizard actually comprises several fault bounded slices of ophiolite. One large section in the south-east, separated from the rest by a major thrust fault, has the peridotite, gabbro and igneous sections, although the transition into pillow lavas and oceanic sediments is missing. The contact between the mantle and the oceanic crust is clearly seen over a 200m stretch of beach at the village of Coverack, where steeply dipping gabbro sheets, cut through by basalt dykes, give way to ultramafic rocks, having passed through a transition zone where the gabbro and mantle rocks intermix.

Much of the rest of the peninsula to the west of this thrust is dominated by peridotite and serpentinite, but there are a number of exposures of metamorphosed igneous basalt or gabbro, called amphibolite or hornblende schist. A faulted contact between hornblende schist and serpentinite is visible at Mullion Cove on the west coast of the Peninsula. This pretty harbour, still used by local fishermen, has an old lifeboat station – vital on a wild rocky coastline that has claimed thousands of lives over the centuries.

A short distance off Mullion Cove is Mullion Island, where there are excellent exposures of pillow lavas, formed when hot magma was extruded onto the ocean floor, as well as cherts and limestones, representing the top of the ophiolite sequence.

The contact between the Lizard ophiolite complex and the surrounding material is a fault zone running across the peninsula. It is seen at Polurrian on the south-west coast, where hornblende schists of the ophiolite complex have been thrust against metamorphosed Devonian mudstones, and at Porthallow on the east coast, where serpentinised peridotite and a small section of the Old Lizard Head schists are faulted over the Devonian Meneage melange.


Photo: Jane Whaley

The clear turquoise waters at Kynance Cove on the Lizard Peninsula are surrounded by cliffs and rock islands of beautiful red and black serpentinite rock, the colours dependent on the degree of magnetite released during the alteration of the rock from the original olivine-rich peridotite.


Photo: Jane Whaley

Veins of granite intruding into metamorphosed schists at Cape Cornwall

GRANITE AT LAND'S END

Away from the Lizard Peninsula, the geology of south-west Cornwall is dominated by marine clastic rocks of the Middle Devonian Gramscatho group, predominantly siltstones and mudstones. The exact age of these rocks has been the subject of much debate, primarily because they have undergone changes both from tectonic pressure which induced folding and faulting, and as a result of massive granite intrusions near the end of the Variscan orogeny, 300 Million years ago.

The granite was emplaced at great depth, but subsequent erosion has exposed the granite in the form of large areas of relatively bleak uplands, seen in Cornwall at Bodmin Moor, Land's End, and the Isles of Scilly, as well as smaller exposures such as St. Michael's Mount. The granite is predominantly a coarse crystalline rock, although there are occasional intrusions of finer grained material, and there are also dykes and sills of igneous material running into the surrounding rock. As the hot magma intruded into this sedimentary rock, the heat and pressure altered them significantly, creating a ring of transformed rocks, the 'metamorphic aureole', around the granite.

There are some excellent exposures of the contact between the granite and the metamorphosed sediments on the Land's End Peninsula. Cape Cornwall, 7km north of Land's End, is composed of Devonian Mylor Slates, but in a cove just to the south of the headland these have been metamorphosed into hornfels by contact with the solidifying magma, and the transitional contact between the two can be clearly seen on the rocks of the small beach.

Another intriguing exposure of the granite contact is at Porthmeor Cove, 15 km north-east of Land's End, which like Cape Cornwall has been designated an SSSI (Site of Special Scientific Interest). On the northern side of this beautiful remote bay the roof of the granite intrusion is exposed at the surface, with veins of fine and coarse grained igneous rocks intruding into the surrounding rocks, which are extensively veined and altered.

WALKING WEST CORNWALL

If large quantities of Mesozoic and younger sediments ever overlaid the Cornish Peninsula, there is little evidence of them now. The greatest changes made to the landscape in more recent times have been as a result of changes in sea level, with erosion platforms and raised beaches visible at several levels. This has also created another major feature of the Cornish landscape, in the form of drowned river valleys or rias, such as the Fal estuary and the picturesque, tree-lined Helford River.

By far the best way to appreciate the geology of Cornwall is to walk the coast, and it is possible to do just that using the South West Coast Path National Trail, which stretches 1,000 km from Somerset to Dorset and includes the entire coast of Cornwall. Much of it passes along the top of the cliffs and it includes all the sites discussed here, plus many more, with equally gorgeous scenery and fascinating geology.

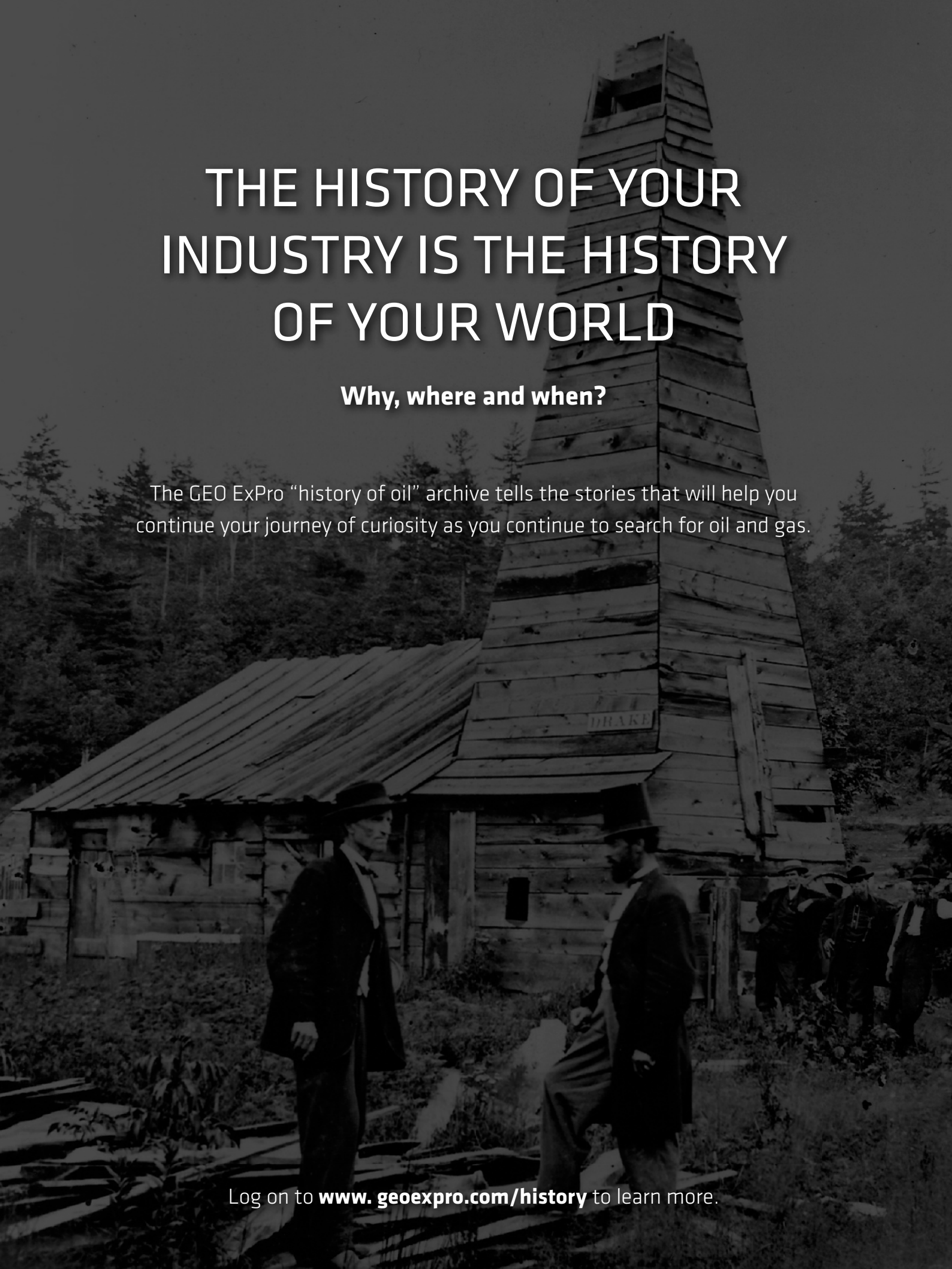
The Tin Islands

Cornish granite contains high amounts of tin, tungsten and copper, leached out from the cooling magma through fissures in the granite and faults in the surrounding country rock, eventually solidifying in concentrated lodes of minerals. Metals, principally copper, zinc and lead, were also leached from the surrounding rocks and incorporated into the lode system. As a result, metal mining was of great economic importance to this area, which due to its poor agricultural land and distance from major population centres was relatively impoverished until the influx of tourism.

Cornish tin found in streams was first used in prehistoric times for the production of bronze – in fact, metal traders from the Mediterranean called Britain the 'Cassiterides', or 'Tin Islands'. In the 16th century miners moved underground to seek out the source lodes, particularly in the Land's End granite area. Copper mining developed in the 18th century, and for a short while in the 1830's Cornwall dominated world copper production, although tin remained an important ore. Iron and silver were also mined in small quantities. Flooding of the mines by groundwater meant that the invention of the steam driven beam engine was a major factor in the development of the industry, and at its height there were more than 600 steam engines operating in Cornwall. The last working tin mine in Cornwall closed in 1998.

Porthmeor Cove is the only location in SW England where a fully exposed granite cupola can be seen. Extensive veins and dykes intrude into the metamorphosed Devonian slates of the headland and the dark metabasic rock immediately surrounding the granite.

The Cornish countryside, particularly the bleak granite moorlands, is dotted with abandoned engine houses, remnants of the once thriving mining industry.



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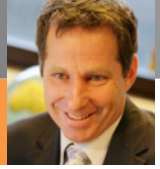


Jarand Rystad (M.Sc.)
Managing Partner Rystad Energy

RYSTAD ENERGY

Majors Catching Up in US Shale Gas

Shale gas is one way for the supermajors to avoid the production decline experienced over the last 5 years.

The supermajors (ExxonMobil, Shell, BP, Chevron, ConocoPhillips, Total and ENI) have not been able to deliver production growth for the last five years. On average, their production has declined by 1.5% per year since 2005, an annual reduction of over 300,000 boepd as a group.

Going forward, growth prospects for the supermajors seem somewhat better, with **deep water** production as the main contributor, offering nearly 200,000 boepd in yearly growth for the seven majors to 2020. **Oil sands** production, where the same companies have a 30% market share, has the potential to contribute another 100,000 boepd to them as a group in the same period. In total, the growth from these two segments should with some margin balance out the decline in the rest of the portfolio.

However, with the recent advances in **shale gas** in the United States, the majors have an opportunity to see additional development, making real growth more likely in the decade to come. Our bottom-up assessment of the potential of North American shale gas in total is a yearly growth of 400,000 boepd to 2020. If the supermajors get a 30% market share in this play as well, as they have for oil sands, this would add another 120,000 boepd in production per year, or more than the growth from oil sands in the same period, and at a lower cost per flowing barrel.

However, to do this the supermajors need to catch up. Two years ago, their market share in shale gas was close to zero, but it has recently climbed to above 20% through some material acquisition. **ExxonMobil's** USD 41 billion acquisition of XTO is the most prominent, immediately increasing the company's 2010 production by around 500,000 boepd, 33% of which is shale gas. The growth potential from this portfolio is a further 30,000 boepd per year to 2020, and ExxonMobil will then produce 800,000 boepd from the XTO portfolio, of which 60% will come from shale gas.

BP was, however, the first major to move into shale gas, with two deals in 2008 of in total USD 3.7 billion, buying into Cheaspeake's interests in the Woodford (100%) and Fayetteville (25%) shales. BP's 2010, production from these shales are expected to be slightly above 20,000 boepd in shale gas production, but it could grow towards 45,000 boepd by 2020.

Shell bought into 50% of Encana's portfolio in Haynesville in 2009, with a 2010 production potential at 50,000 boepd, and prospects to grow to 150,000 boepd by 2020. **Eni** got into 27.5% of Quicksilver's Barnett shale production in May 2009 in a modest USD 280 million deal. This will give ENI access to up to 10,000 boepd of gas production in 2010, however with a quite flat production profile going forward. And **Total** came in late in 2009 with its acquisition of 25% of Chesapeakes Barnett shale portfolio for USD 2.25 billion. This would immediately give Total 25,000 boepd in production, with the potential to grow towards 40,000 boepd in the decade to come.

ConocoPhillips has also taken shale positions in the Eagle Ford shale in southern Texas and Horn River shale in Canada. Only **Chevron** among the supermajors had been late to the party and has currently no shale gas position in US. However, they have been the early movers into shale gas positions in Canada and Poland.

In summary, the supermajors have aggressively been building up their share of the shale gas production over the last two years. In 2010 their share is expected to be 275-300,000 boepd, growing by 500,000 boepd to 775,000 boepd in 2020 if the expansion ambitions do not meet any major obstacles, particularly in the market or environment. Of this, ExxonMobil will have 60% of the supermajors' joint shale gas production. Thus, we would not be surprised to see further acquisitions into shale gas plays by other majors. USD 60 billion in acquisitions are needed to reach 30% market share. This might be the most accessible way to arrest portfolio decline.

Photo: Tuhffisch

Drilling for gas in the Marcellus Shale.

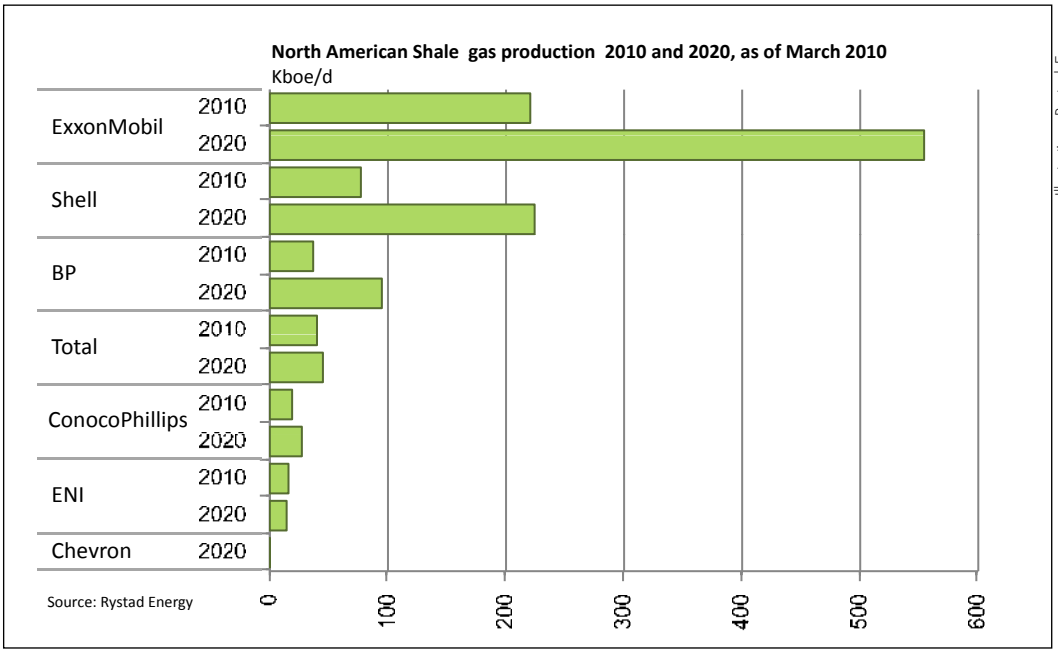


Illustration: Rystad Energy

GHANA:
Tweneboa-2 Confirms Major Field

Ghana's exciting story continues with the announcement in January 2010 that the Tweneboa-2 appraisal well in the Deepwater Tano block has identified a significant hydrocarbon column, in communication with Tweneboa-1, 6.5 km to the north-west. This confirms **Tweneboa** as major oil and gas-condensate field. The well found a gross reservoir interval of 153m, including 32m of net hydrocarbon pay, in stacked reservoir sandstones, part of an extensive turbidite fan system, confirming pre-drill expectations of a down-dip oil accumulation in an expanded sand section. The field lies at a depth of 3,850m in over 1,300m of water, 50km from the coast and close to the border with Cote D'Ivoire. Tullow operates the Deepwater Tano licence and is partnered by Kosmos Energy, Anadarko, Sabre Oil & Gas, and the Ghana National Petroleum Corporation.

To add to the good news for this cash-strapped country, a further promising discovery was made by Vanco, operator of the Cape Three Points Deep Block, which confirmed at the end of February that the **Dzata-1** well found a 94m hydrocarbon column with stacked oil and gas zones, including good quality light oil. Dzata-1 is situated in a water depth of 1,878 m, about 100km south of the port of Takoradi, and is the deepest water exploration well drilled to date in the Ghanaian Tano Basin. The discovery is in a Cenomanian/Albian faulted anticlinal trap, at a depth of over 3,600m, and appears to open a new prospective trend in the eastern part of the prolific Tano Basin. Vanco have a 28.34% stake, shared with Lukoil at 56.66% and GNPC, the state oil company, which holds a 15% carried interest.

Image: Lukoil

Offshore Ghana has been the site of several major discoveries in recent years, including the giant Jubilee Field, which has estimated upside reserves of nearly two billion barrels. The country is rapidly pushing towards its first offshore oil production, anticipated possibly later this year.

MOZAMBIQUE:
1st Deepwater discovery

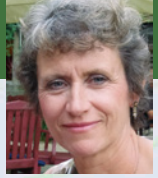
In mid February, Anadarko announced the first deepwater discovery off the East African country of Mozambique. Although still drilling at over 4,200m, it was announced that the **Windjammer** new field wildcat in the frontier Rovuma Basin had encountered 365 m of gross pay and 145m net of high quality, gas-bearing sands. Windjammer lies in 1,460m of water, about 50 km east of the coast.

Anadarko has acreage covering 10,500 km^2 of the Rovuma Basin in north-east Mozambique, both on and offshore. It has identified 50 leads and prospects with seven different play types in the basin, but this is the first well it has drilled, having previously undertaken an extensive 3D seismic campaign, the biggest such project in the company's history. Anadarko believe that the Rovuma Basin is one of the last under-explored Tertiary deltas with a proven petroleum system and that the area has geological similarities to the Gulf of Mexico. It will drill several more wells in the offshore basin this year. After completing Windjammer the drillship, the Belford Dolphin, will move to the Collier prospect, about 80 km to the south.

Image: Anadarko Petroleum Corp.

Anadarko, the operator, have a 43% interest in the well, while BPRL Ventures Mozambique has 11.7%, Cove Energy Mozambique Rovuma Offshore, 10%, Mitsui E&P Mozambique Area 1, 23.5% and Videocon Mozambique Rovuma 1, 11.75%.

Although hydrocarbons have been found in Mozambique from the beginning of the 20th century, modern exploration began after independence in 1975, with the acquisition of new data in 1981. The Rovuma Basin has long been considered very prospective, and the Mnazy Bay gas field was discovered in 1981 on the Tanzania side of the basin, about 60 km north-west of the Windjammer discovery. Onshore well Mocimboa , drilled in 1986, also had promising shows. The Pande and Temane gas fields were found in the 1960s and briefly came on stream in 2004, but only a very small amount is being produced at the moment.



Jane Whaley

FALKLANDS: Trouble Brewing?

Oil exploration in the South Atlantic has been hitting the headlines recently, but for all the wrong reasons. On 22nd February 2010 Desire Petroleum, a company set up in 1996 exclusively to explore for oil in the North Falklands Basin, announced that it had spudded an exploration well, **Liz 14 /19-A**, in relatively shallow water about 100 km north of the Falkland Islands. The well is being drilled to an estimated target depth of 3,500 m and drilling operations are expected to take approximately 30 days. Mean recoverable reserves for the prospect are 281 MMbo.

The North Falkland Basin is thought to contain a late Jurassic to early Cretaceous lacustrine source rock of world-class quality, which it has been estimated may have expelled as much as 100 Bbo into the surrounding sediments, with hydrocarbons trapped in Cretaceous fluvio-lacustrine and lacustrine sands. Only six wells have been drilled in the basin, all in 1998, five of which found hydrocarbons. All of these tested the same play concept, and a number of promising play concepts and targets remain to be tested in the basin.

It is this potential for major discoveries in waters which are already a point of dispute between Argentina and the UK which makes the drilling of this well so topical. Less than 30 years ago the two countries went to war over the sovereignty of the Falklands - or the Malvinas, to the Argentines – and over 900 people lost their lives in the process. Argentina has protested to the UK over the renewed drilling.

Photo: Allan White/Falkland Islands Tourist Board

Pebble Island, part of the West Falkland group of islands, is composed of Silurian to Devonian sandstone and mudstone.

RUSSIA: Remote Discovery

Russia's largest oil producer, Rosneft, recently announced the discovery of a large new oil field in East Siberia, one of the most remote areas in the world. The discovery, named Savostyanov, after a senior Russian geophysicist who died last year, is reported to have recoverable reserves of close to 1,2 Bb of oil. As with other fields in the area, the geology is structurally complicated and the field will present a number of production challenges before coming on stream.

Savostyanov is in the Mogdinsky and East Sugdinsky license areas in Katangsky District of Irkutsk Region, 4,000 km east of Moscow and over 1,000 km north of the regional capital, Irkutsk. East Siberia is reported to have an available resource potential of over 18 Bboe. Exploration in this area started in 1980, but due to its remoteness and lack of infrastructure, first commercial production only started in 2008. This was from Verkhnechonskoye oil and condensate field, 80km from Savostyanov, which with reported recoverable reserves of almost 1,5 Bboe. It is believed to be the largest field in Eastern Siberia. It has structurally complex pre-Cambrian reservoirs overlain by significant salt deposits, and only in recent years have the engineering techniques required to develop the field, such as high-angle and horizontal wells, been available.

The new discovery will also benefit from the construction of the East Siberia — Pacific Ocean (ESPO) Oil Pipeline to export crude oil from Russia to the Asian Pacific markets of Japan, China and Korea. The first stage of this line, which lies 150km from the field, was completed in 2009.

To counteract the remote location and lack of infrastructure, Russia has introduced fiscal incentives to encourage oil companies to explore in the area, including a zero export duty for 13 East Siberian fields.

Rosneft's new discovery lies 80 km from the BP/TNK gas condensate field, Verkhnechonskoye.

Understanding Our Energy Future

Dr. Scott Tinker travels the world extensively, speaking on his favorite subjects; global energy, the environment, the economy and education. Now, he is making a feature length documentary on global energy with the working title "The Bridge" and was kind enough to give us a sneak preview.

What motivated you to produce a documentary on global energy?

When being interviewed for a PBS documentary a couple of years ago, the producer-director encouraged me to reach a broader audience and emphasized the need for a balanced documentary on energy. I have been speaking about energy issues for so many years and this project is really a passion; my "book", if you will.

What is the central purpose of this film?

Educating the public about the realities of energy so that they can participate in the solution and make informed, wise energy decisions about the way they live, the products they buy, and the policies they vote for – which in turn will help enable a secure energy future for all.

What is our energy bridge to the future?

Economic prosperity allows for environmental investment. Both depend on secure energy, which means available, affordable, reliable and clean. Today, fossil fuels represent 87% of our energy consumption, and because coal, natural gas and even oil are still relatively abundant and offer high energy density, they will be around for a while. They key is to stabilize the supply of fossil fuels and use it more efficiently and cleanly as a stable foundation in the bridge to the alternative energy future. This film and companion website will educate the public about the transition from fossil fuels to alternatives: how long it will take; what it will look like; what choices will make this transition a smooth and gradual success; and which good intentions could have the opposite effect.

What will be our biggest challenge along in the way?

We use energy for transport, heating, and electricity. Transportation fuels are liquid and come mostly from conventional oil. That lack of diversity offers the biggest challenge. A great opportunity lies in the electricity sector, which is a much more diverse portfolio of fuels including coal, natural gas, nuclear, hydro, wind, solar, geothermal, waves, tides and more. Diversity is good; it is secure.

Scott W. Tinker was born into the oil and gas business in the Illinois Basin and had a 17-year industry career that included exploration, production and research. He joined the University of Texas at Austin in 2000 where he is the Director of the Bureau of Economic Geology, State Geologist of Texas, Allay Endowed Chair in the Jackson School, and Director of the Advanced Energy Consortium. Dr. Tinker is the past President of the Association of American State Geologists and the American Association of Petroleum Geologists.

Photo: Allyson Tinker

How do you hope to convey this to the public?

The film will travel to the premiere energy production sites worldwide and take us right inside the major facilities across all energy sectors. We have interviewed CEOs of leading energy companies, high ranking government officials, academic leaders and globally recognized energy experts. They will be linked together with scenes that introduce energy issues relevant to every viewer, made clear through unexpected visuals and stories.

Of the CEO's, presidents, ministers, scientists, and engineers from all over the world, what insights toward world energy have you learned from these interviews so far?

Three things stand out. One is **energy efficiency**. Everyone agrees we waste far too much of our resources. A second is that nations and states are going **to use the energy that they have**, be it nuclear, wind, coal, and beyond. For better or worse, this is still driven largely economics. Finally, the scale of **energy demand** is unfathomable. To meet the demand it will take tremendous infrastructure, materials and investment. The challenge is to be able to move energy from the source of the fuel to the end user.

Any big surprises?

Geothermal surprised me; I see interesting potential here. I think the viewer will be surprised by the magnitude of the natural gas resource, particularly unconventional and be amazed by the rapid growth in wind.

Just what does our energy future look like?

I am very optimistic. We have vast, diverse energy resources available to us. We are facing increasing demand, mostly because there are more people and developing nations using more energy. Energy of the future can be different from that of the past if we become broadly educated; people are capable of remarkable invention and have a great ability to adapt and change.

Thomas Smith

GOM: More Giant Oil Discoveries

Last year, the Keathley Canyon area yielded three of the world's top oil finds, bringing in high leasing bids and continued drilling activity.

What started in 2001 with the Baha #2 well discovering oil in a thick Paleogene submarine turbidite sand sequence continues across the Gulf of Mexico (see GEO ExPro Vol. 4, No. 1 pp 30-33). The **Lower Tertiary Wilcox** stratigraphic trend in the deepwater Gulf may exceed all expectations. Only a couple of years ago, this petroleum system's potential was pegged at around 15 Bbo (2.4 Bm^3) recoverable. The recent Keathley Canyon discoveries could exceed the size of previously discovered fields in the trend.

Three significant discoveries

The first major oil discovery of 2009 for the Gulf of Mexico occurred on Keathley Canyon Block 872 where the well drilled on the **Buckskin** prospect hit over 92 m of net pay in the Lower Tertiary. Repsol, with a 12.5% working interest, is the current operator. Chevron, with a 55% working interest, will become operator for future operations.

Chevron claims that the recent Buckskin discovery may be "very significant" and larger than the 500 MMb Jack discovery they made in 2004. The Jack discovery is in the same trend, 70 km east of Buckskin. Chevron plans to drill several appraisal wells over the next two years to further evaluate the extent of the discovery.

The second discovery was announced in September 2009 by BP. According to a BP spokesman, the **Tiber** prospect on Block 102 "will be bigger" than the 2006 Kaskida discovery which is estimated to hold 3 Bbo. The Tiber well is the deepest oil discovery well drilled to date at 10,685 m total depth.

With the Tiber discovery, BP is building on their 2006 Kaskida discovery, the first Lower Tertiary discovery in the Keathley Canyon. The Kaskida discovery encountered 244 m of hydrocarbon-bearing sand. They recently announced that their appraisal well at Kaskida tested similar reservoirs 8,000 m west of the discovery well which further confirms a wide reaching Lower Tertiary play. They are shooting wide azimuth seismic over the discovery and will drill another test in 2011.

BP is already the biggest producer in the Gulf of Mexico and these latest discoveries will help them boost output by 50% to 600,000 boe a day by 2020. The Keathley Canyon discoveries will also keep the GOM a leading oil producing area for the U.S. currently at 25% of the total domestic production (as of March, 2009, 1.3 MMbopd). Within the next 10 years, Minerals Management Service expects GOM production to be between 1.6 and 1.9 MMbopd.

Finally, Anadarko (a 25% owner in the Kaskida discovery) confirmed its **Lucius** prospect discovery with a sidetrack appraisal well located on Block 875. The sidetrack was drilled up dip and 975 m south of the discovery well and encountered almost 183 m of high-quality oil pay and additional gas-condensate pay, both in sub-salt Pliocene and Miocene sands. The discovery, announced in December, 2009, reportedly found over 61 m of net pay in a three-way closure against salt. Anadarko is still conducting additional appraisal activity but contends "this is a major discovery with substantial resource potential."

Renewed interest

The deep, pre-salt play off Brazil has been receiving most of the exploration attention over the past several years. These discoveries have served notice that the deepwater Gulf of Mexico is still a very attractive play. At the Western Gulf of Mexico Oil and Gas Lease Sale 210 in August, 2009, BP added additional emphasis to the region with a high bid of almost USD 30 million for Keathley Canyon, Block 96. The tract is located in 1,504 m of water and received three bids. Twenty-seven companies submitted bids for 162 tracts totalling over $115 million. Both BP and Chevron are continuing to expand their lease holdings in the area obtaining 34 and 25 tracts respectively in the sale. The next lease sale is slated for the Central Gulf of Mexico off Louisiana, Mississippi, and Alabama on March 17, 2010.

Halfdan Carstens

Unable to Replace Production

Offshore Norway, more oil and gas is now being produced than found. While many discoveries are being made, most of them are small.

The Norwegian Petroleum Directorate (NPD) recently released their updated resource account as of December 31st 2009.

While some 33 billion barrels (5.3 Bm^3) of oil equivalents have been produced over almost 40 years (it all started with Ekofisk in 1971), as much 73 Bboe (11.7 Bm^3) may still be left in the ground. Some of this, roughly 30 Bboe (4.8 Bm^3), is proven ("total remaining proven recoverable resources") and will be produced from existing fields and discoveries. The rest has to be found through exploration in mature and frontier regions.

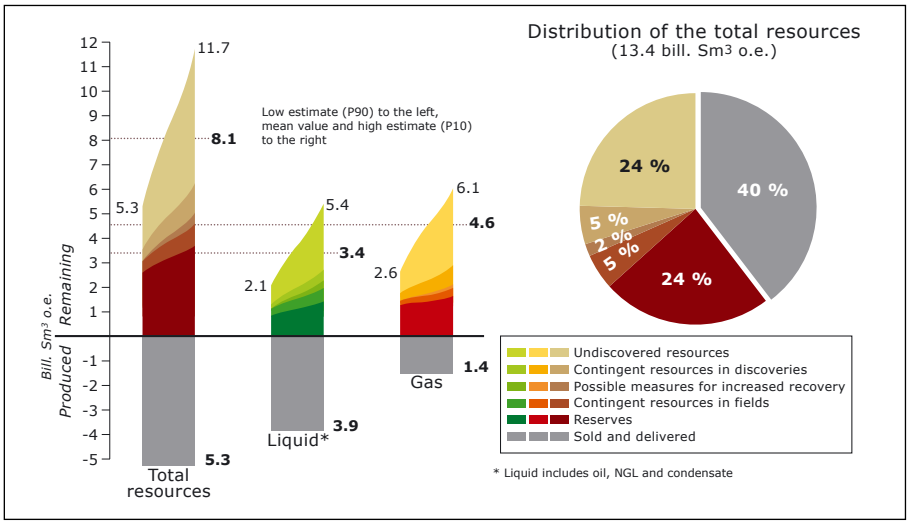
For that purpose, some 50+ oil companies are willing to invest. This includes some of the supermajors, like BP and Shell, several majors such as Statoil and Talisman, and a huge pack of smaller companies that are taking advantage of the Norwegian tax system which favours companies not yet having producing assets.

This year's report shows that 28 discoveries were made in 2009. The volumes in most of the new discoveries are, however, between 2 MMboe and 240 MMboe. The expected total volume of the new discoveries is estimated at some 900 MMboe, of which the larger part is gas. This figure compares with 1.5 Bboe sold and delivered. The deficit is a major concern for the government and is the reason for the very favourable fiscal terms for companies not having production.

So far, the success is not overwhelming. While the authorities' goal is to mature 5 Bbo (800 Bm^3) as reserves over the ten years prior to 2015, only 400 MMb (64 MMm^3) of oil were entered as reserves in 2009. Accumulated gross oil reserve growth since 2005 is only 37 per cent of the authorities' goal, which is under the linear trend to reach this target.

The resource estimates are based on reports submitted annually by the operating companies, NPD evaluations for fields and discoveries and NPD estimates of undiscovered resources. In the figure below separate estimates are, for geological reasons, given for the North Sea, the Norwegian Sea and the Barents Sea.

Many countries ought to look at NPD as a role model. In putting together these numbers, the government gets a superb overview of the resource situation. And it can only be done by having detailed geological knowledge combined with a proper understanding of reservoir characteristics.



This is the key figure in the resource assessment of the Norwegian continental shelf as presented by the Norwegian Petroleum Directorate. While more than 30 Bboe may still be left in the ground to be produced, the uncertainty should not be overlooked. The P90 and P10 estimates have a difference of 40 Bboe (6.4 Bm^3). The high estimate of 73 Bboe (11.7 Bm^3) is certainly an attractive proposition.

Proved reserves
"The estimated quantities of oil which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under current economic and operating conditions."
BP Statistical Review of World Energy

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