

Geotourism: The Cape Peninsula

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Middle East:

## Why So Much oil in the Middle East?

Qatar:

### 70 Years of Oil History

Seismic foldout:

### West of Shetland

Recent Advances in Technology:

### Marine Seismic Sources



# GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

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Photo: Halldan Carstens

### Why so Much Oil in the Middle East

In terms of oil reserves, the Middle East is second to none. This "oil miracle" of the world has been shaped by a set of favourable factors, some global and others local, inscribed in the geologic history of the region. Here we see the oil museum in Muscat, Oman.

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IMPROVED SUB-BASALT IMAGING

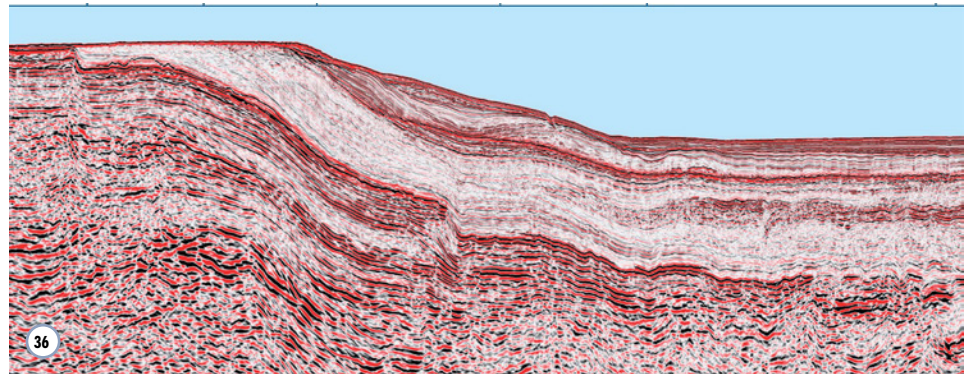


Illustration: TGS

### GEOSCIENCE EXPLAINED: Seismic Foldout

Newly reprocessed long offset seismic data from the Faroe Shetland Basin now provides a tool to enable interpreters to produce meaningful correlation in the sub-basalt section and raises some exciting geological questions for the West of Shetlands.





## IRAQ'S OVERWHELMING PROBLEMS

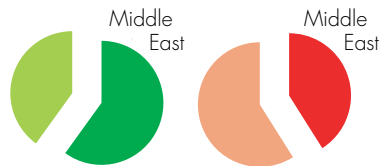
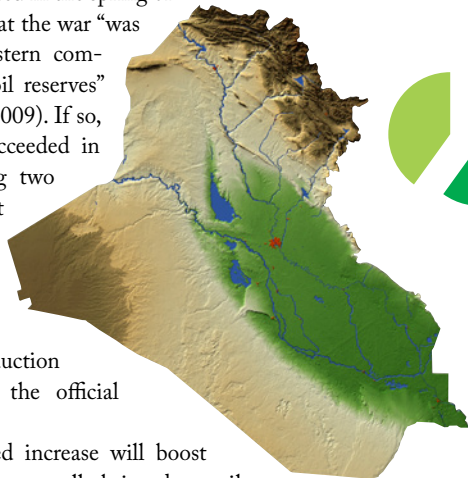
Roughly 60 percent of the world's oil reserves and 41 percent of the world's gas reserves belong to Middle Eastern countries. Some of that - actually, quite a bit - rests in the Iraqi subsurface. According to the BP Statistical Review of World Energy (2009), Iraq's estimated oil reserves are now 115Bb, only surpassed by Saudi Arabia and Iran on a world-wide basis. Others present figures that are even higher. The result is the same. By making these barrels available to the world, as is now being done by Baghdad officials, production may soar from 2.5MMbopd today to more than 10MMbopd in 2017. That, at least, is the ambitious government target.

When Iraq was invaded in the spring of 2003, many believed that the war "was merely a grab by Western companies for Iraq's vast oil reserves" (TIME, December 7, 2009). If so, they have certainly succeeded in their efforts. Following two licensing rounds last year, altogether ten contract areas have been awarded. And, if the companies succeed in their efforts, production may eventually reach the official target, or even more.

In fact, the projected increase will boost global output and may eventually bring down oil prices.

The bad news is that the war-torn country has lost most of its infrastructure. What was there when production peaked at 3.7MMbopd in 1979 is now largely gone. Their almost insurmountable problems also include brain drain, meaning that there will be a critical shortage of geologists, geophysicists, engineers and managers. Unlike their neighbours Saudi Arabia, Kuwait and Iran, experts need to be imported into the country in order to achieve the goals.

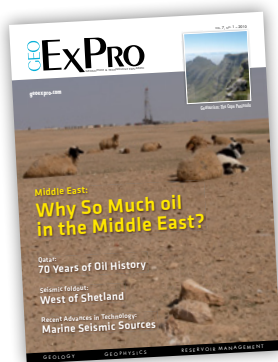
Thanks to Saddam Hussein's behaviour, the timely invasion of Iraq seven years ago and the new government's need for technical and financial investments, the huge deposits of oil and gas in Iraq are now again available to assist international oil companies to book new reserves.



Middle East oil and gas reserves compared to the rest of the world's reserves. Oil in green, gas in red.



Halfdan Carstens  
Editor in Chief



### THE MIDDLE EAST "OIL MIRACLE"

The Middle East is unique when it comes to petroleum reserves. As shown in the graph above, roughly 60% of the world's oil reserves are found beneath vast, inhospitable deserts with little else to offer. Sheep feeding on almost barren deserts is nevertheless a familiar sight in some areas. In this particular case, in Syria, they have found a sweet-spot close to a rig drilling for oil.

In this edition of GEO ExPro

we look into why the Middle East is flush with oil and gas. As explained in our Cover Story, it has to do with both regional and global factors, meaning that the long story begins in the late Precambrian. And, as every petroleum geologist knows, it has to do with source rocks, reservoir rocks and cap rocks. In addition, a favourable time relationship between migration and trap formation is needed.

**GeoPublishing Ltd**  
15 Palace Place Mansion  
Kensington Court  
London W8 5BB, U.K.  
+44 20 7937 2224

**Managing Director**  
Tore Karlsson

**Editor in Chief**  
Halfdan Carstens

**Contributing Editors**  
Thomas Smith  
Thomas.smith@geoexpro.com

Jane Whaley  
Jane.whaley@geoexpro.com

Rasoul Sorkhabi  
rsorkhabi@egi.utah.edu

Paul Wood  
sciwrite@btinternet.com

**Editorial enquiries**  
GeoPublishing  
7491 Trondheim, Norway  
+47 73 90 40 90 / +47 90 56 35 95  
halfdan.carstens@geoexpro.com  
www.geoexpro.com

**Marketing Manager**  
Kirsti Karlsson  
+44 79 0991 5513  
kirsti.karlsson@geoexpro.com

**Subscription**  
GeoPublishing Ltd  
+44 20 7937 2224  
15 Palace Place Mansion  
Kensington Court  
London W8 5BB, U.K.  
kirsti.karlsson@geoexpro.com

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# Life in the UKCS yet?

Drilling activity on the UKCS fell dramatically in 2009. Well numbers were on a par with 2005 - and only 7% were exploration wells - but the mood at the seventh Prospect Fair, PROSPEX, in December 2009 was distinctly one of cautious optimism.

PROSPEX, sponsored jointly by the PESGB and DECC, was held in the Business Design Centre in London, and attracted more than 700 delegates, 73 exhibitors and 24 talks. It showed that, despite the economic climate, there is still plenty of interest in North West Europe and the UKCS in particular. The year actually saw an increase in exploration activity in the challenging areas West of Shetland, and there was much talk about

the 26th UKCS Seaward Licence Round, expected early in 2010.

As Simon Toole from DECC said in his opening address, there is still an estimated 20 Bbo in the UKCS waiting to be found. Although some of the smaller players appeared to be suffering as a result of the economic downturn, he pointed out that more than 400 MMboe per year were discovered between 2007 and 2009, with the Promote Initiative alone leading to 18 published successes. He said that the 26th Licence Round may introduce a new nine year West of Shetland frontier licence, as well as fresh acreage in the underexplored Western Approaches and English Channel.

Chris Bulley from Hannon

Westward LLP gave an interesting overview of the opportunities available in the UKCS, emphasising the fact that more than 500 prospects with an average size of 44 MMboe have already been identified but not developed in the area. Extrapolating from previous rounds, he anticipates that this new round should attract about 20 well commitments and see the awarding of about 250 blocks.

Delegates at the conference commented on the generally buoyant and optimistic mood. One exhibitor even complained that the first day was too crowded! Signs that the industry has not yet finished with the UKCS yet, perhaps?

## ABBREVIATIONS

### Numbers

(U.S. and scientific community)

- M: thousand =  $1 \times 10^3$
- MM: million =  $1 \times 10^6$
- B: billion =  $1 \times 10^9$
- T: trillion =  $1 \times 10^{12}$

### 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<sup>3</sup> gas
- MMscmg: million m<sup>3</sup> gas
- Tcfg: trillion cubic feet of gas
- Ma: Million years ago

### LNG

Liquefied 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](http://www.glossary.oilfield.slb.com)



PROSPEX, held in London in December 2009, has developed into a major event for those active in the North Sea.



# Geologging on the Forties Field

Aberdeen based HRH Geological Services has spent many years helping companies find the right technology to unlock the potential of their fields by turning geological data into more useful digital formats which can be integrated into the workflow. Its innovative Geologging service is the latest technique to assist in this.

“Geologging improves workflow and connectivity between the rig site and the office,” explains HRH’s Managing Director David Harrison. “The onboard Geologgers, all fully qualified and trained geologists, use our Gravitas software to turn the geology into logs, charts and reports, which link into the platform’s incumbent drilling monitoring package and connect the asset to the digital oilfield. The key value of the software lies in the number of ways that it collects data from different rig vendors. This is then produced in various formats, each one allowing different key rig personnel to use it to improve their assumptions while drilling. The software provides all sorts of different reporting methods throughout each stage of the well life cycle, from the planning operational stages to the continuing and final analyses.”

“The Geologging service also means that there is no longer a need to process cuttings offshore, as the cuttings samples are dried, stored and analysed onshore at our premises in Aberdeen. This halves the number of mudloggers needed on a rig from four to two, significantly reducing costs and space.”

This change of conventional workflow caught the interest of oil company Apache North Sea, specialist in field rejuvenation, when Apache was analysing ways to improve production at its new acquisition, the legendary Forties field. Found in 1970, Forties is still the largest ever UKCS discovery, with an esti-



HRH Geologgers are trained to a significantly higher level than conventional mudlogging personnel, frequently being deployed as wellsite geologists in their own right.

ated five billion barrels of oil in place, but when Apache took it over in 2003, production was down to 35,000bpd, compared to its peak of 500,000bpd in the late Seventies.

“Apache knew that reducing the number of people on board was key to success,” David explains. “Until 2006, the Forties field had operated with conventional mudlogging teams of four to six people. HRH replaced this with our Geologging service, which requires only two people working back to back on 12 hour shifts, freeing up platform space. Since

the detailed core investigations are undertaken onshore, the geologgers have more time for geological interpretation, with the Gravitas software ensuring that information flows rapidly to the decision makers in almost real-time.”

“Initially, Apache had reservations as to whether by using such a reduced team there would be a consequent reduction in quality of interpretation and analysis, but we are pleased to say that this fear has been proved completely unfounded. Oil companies would not compromise the quality of geological

data for a bit of extra room, but the data our systems are supplying is as good as, if not better than, the traditional methods.”

“We are happy to know that our Geologging service has been a vital contribution to the renewed success of the Forties field,” David Harrison concludes. “In the three years since we started working there, 70 wells have been drilled, and production has doubled to approximately 70,000 bpd. Geologging has freed up rig space and reduced head count, cut costs and delivered a better service. A win-win situation!”



# World Leaders in Thermal History

What is Apatite Fission Track Analysis – and how can it help the oil industry?

“We use a technique called Apatite Fission Track Analysis (AFTA®), in tandem with other methods, to determine the thermal history of rocks and, in particular, to identify when a rock section cooled from its maximum post-depositional temperature,” explains Paul Green, Technical Director of Geotrack International, the only company in the world to specialise in this technique.

## Need for knowledge

Most oil and gas is found in basins with relatively simple histories, where source rocks have undergone almost continual burial to reach the temperatures required to generate hydrocarbons.

But in some regions, rocks have been exhumed from their maximum burial depths to shallower levels. These areas are conventionally viewed as less attractive for exploration, as seal may have breached, and the timing of hydrocarbon generation is also more difficult to reconstruct because some geological section is missing. However, many exhumed basins, such as the Southern North Sea Basin of

the UK and the Recôncavo Basin of Brazil, have been found to contain significant quantities of hydrocarbons. In these areas, discovering hydrocarbons requires detailed knowledge of the magnitude and timing of exhumation and its associated effects.

This is where Australian company Geotrack International comes in.

## The method

“We analyse ‘fission tracks’ within detrital apatite (a phosphate mineral) grains extracted from sandstones and other clastic rocks. Each track is created by radiation damage resulting from spontaneous fission of a single atom of uranium ( $^{238}\text{U}$ ), and the number of tracks in an apatite grain depends on uranium content and time. Therefore, by measuring the amount of  $^{238}\text{U}$  and number of tracks, we can calculate the time over which the tracks have accumulated. However, the length of tracks is reduced by burial, as temperature increases the speed at which the radiation damage is repaired, which is also affected by the chlorine content.”

“Apatite Fission Track Analysis is therefore based on measuring fission track age and length and the chlorine content of each grain, and modelling these parameters to determine the most likely thermal history scenarios.”

Multiple cooling episodes can often be resolved from data in individual samples. “This sort of information cannot be obtained from any other source, and we can therefore provide unique constraints on when hydrocarbon generation effectively ‘switched off’,” Paul continues.

“By combining this data with structural information, it is possible to identify areas where hydrocarbons were generated after traps were formed, which can significantly reduce exploration risk.”

## Burial histories revealed

This technique has revealed hidden complex burial histories, showing that areas which had previously been thought to have experienced either prolonged stability or more or less continuous subsidence have in fact undergone major episodes of exhumation. “AFTA often exposes accepted geological histories to question,” Paul adds. “For example, we have discovered a remarkable coincidence in the timing of major phases of exhumation from Alaska and Arctic Canada, through Greenland into Norway and through the North Atlantic to the UK. We found that these phases of exhumation coincide with times of major regional rearrangements of the tectonic plates throughout the Arctic and North Atlantic regions, which cannot be explained by current theories.”

“Similarly, it is often assumed that the 2,000m high plateaus seen in places like Southern



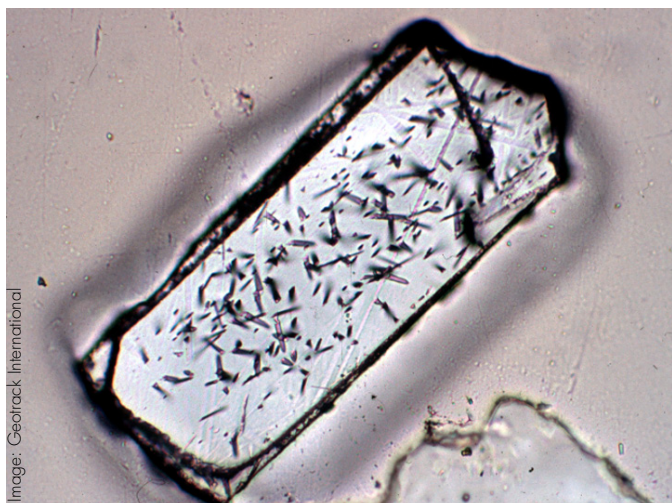
Photo: Jane Whaley

Dr Paul Green, together with Dr. Ian Duddy, founded Geotrack International in 1986 to enable AFTA to become a routine tool in the hydrocarbon industry.

Africa have been high and stable since the rifting of the continent that led to formation of the margins. But our AFTA data shows this is not the case, and the landscapes are much younger. We have studied this phenomenon in Namibia, SE Australia, Greenland and Brazil.”

Geotrack International formed out of a research group at the University of Melbourne in the 1980's, in order to provide thermal history reconstruction to the oil exploration industry. Specialising in AFTA and supporting techniques like vitrinite reflectance, it also provides services such as petrographic analysis and microanalytical methods. Over 1,000 studies have been successfully conducted throughout the world, covering a range of geological settings, including thrust belts, foreland basins, inverted basins, intra-cratonic settings and rifted margins.

® AFTA is the registered trademark of Geotrack International



This apatite crystal shows etched tracks caused by radiation damage resulting from spontaneous fission of a single atom of uranium.



# The Art of Geology

“You need a knowledge of psychology in this job, to understand how and why people do deals,” explains Mike Lakin, founder and Managing Director of Envoi. “You must be good at communicating with people and getting them to quickly understand what an opportunity is offering, and to believe in you and your expertise.”

After a number of years working in the oil industry as a geologist with Carless and then Kelt, Mike joined Petresearch, where he was first exposed to international project marketing. He soon saw a specific need for a company specialising in marketing international farmout deals and putting potential buyers and sellers together, which at the time was generally done by the companies themselves.

Mike established Envoi in 1999 “to act as a match-maker, really!” he laughs. “Companies come to me either seeking partners to spread exploration risk, or wishing to divest themselves of non-core area assets and looking for prospective purchasers. “The skill we offer is to be able to rapidly see the potential in an asset, to summarise it succinctly and visually in Envoi’s recognised format, including its unique style of montage, and then target and contact the right people for our clients.”

“Envoi’s project synopses always follow the same format, so our clients know what to expect, and where to find the information they need quickly,” Mike continues. “The idea is to make it easy for them to evaluate an asset and match it against their corporate search criteria. The initial page and the back page montage are designed for managers, with

sufficient information for them to assess an opportunity quickly. If they are interested, they pass it on to their exploration department who evaluate the more detailed analysis on the inside pages, where we discuss exploration history, regional geology, petroleum systems, prospects, scoping economics, fiscal regime and deal terms.”

“I can understand why geology was once classed as an Arts degree,” Mike adds. “It is an art – you are drawing pretty pictures of what you think is happening

in the sub-surface. I try to visualise it and then get across the 3D concept of a regional petroleum system, including hydrocarbon potential, generation, trap, all on the one page montage in order to market an asset.”

With a portfolio of active projects in many parts of the world, currently including the North Sea, Turkey, Paraguay, and the North West Shelf of Australia, Mike feels that Envoi can offer an excellent and cost-effective service through its large global network of senior contacts,

covering over 760 companies worldwide. Envoi is not a large organisation, consisting of Mike, a part-time marketing person and a number of very experienced associates who work on a project by project basis. “I work on the basis of familiarity. By coming to exhibitions and conferences and by putting my picture on the literature, people are used to seeing me and associate me with the product. I can therefore offer a truly personal service.”

“Our growing reputation and expertise is illustrated by the fact that recently we have been contacted by companies approaching this from the other side, as it were,” Mike says. “They are asking us how they can find new deals, as they know we can assess deals that might suit and can access our extensive contact network quickly.”

Envoi stands for Energy Venture Opportunities International, because, as Mike says, he acts as the envoy for the people he represents. “I know I can ‘hit’ the right person, in the right way and quickly. It has taken me 17 years to build up this component knowledge and it is the backbone of the company’s expertise.”

*To see an example of a montage, please go to [geoexpro.com/issues/2010-01/](http://geoexpro.com/issues/2010-01/)*



Photo: Cillianne Tedder

Mike Lakin is a geologist with over 20 years experience in the industry. He is MD of Envoi, which specialises in marketing international farmout deals.



Previous issues: [www.geoexpro.com/issues](http://www.geoexpro.com/issues)



Thina Margrethe Saltvedt (Ph.D.)  
Senior macro/oil analyst at Nordea Markets, Oslo, Norway



## Capacity Constraints on the Agenda in the Oil Market

Oil prices are expected to rise gradually in 2010 and accelerate at the end of 2011 as the world economy gradually strengthens and the oil fundamental balance tightens.

The demand for oil is sensitive to global economic cycles. The global economy is now gradually recovering and industrial production is picking up pace. Robust growth in oil-intensive emerging economies is expected to be a key driver of oil demand. Urbanisation and increasing living standards, especially in countries with large populations such as China and India, are expected to accelerate the demand for energy and continue to boost car sales.

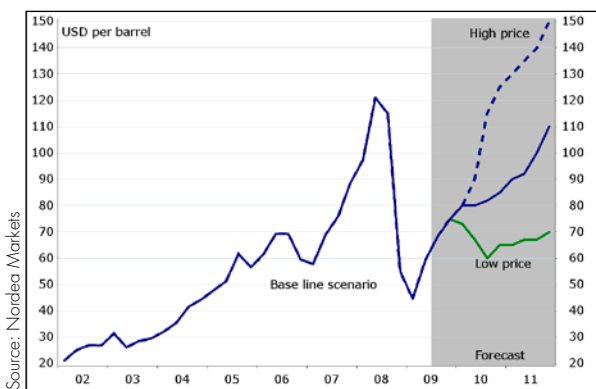
Transport fuel is expected to increase its share of total oil consumption. Although the Copenhagen Accord was weaker than expected, we still anticipate binding deals on climate gas emissions to be signed within the forecast period. In the long term, binding requirements for emission cuts are expected to gradually change the framework for the total energy spectrum.

As oil demand now gradually recovers, the market will soon shift its focus back to a world that is running out of accessible oil. Production is now falling at 6.4% per year from old mature oil fields. Huge investments are thus necessary just to offset losses from steep production falls in areas such as the North Sea, Alaska, the Mexican Cantarell field and West Siberia in Russia.

Increasing investments are also needed to expand capacity to meet the world's growing need for energy. High costs, the financial crisis and global recession have put adequate investments in new capacity at risk.

Timely investments in the Middle East are essential as a growing share of the future oil production is expected to take place in this region. The region has around 60% of the world's proven oil reserves. Last year's licensing rounds for Iraqi oil fields have increased the capacity potential in the medium term. But the obstacles to invest are many such as sovereignty over oil reserves, increasing national protectionism and political unrest.

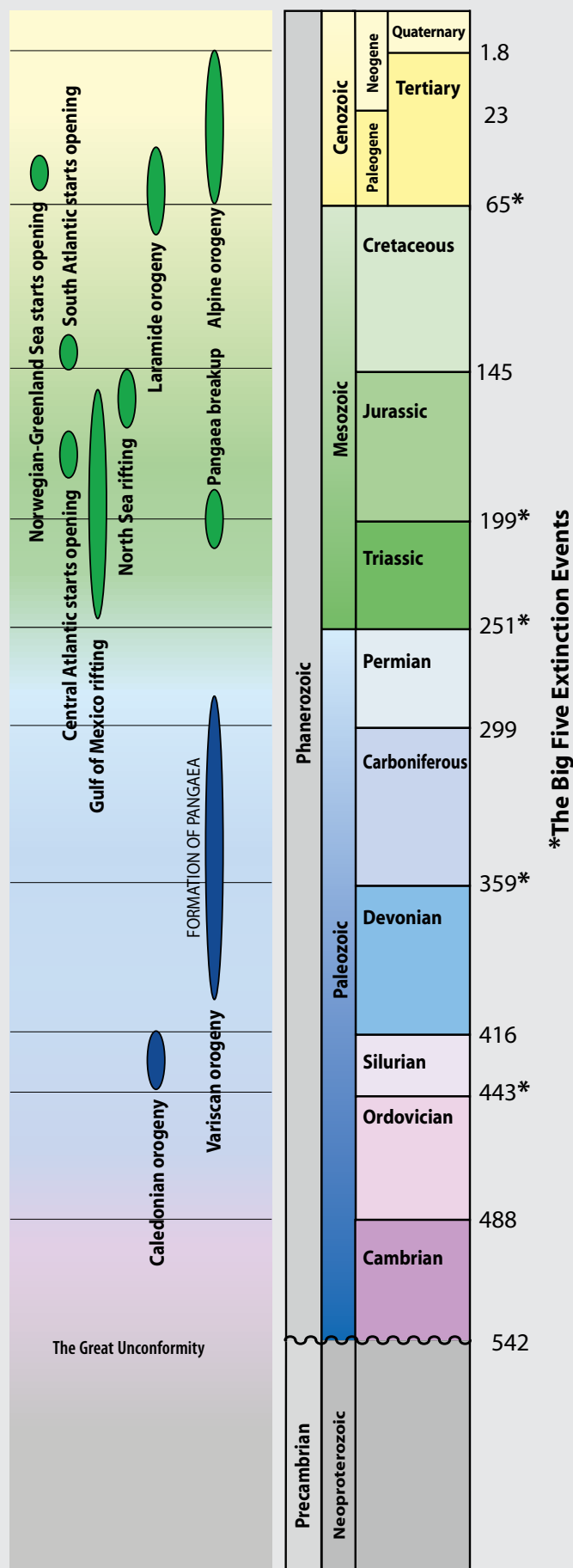
Aggravating the risk of inadequate investments to meet future supply requirements is the unfavourable investment climate in other oil regions such as Nigeria, Venezuela and Russia. Russian oil production increased, surprisingly, in 2009 after peaking for the second time in 2007. However, the upside potential is limited without further tax cuts. Limited access to investing in areas with larger reserves at lower costs forces oil companies to invest in higher cost areas, which also contribute to higher prices.



Oil price scenarios - baseline, high and low price for the period 2002-2011.

### MAJOR EVENTS

### GEOLOGIC TIME SCALE







## More data offshore U.S. East Coast

Spectrum has accelerated its preparations to collect seismic data in the U.S. waters of the Atlantic Ocean in response to the recent announcement by the Department of the Interior to begin the environmental analysis of geological and geophysical activities off the east coast.

Spectrum was the first company to actively collect multi-client seismic data since the leasing and drilling moratorium went into effect in the mid-1980s. It is currently re-processing and studying existing seismic data from the U.S. East Coast. Through these activities, Spectrum is gaining knowledge to identify the most prospective areas for oil and gas exploration and the technologies to best image and understand the subsurface in this frontier region.

In 2006, the company submitted permit applications to the Minerals Management Service (MMS) to conduct seismic, gravity and magnetic surveys off the US East Coast. The new survey would extend Spectrum's U.S. multi-client library, which has been growing since the company began acquisition offshore Florida in 2003. This modern seismic now covers much of the "un-leased" area of Eastern Gulf of Mexico.

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 re-processed data.

## More data in Indonesia

TGS has launched a 2D seismic acquisition program offshore West Papua in East Indonesia. The program adds 2,240 km of new 2D data designed to help evaluate the petroleum potential south of the Salawati Basin. The Salawati Basin is recognised as one of the largest oil basins in Eastern Indonesia with total cumulative oil production of more than 300 million barrels.

Data acquisition is now underway and is expected to conclude by the second quarter of 2010.

The program has industry pre-funding and supports the Indonesia government's overall objective to attract exploration and raise declining production levels.

Upon the completion of the program, the TGS Indonesia library will exceed 100,000 kilometers of 2D seismic; 400,000 kilometers of multi-beam bathymetric data and 1,200 core samples covering over 1 million square kilometers of Indonesia's deep-water basins.



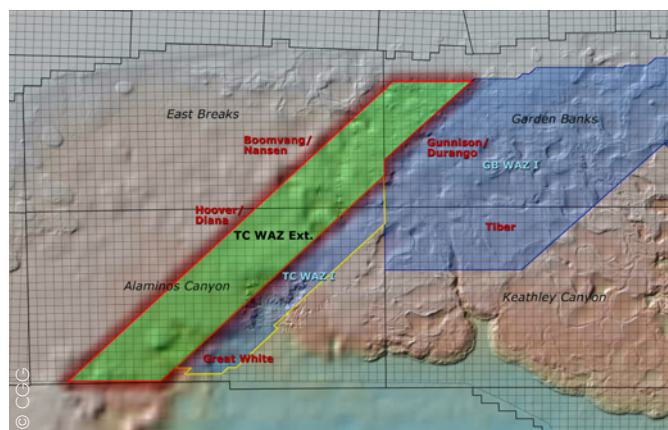
## More data in the Gulf

CGGVeritas has begun acquiring the Three Corners Extension 3D Wide-Azimuth multi-client survey in the western Gulf of Mexico. The 415-OCS block wide-azimuth survey is an extension of the recently completed Three Corners Wide-Azimuth survey. The combined survey will cover over 600 blocks in East Breaks and Alaminos Canyon.

Acquisition is scheduled to be completed during the second quarter of 2010, enabling the delivery of a Fast Trax 3D PSDM RTM volume to the industry prior to MMS OCS Western lease sale 215 sched-

uled for August 2010. Final products from the survey are expected to be delivered in the second quarter of 2011.

According to Colin Murdoch, Executive Vice President, North America region, CGGVeritas, the customers have been impressed with the preliminary image results from the Three Corners survey. "Until now the Alaminos Canyon protraction area has been one of the most difficult areas to image in the Gulf of Mexico, yet our wide-azimuth acquisition and advanced imaging technologies have shown excellent results," Murdoch says.



## More data in Liberia

TGS has commenced acquisition of the next phase of 3D projects offshore Liberia. This newest project covers Liberia blocks 8 and 9 and totals 5,000 km<sup>2</sup>. The MV Polarcus Nadia will acquire the project and TGS will apply advanced pre-stack time and pre-stack depth imaging techniques to create the final subsurface image.

The TGS African data library includes a series of 2D and 3D seismic projects covering

the Africa Transform Margin. Recent petroleum discoveries in the Gulf of Guinea and offshore Sierra Leone have attracted significant exploration interest in this region. Upon completion of this latest project, TGS will have more than 30,000 kms of 2D and 18,000 km<sup>2</sup> 3D seismic covering this emerging exploration play in West Africa.

The acquisition of the survey will complete in Q2 2010 and is heavily pre-funded.

## Arctic Energy, Tromsø, Norway, May 31-June 4, 2010

The Arctic Energy is a forum for presenting recent developments in the geological research, exploration and exploitation of petroleum resources in the Arctic and for discussing future challenges. The conference aims at participants from the petroleum industries, academia, governmental institutions, consultants and service companies.



GEOLOGICAL SOCIETY OF NORWAY





### 3D in Saudi waters

ARGAS, a Saudi Arabian joint venture owned 49% by CGGVeritas and 51% by TAQA, has been awarded two major Ocean Bottom Cable (OBC) 3D data acquisition contracts by Saudi Aramco. The two contracts have a combined value of around \$375 million.

The first project is scheduled to start in June 2010 and operate for a period of 18 months while the second is scheduled to run from October 2010 for a period of 24 months; each contract respectively has an 18- and 24-month optional extension period.

The projects will cover an

initial 6,000 sq km over the next three years and require operational expertise working in complex environments, such as producing oil fields and busy shipping lanes within the Saudi waters of the Gulf with depths ranging from 20 to 60 meters.

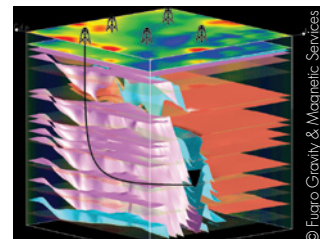
ARGAS will mobilize two fully independent OBC crews equipped with the latest Sercel SeaRay 4C equipment and recording systems. These fully offshore operations will be managed through a fleet of vessels equipped with CGGVeritas deployment and positioning systems geared to operate in such environments.

### More accurate MWD

Fugro Gravity & Magnetic Services has introduced its MagCUBE™ technology, which enhances geomagnetic referencing by increasing the accuracy of measurement while drilling (MWD) in directional drilling applications.

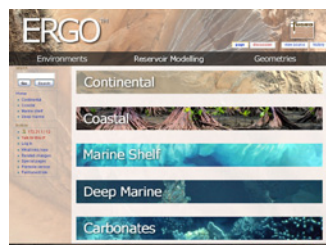
MagCUBE utilizes the magnetic intensity measured at the surface from an airborne, marine or land magnetic survey. The surface magnetic data is geomagnetically referenced to the magnetic survey data measured in the wellbore to provide a finer subsurface anomaly vector, which provides a more accurate well path to avoid costly side tracks.

Geomagnetic referencing is frequently used by leading drilling companies. When enhanced by MagCUBE, it can lead to significant savings in overall project costs by providing accurate, real-time data on well position while corrections to trajectory are still possible, minimizing the need to side track; and minimizing the costs of extra rig time required to run a post-drilled gyroscopic survey.



### ERGO: It's logical

Fugro Robertson's 40 years of experience in sedimentology and reservoir characterisation has led to the development of a new tool designed to help decision-making in static reservoir modelling. It's



called ERGO.

To optimise modern reservoir modelling techniques, it is important to understand the geological controls on reservoir formation. However, modellers often underestimate the value of geological analogues, and good quantitative and descriptive data for reservoir geometries is not always easily available. ERGO bridges that gap, offering a great source of input data (quantitative reservoir geometries) combined with an expert knowledgebase of depositional processes and reservoir modelling methods.

Web-delivered via a Wiki™-based front-end, it provides easy access to the geometry database and the tools to investigate it

Key functionality includes the ability to easily calculate inputs for modelling software by using simple statistical and charting tools that enable the user to understand and apply relationships derived from analogue datasets.

ERGO data sources include public domain literature, remote sensing datasets and targeted fieldwork. 11,000+ detailed reservoir geometries have been col-

lected, describing sandbody and geomorphic reservoir elements in Fluvial/Alluvial and Deep Water environments, with innovative attribution derived from in-house datasets such as Tellus™, Plate Wizard™ and Merlin™.

Already a well-proven tool, ERGO is being expanded to cover the full range of depositional environments. The eventual goal is to develop ERGO so that it is capable of generating quantitative data that describe geological analogues for all modelling and exploration scenarios.

### Improving subsalt imaging

CGGVeritas says that the successful deployment of its Nautilus acoustic positioning and streamer steering system on the Alizé, one of its high-end vessels, has dramatically increased production levels on the first project of

the mega 3D seismic program currently being acquired for PEMEX in the Gulf of Mexico.

Despite severe winter weather conditions the Alizé, on its first project of the program, has achieved a one-day production record of 117 km<sup>2</sup> and has significantly exceeded production targets. This has been supported by the deployment of 12 Sercel Nautilus-Sentinel® steered solid

streamers and the fact that, with a 12 by 8-km by 100-m configuration, the Alizé is towing one of the largest areal receiver arrays in the industry.

Nautilus has dramatically reduced the infill requirements through consistent streamer separations and depth control across the entire spread.

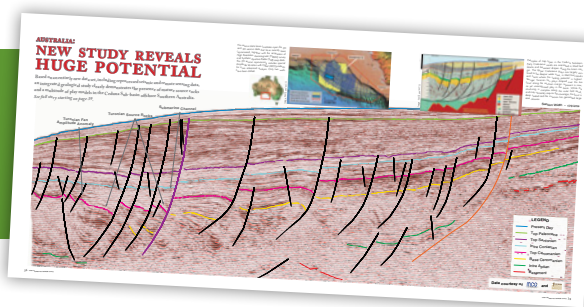
The first project in the PEMEX survey program targeting subsalt

areas, known as Han Sur-Oeste de Tamil, covers a surface area of 12,300 km<sup>2</sup> in the Mexican deep waters of the Gulf of Mexico.

Robert Brunck, Chairman and CEO, CGGVeritas, claims that the Alizé's deployment of a combination of advanced Sercel Sentinel solid streamers and Nautilus is setting a new benchmark for safer operations, quieter data and better crew efficiency.



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# Why So Much Oil in th





In terms of oil reserves, the Middle East is second to none. This “oil miracle” of the world has been shaped by a set of favorable factors, some global and others local, inscribed in the geologic history of the region.

RASOUL SORKHABI, PH.D.

The term “Middle East” is not without problems. First, it has colonial connotations, as the term first appeared in the mid-nineteenth century as part of the Europe-centered division of the East into the Near, Middle and Far East. Second, there is no consensus on the geographic extent of the Middle East. Some define it as the region between India and Egypt, in which case it has been aptly designated by the United Nations as Western Asia. Other definitions also add North Africa or central Asia.

For the purpose of this article, the term “Middle East” focuses on the oil-rich countries in southwest Asia including Iran, Iraq, Syria, Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates (UAE), Oman, and Yemen. These ten countries together have an area of 5.1 million square kilometers or about 3.4% of Earth’s land surface, but they possess 60% of world’s known oil reserves and 41% of natural gas reserves.

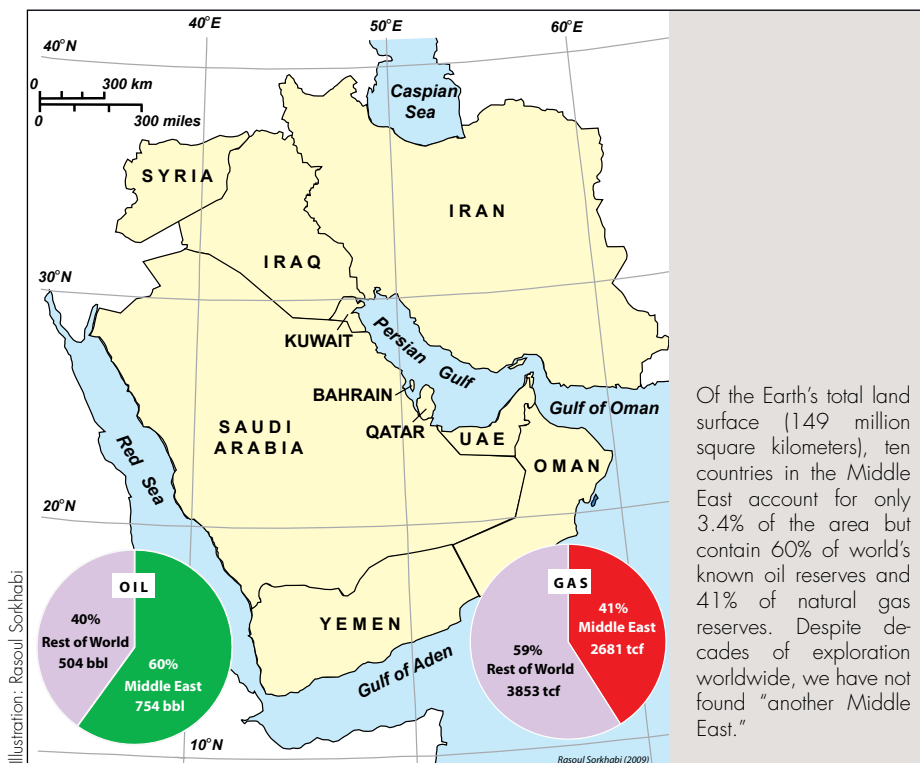
From time to time, regions such as the Caspian or West Africa have been fantasized as “another Middle East” but none has materialized, which begs this important question: Why is there so much oil in the Middle East? This article synthesizes our knowledge about this question and briefly describes the geological factors for the abundance of oil in the Middle East.

#### **GONDWANA MARGIN AND TETHYS**

The Proterozoic–Cambrian transition at 542 Ma opened a new chapter in the geologic history of the Middle East with far-reaching implications for petroleum resources of this region. After a long history of ocean subduction and micro-continental collision along the northeastern margin of Africa, from about 700 Ma to 600 Ma, the basement rock of the Middle East (the Nubian-Arabian shield) was consolidated. This event, together with some other collisions assembled the supercontinent of Gondwana in the southern hemisphere, comprised by Africa, India, Australia, Antarctica, and South America. The Middle East was then positioned on the north-facing passive margin of Gondwana. Throughout Paleozoic and Mesozoic times, the Middle East was a locus of sedimentation over a long and wide shelf affected, from time to time, by sea level changes. As Gondwana consolidated at the turn of the Cambrian, microorganisms and marine species also rapidly evolved and diversified, thus enriching marine sediments with organic carbon necessary for oil generation.

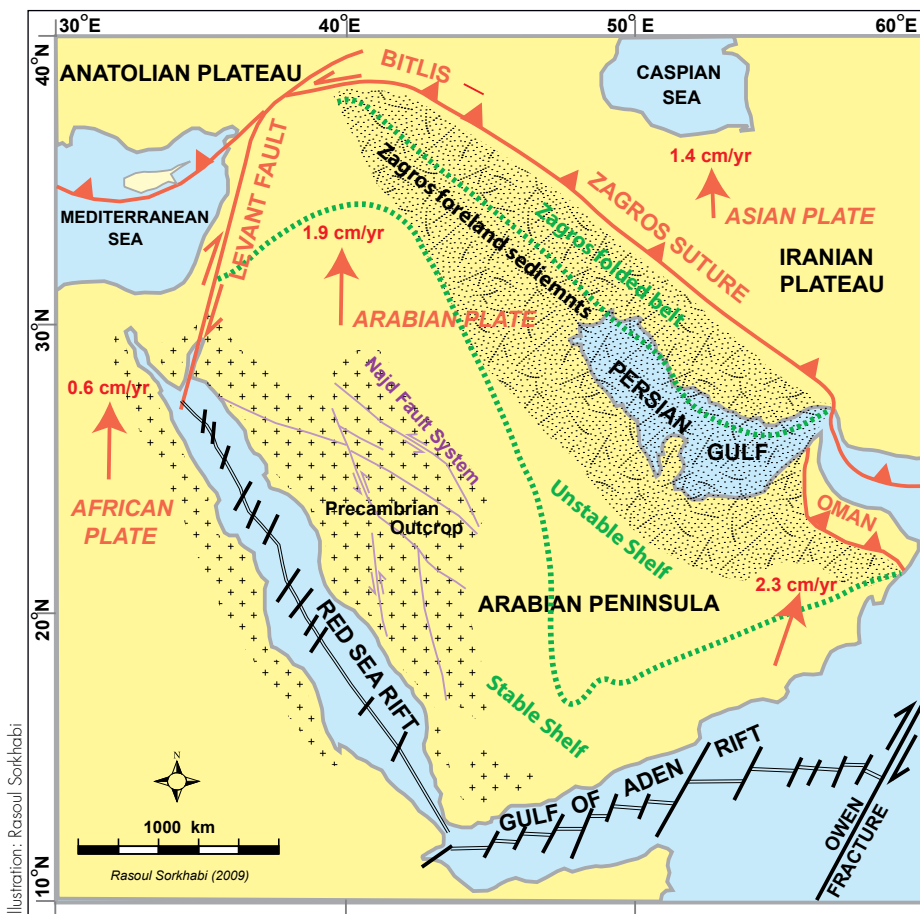
The Tethys Ocean, which washed the northern margin of Gondwana, was not a single ocean, but developed in at least three oceanic basins: Proto-Tethys (Infracambrian–Carboniferous), Paleo-Tethys (Ordovician–Early Jurassic), and Neo-Tethys (Permian–Paleocene). This ▶

# e Middle East?



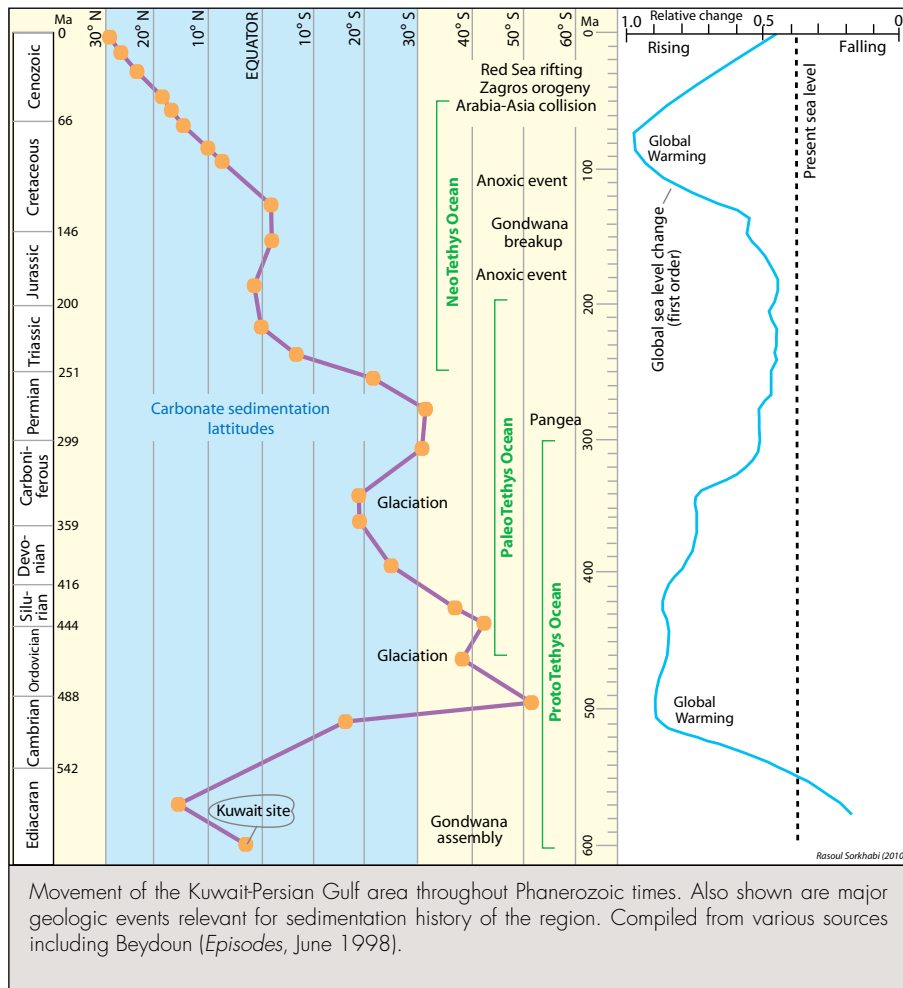
sequential development of Tethys took place as continental fragments successively broke away from the Gondwana margin and drifted northward to join the paleo-Asian continent. The opening of each Tethys ocean was accompanied by extensional tectonics which, in turn, created continental rifts during the Infracambrian (Ediacaran-Cambrian transition period), the Ordovician, and the Permian in the Middle East. These rift basins added favorable sites for petroleum generation in the region.

At the end of the Paleozoic, Gondwana merged with Laurasia to form the largest supercontinent ever, Pangea. It was also during this time that Proto-Tethys closed and Neo-Tethys began opening. In the Late Cretaceous, Neo-Tethys began to subduct beneath the southern margin of paleo-Asia (along the Anatolia-Iran-Tibet margin) and shrank in size until the ocean completely disappeared in the Eocene and gave way to a foreland basin in front of the rising Bitlis-Zagros-Himalayan mountains.



Tectonic framework of the Middle East divided into (1) Zagros fold-and-thrust belt, (2) Unstable Arabian shelf, and (3) Stable Arabian shelf. The Arabian continental plate, which collided with the Asian plate along the Bitlis-Zagros suture during the Eocene is still converging with Asia at rates of 1.9 to 2.3 cm per year based on GPS measurements. (Global measurements of relative plate motions of Arabia with respect to Eurasia show higher velocities of 2.4-3.5 cm per year). This continental collision gave rise to the Zagros Orogen and its Cenozoic foreland basin which was superimposed on the Paleozoic-Mesozoic Tethys shelf. The cumulative thickness of sediments in the region thus reaches up to 12 km. The Zagros deformation and salt domes have folded the sedimentary beds into large, gentle anticlines ("whaleback" structural traps). The western and southern boundaries of the Arabian plate are bounded by the Red Sea and Gulf of Aden rifts. These Neogene continental rifts have separated Arabia from Africa, and are further pushing Arabia against Asia. The rift-shoulder uplifts have outcropped the Precambrian rocks (part of the Nubian-Arabian shield) along the Red Sea and are capped at places by rift volcanic.





The Phanerozoic sedimentary succession in the Middle East reaches up to of 12,000 meters and may be divided into three mega-sequences: (1) The Infracambrian-Carboniferous sequence, consisting largely of siliciclastic rocks and showing long gaps in sedimentation (during the middle-Paleozoic lower sea levels); (2) the Permian-Cretaceous sequence, made up of mainly carbonate rocks with only brief hiatuses; and (3) the Cenozoic foreland sequence including both carbonates and siliciclastics (toward the top) and with early Paleocene and Oligocene hiatuses in some areas.

This tectonic-sedimentation framework impacted on petroleum generation and accumulation in the Middle East in ways unique to this region.

### BACK TO THE SOURCE

Organic-rich source rocks (with total organic carbon >5%) are not unique to the Middle East. What is remarkable about Middle East's source rocks, though, is that they were deposited on a passive continental-shelf margin spanning Paleozoic and Mesozoic times in

relatively stable conditions, which took advantage of sea-level rises, anoxic (reducing) environments, and nutrient-rich upwelling sites off the coast. Moreover, these marine shales and marls contained oil-prone kerogen types I (protein/lipid-rich algal organic matter) and II (lipid-rich but with lower hydrogen-to-carbon ratios).

One of the lucky horizons for petroleum generation in the Middle East is the Silurian "hot" shale called the Qusaibah Shale in Saudi Arabia but also found in some other parts of the Middle East and North Africa. Paleogeographic modeling of Paleozoic continents and atmospheric circulations (Judith Parrish, *AAPG Bulletin*, June 1982) shows that during the Silurian the Middle East was close to a major upwelling current that enriched the sediments with exceptional amounts of organic matter.

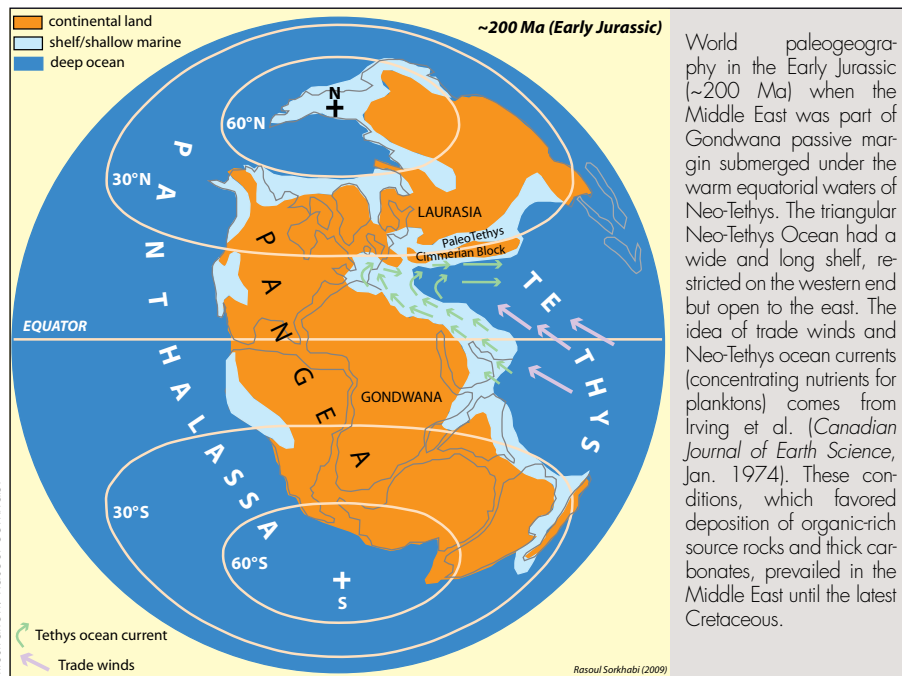
Over 70% of the Middle East oil was generated from Jurassic-Cretaceous sediments (accounting for less than 30% of the Phanerozoic eon). Some of these classic source rocks include the Sargelu Formation (Middle Jurassic, 150-200 m thick in type locality),

Garau Formation (Lower Cretaceous, over 800 m thick), Gadvan Formation (Lower Cretaceous, 100 m thick), and Kazhdomi Formation (Middle Cretaceous, 200 m thick) in the Zagros basin of SW Iran and age-equivalent limy-shale formations in Iraq and the Persian Gulf areas.

To explain these rich source rocks we need to consider the position and extent of the Neo-Tethys shelf during Jurassic and Cretaceous times. Neo-Tethys was then located close to the warm, organic-rich Equator; it enjoyed a 2000-3000 km-wide wide shelf and a length of at least twice that (R. J. Murriss, *AAPG Bulletin*, May 1980). Moreover, Neo-Tethys was triangular in shape pointed (thinning) toward west; it was thus a partly enclosed basin with its wide shelf oriented almost west-east, and in a favorable position to benefit from organic-rich sedimentation processes and high stand sea-levels.

In Late Jurassic-Early Cretaceous times, Gondwana was split apart, and as rift volcanism and sea-floor spreading developed, ocean temperatures rose and ocean waters became enriched with nutrient elements from volcanic outpourings (along mid-ocean ridges and continental margins or island arcs). Oxygen-analyses of planktonic foraminifera from mid-Cretaceous marine sediments have shown that 125-85 Ma was a time of severe global warming due to a rapid increase in atmospheric carbon dioxide concentrations (mainly from increased volcanic activities). This is consistent with sequence stratigraphic evidence for sea-level maxima in mid-late Cretaceous times. Warm climate, high-stand seas, and increases in the nitrogen-phosphorus-carbon contents of oceans, in turn, led to a profuse radiation of plankton populations - a key factor in the organic richness of marine sediments laid down during that period. Neo-Tethys most benefited from these events and the Middle East was in a right position at a right time.

Based on their sedimentary facies distributions, R. J. Murriss has divided the Mesozoic carbonates of the Middle East into two categories: (1) Carbonate ramps (mixed with clastic clayey beds) with cycles ("layer cakes") ranging in thickness from 30 to 100 m and deposited during marine regressions when clastics were brought into the basin, and (2) differentiated carbonate shelf or platform carbonates, which were deposited under transgressive conditions, and differentiation is marked with starved (sediment-deficient) euxinic basins separated by high-energy margins from carbonate-evaporite platforms. Rich source rocks are included in the second category.



**INTO THE STORAGE AND TRAP**

The Middle East is renowned for its rich carbonate oil reservoirs. Such reservoir rocks are also found in North America and Western Siberia (mainly Paleozoic), Central-South America (mainly Mesozoic), and Southeast Asia (mainly Miocene). In the Middle East, however, carbonates were deposited on a long and wide shelf from the Permian to the Paleocene with insignificant hiatus. Even after the Arabia-Asia collision, carbonate sedimentation continued in a very shallow marine environment (an ongoing process in the Persian Gulf). Indeed, large oil fields in the Middle East have thick stacks of multiple carbonate payzones.

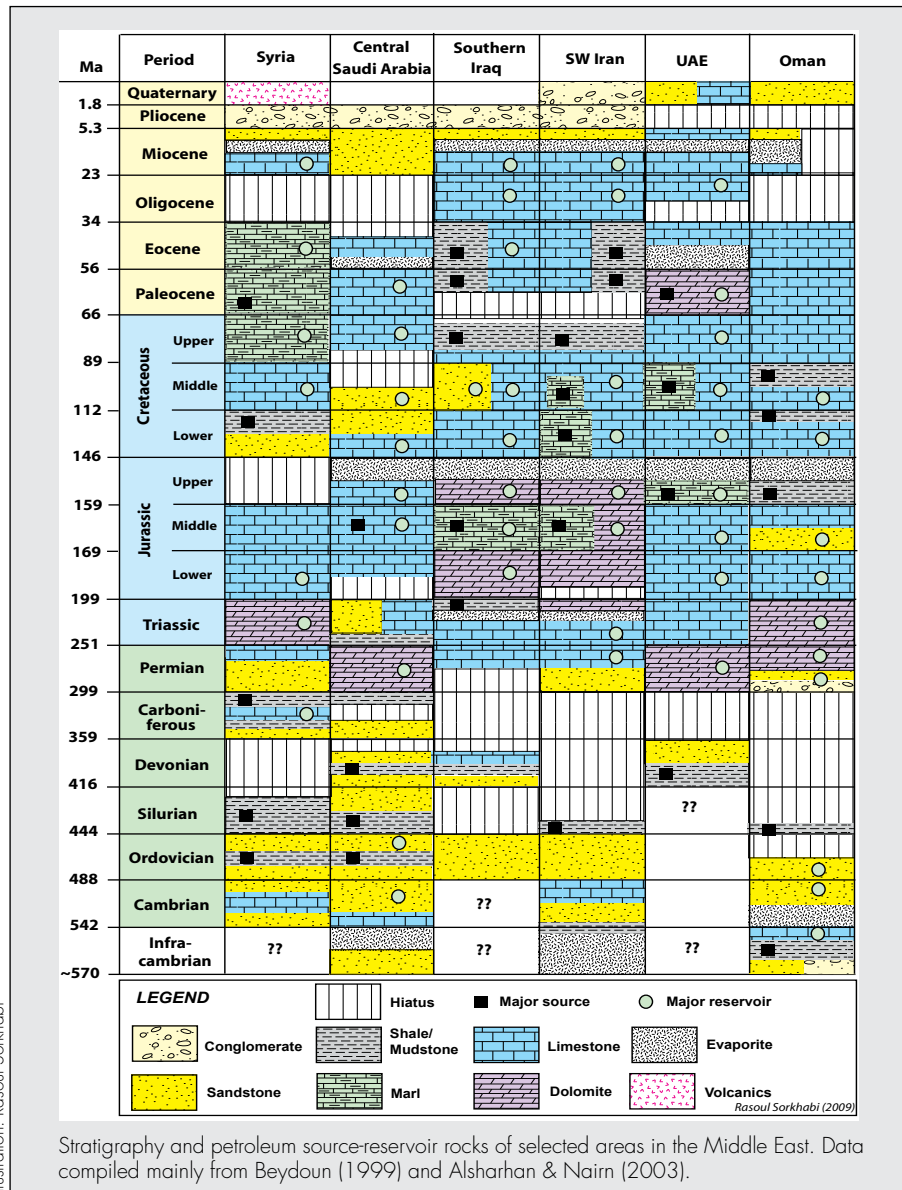
Limestone and dolomite reservoirs of the Middle East have fairly good porosity and permeability. Primary porosity has been well preserved in packstones and grainstones such as those of the Upper Jurassic Arab Formation widely spread in the Middle East. In Saudi Arabia's Ghawar field (the world's largest oil field), two producing members (C and D) of the Arab Formation, respectively, have thicknesses of 30 m and 80 m, and a porosity of 20%. The same formation in the UAE ranges from 130-240 m in thickness and 10-30% in porosity. Moreover, the Zagros deformation has created fracture networks enhancing permeability, especially in cemented limestones of southwest Iran (Asmari Formation) and eastern Iraq (Jerribe Formation), where its thickness ranges from 120-480 m, and has a porosity of 8-24%.

Apart from marine shale and marl cap rocks, a vast part of the Middle East basins also contains evaporite beds, which are efficient seals because of their ductility. The main evaporite horizons include (1) the Infracambrian Hormuz salt; (2) Triassic interbedded evaporites; (3) Late Jurassic Gotnia-Hith Formation; and (4) the Miocene Gachsaran Formation. In this manner, the entire Phanerozoic succession is bounded by evaporite seals both at the bottom and on the top.

These ductile evaporite and shale beds have also acted as detachment horizons for the Zagros thrust structures, thus producing vertical compartments of petroleum systems within the sedimentary succession.

**ZAGROS DEFORMATION AND SALT DOMES**

Basin modeling from various parts of the Middle East has shown that the Jurassic-Cretaceous source rocks were buried to oil-generation-window temperatures during the Neogene, and this partly overlapped in time





with Zagros deformation and development of large anticlines as structural traps.

Three important features of Zagros deformation helped to preserve oil accumulations in the Middle East:

Firstly, the Cenozoic Zagros foreland basin was superimposed on the Paleozoic-Mesozoic Tethyan sediments, providing an overburden necessary for preservation as well as burial heating of the underlying source rocks.

Secondly, the relatively slow motion of the African-Arabian plate during the Cenozoic prevented a wide-spread, severe tectonic deformation unlike what occurred in other parts of the Tethyan belt, most notably in the Himalayas. (The Indian plate has moved at a rate of 5-6 cm per year after the India-Asia collision at 50 Ma, which is about three times faster than that of the African-Arabian plate over the same period.)

Thirdly, the presence of ductile Hormuz salt at the base of the Phanerozoic sediments helped to detach the sedimentary cover from the underlying igneous-metamorphic basement rock. Therefore, Zagros deformation evolved as a thin-skinned tectonic deformation in which the basement rock did not override the sedimentary cover nor did it exhume the entire Tethyan shelf sediments. (This scenario has happened in the thick-skinned tectonic deformation and uplift of the Himalayas.)

Indeed, in the Zagros Mountains, Precambrian metamorphic rocks are not outcropped, and those metamorphic schists and granites in Zagros, which were once thought to be of Precambrian age, have been dated as Paleozoic by high-resolution radiometric methods. Note that a thin-skinned deformation in the Zagros fold-and-thrust does not overrule the possibility of basement deformation at deeper levels; it simply means that deformation of the sedimentary cover has been decoupled from that of the basement (of which we have little knowledge). Perhaps, millions of years in the future, Zagros will also look much like today's Himalayas, especially if the motion of the Arabian Plate, currently being pushed by the Red Sea rifting, becomes faster as the Red Sea develops into a wide ocean.

The Infracambrian Hormuz salt has also created salt diapirs and folds, which provide favorable structural traps for oil; these salt movements date back to the Late Cretaceous. Although the Hormuz salt has been mapped only in some areas of the Middle East, its true extent is not precisely known as it has not been drilled in areas such as southern Iraq or the UAE.

## SUMMING-UP

For petroleum to be successfully generated, migrated, accumulated, and preserved, all elements and processes of the petroleum system, including organically rich and thermally matured source rocks, porous-permeable reservoir rocks, effective extensive cap rocks, and appropriate time relations between oil migration and trap formation should be present. Obviously, the Middle East qualifies all these conditions to a high degree and quality.

Since our discussion is at the regional scale of the Middle East, we have to simplify and generalize the issue and thus ignore variations in structural and sedimentation histories within the region. One such variation, for example, is that as we move away from the Precambrian outcrops in western Saudi Arabia toward the High Zagros in southwest Iran, the basin(s) become deeper and Mesozoic-Cenozoic sediments attain enormous thicknesses. Few wells have, indeed, penetrated the Paleozoic sections in these deeper parts of the basin. Moreover, some parts of the Middle East, notably the central and northern Iran, virtually remain unexplored. While keeping these shortcomings in mind, several key points may be highlighted to explain the abundance of oil in the Middle East:

- (1) A 500-million history of sedimentation on the passive continental margin of Gondwana;
- (2) Sedimentation largely within latitudes 30° North-30° South where climate is warm and organic activity is at high levels;
- (3) Wide, long (east-west oriented) shelf of Neo-Tethys during the Jurassic-Cretaceous;
- (4) Favorable position of the Middle East during the mid-Cretaceous global warming, sea level rise, and plankton abundance;
- (5) Marine source rocks containing oil-prone kerogen types;
- (6) Proximity of interbedded source rocks to reservoirs minimized oil migration pathways;
- (7) An enormous thickness of sediments (predominantly carbonates but some clastics as well) provided the necessary storage for the huge amounts of generated oil;
- (8) Presence of effective regional seals, both marine shale and evaporites, at the bottom, on the top, and within the sedimentary package;
- (9) Superimposition of the Cenozoic Zagros foreland basin atop the Tethyan shelf sediments;
- (10) Relatively slow motion of the Arabian plate and the presence of ductile evaporite-shale layers at the base of the Phanerozoic sediments resulted in a thin-skinned tectonic regime in which the Precambrian igneous-metamorphic basement did not override or



View of the Qatif Central Producing Plants during its construction in the early 2000s. Completed in 2004, these facilities, according to Saudi Aramco, produce 800,000 barrels per day from rejuvenation of the onshore Qatif field (first produced in 1951) and the offshore Ab Safah field (first produced in 1966).

exhume the entire Tethyan shelf sediments; (11) Large “whaleback” anticlines generated by the “gentle” Zagros compression (folding and thrusting) or salt diapirs provided abundant structural traps for oil accumulations. ■

## Bibliographic Notes

Since the 1950s, a number of petroleum geologists working in the Middle East have opined on the richness of oil in that region; classic papers published in the *AAPG Bulletin* include Baker and Henson (October 1952); Law (January 1957); Kamen-Kaye (December 1970); Murriss (May 1980); Bois et al. (September 1982); and Klemme & Ulmishek (December 1991). The late Z. R. Beydoun also discussed this issue in *Episodes*, June 1998.

*Habitat of Oil*, edited by Lewis Weeks (1958) is the proceedings volume of an AAPG symposium on this topic, which also includes several classic papers relevant to the Middle East. I have benefited from all these sources.

For information on the geology of specific basins and chronostratigraphic events in the Middle East, I have found review papers in *GeoArabia* as well as the following volumes particularly helpful and handy:

Alsharhan, A.S., and Nairn, A.E.M. (2003) *Sedimentary Basins and Petroleum Geology of the Middle East* (Amsterdam: Elsevier)

Beydoun, Z.R. (1991) *Arabian Plate Hydrocarbon Geology and Potential: A Plate Tectonic Approach* (AAPG Studies in Geology #33, Tulsa)

Sharland, P.R. et al. (2001) *Arabian Plate Sequence Stratigraphy* (GeoArabia Special Publication 2, Bahrain)

# The First Oil Discoveries in the Middle East

Flashbacks on the first discoveries of oil fields in the Middle East.

RASOUL SORKHABI

## 1908 (May 26):

Masjid Sulaiman field (Masjid Sulaiman-1 well), southwest Zagros basin, **Iran** (Persia) by the Concessions Syndicate Ltd. (owned by Englishmen William Knox D'Arcy and Lord Stathcona, and the Scottish Burma Oil), forerunner of the Anglo-Persian Oil Company (later British Petroleum). Reservoir: Asmari limestone (Oligocene-Early Miocene), 354 m deep; oil 39.4° API gravity.

## 1927 (October 14):

Kirkuk field (Baba Gurgur No. 1 well), Kurdistan region, **Iraq**, by the Turkish (Iraqi) Petroleum Company (IPC, a consortium of the Anglo-Persian, Shell, Francaise des Petroles, American Near East Development Corporation, and Gulbenkian Foundation). Reservoir: "Main Limestone" or Kirkuk formation (Asmari equivalent) limestone (Oligocene), depth unknown; oil 36° API. Production began in 1934.

## 1932 (June 1):

Jabal Dukhan field (Jabal Dukhan-1 well), Bahrain, by the **Bahrain** Petroleum Company (a subsidiary of the Standard Oil of California); Reservoir: Waisa limestone (Cretaceous) at depths of 600-750 m; oil 38° API. Production began in 1934.

## 1938 (February 23):

Burgan field (Burgan-1 well), **Kuwait**, by the Kuwait Oil Company (owned by the Gulf Oil and the Anglo-Persian). Reservoir: Burgan sandstone (Middle Cretaceous), 1120 m deep; oil 32.5° API. Production began in 1946.

## 1938 (March 4):

Dammam field (Dammam-7 well), eastern **Saudi Arabia**, by the California Arabian Standard Oil Company (a subsidiary of Standard Oil of California). Reservoir: Arab limestone (Upper Jurassic), 1441 m deep; oil 34-35° API. Production began in the same year.

## 1940 (January):

Dukhan field (Dukhan-1 well), **Qatar**, by the Petroleum Development of Qatar (a subsidiary of the Anglo-Persian/IPC). Reservoir: Zekrit (Arab) limestone (Upper Jurassic), 1733 m deep; oil 37° API (Limestone 3) and 42° API (Limestone 4). Production began in 1940 and export began in 1949.

## 1953:

Bab (or Murban) field (Murban-1 well), **Abu Dhabi** (later part of the United Arab Emirates), by Abu Dhabi Petroleum Company (formerly Oil Development of Trucial Coast, a subsidiary of IPC); Reservoir: Kharaib Formation (Lower Cretaceous limestone), 3,776 m deep; oil 40° API. Production began in 1963.

## 1956:

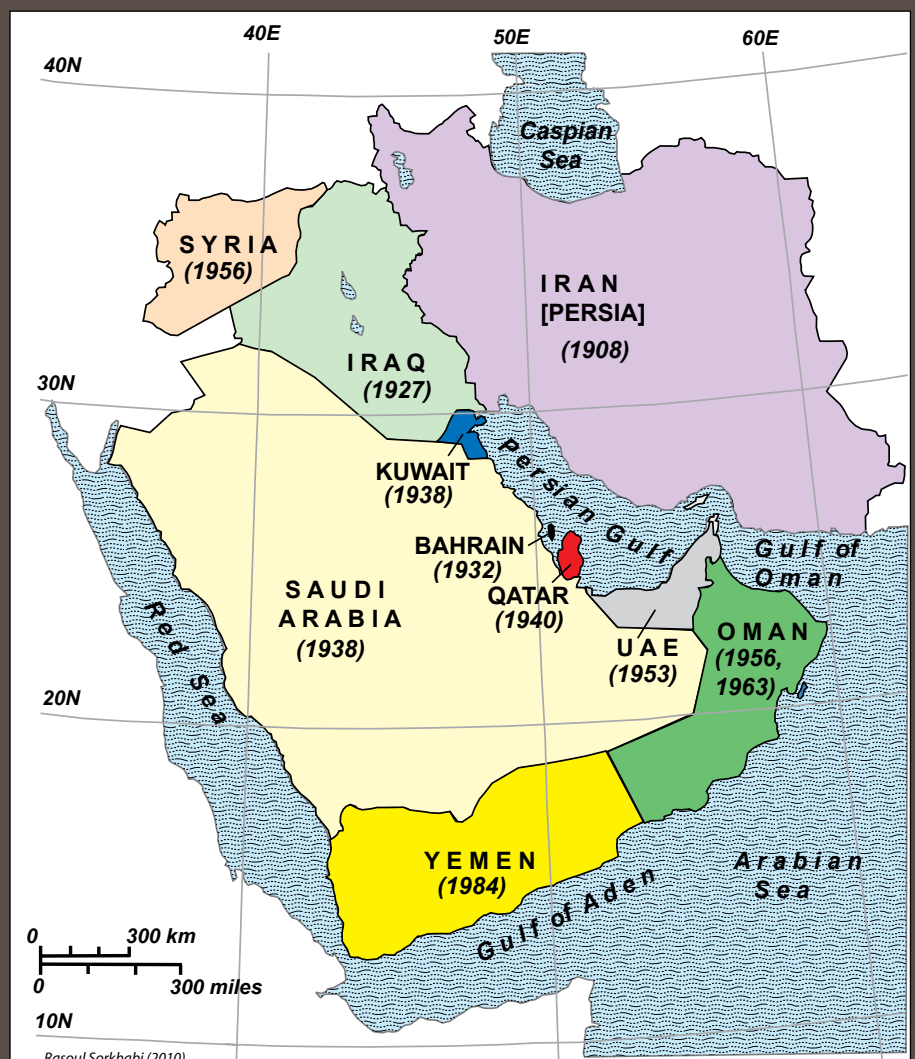
Marmul field (Marmul-1 well), Oman, by Petroleum Department of **Oman** (subsidiary of IPC). Reservoirs: Umm Er Radhuma (Paleocene) 576 m deep (18° API) and Biyadh sandstone (Lower Cretaceous) 854-976 m deep (20.8° API). The field was non-commercial. **1963-67:** The first producing fields, Yibal (1963, depth 2275 m, 38° API), Natih (1963, depth 2202 m, 31° API) and Fahud (1964, depth 590 m, 33.6° API) (all Cretaceous limestone), in Oman were discovered by Shell and Partex (Gulbenkian Foundation). Production began in 1967.

## 1956 (October):

Karatchok field (Karatchok-1 well), northeastern **Syria**, by the American independent James W. Menhall Drilling Company. Reservoir: Massive Limestone Formation (Cretaceous), 3155 m deep; oil 19-21° API. Production began in 1969.

## 1984 (March 4):

Alif field (Alif-1 well), Ma'rib Jawf graben of the Sab'atayn basin, **Yemen**, by the American Yemen-Hunt Oil Company. Reservoir: Sab'atayn Formation (Upper Jurassic), 2400 deep; oil 43 API. Production began in 1987.





# Marine Seismic Sources

## PART I: AIR-GUNS FOR NON EXPERTS

This series on marine seismic sources will summarize salient points for geoscientists who need to sharpen their rusty skills in seismic source technology. It will also discuss the effect seismic sources have on marine life.

*“Double, double, toil and trouble; Air guns fire and ocean bubble.”*

With apologies to Shakespeare's three witches in Macbeth, and thanks to our colleagues Bill Dragoset and Jan Langhammer.

A seismic source is defined as any device which releases energy into the earth in the form of seismic waves. The major source type in marine exploration is the air-gun array, which since the 1970's has been by far the most popular. The air-gun can be described as a chamber of compressed air that is released rapidly into the surrounding water to create an acoustic pulse. The air gun is the most commonly used source because the pulses are predictable, repeatable and controllable, it uses compressed air which is cheap and readily available, and it has only a minor impact on marine life.

### SIZE AND GEOMETRY

An air-gun volume is measured in litres (l) or more commonly, by the conservative petroleum geophysicist, in cubic inches (in<sup>3</sup>). Typical volumes of individual air-guns used by the exploration industry vary from 20 in<sup>3</sup> (0.3 l) to 800 in<sup>3</sup> (13.1 l), while academic seismic refraction studies can use volumes up to 1600 in<sup>3</sup> (26.2 l). An air-gun array consists of 3 - 6 sub-arrays called strings, each string containing 6 - 8 individual guns, so that the array usually involves between 18 and 48 guns, although in special cases as many as 100 guns an array can be used. The air-gun array volume is the sum of the volumes of each gun, and is typically in the range 3,000-8,000 in<sup>3</sup> (49.2-131.6 l).

The air-guns hang in the sea beneath floats between 3m and 10m below the sea surface, generally at about

6m, except for refraction studies when a deeper deployment is needed. The gun pressure mostly used by the seismic industry is 2,000 psi (138 bar) and during a survey, the guns fire every 10-15 seconds.

It is common to arrange several (2-4) air-guns in a cluster, with the guns so close together that they behave as a larger single gun. The main purpose of clustering is to improve signal characteristics, since the bubble motion (see below) is reduced by this configuration.

The energy sent out by air-gun arrays is dominantly directed vertically downwards. The broad band of frequencies from the array form a pulse with peak-to-peak amplitude in the range 14-28 bar-m, corresponding to 243-249 dB re 1  $\mu\text{Pa-m}$  vertically downward. The amplitude levels emitted horizontally tend to be 15-24 dB lower. These numbers are frequency dependent. By filtering out high frequencies there is less deviation between amplitude levels vertically and horizontally.

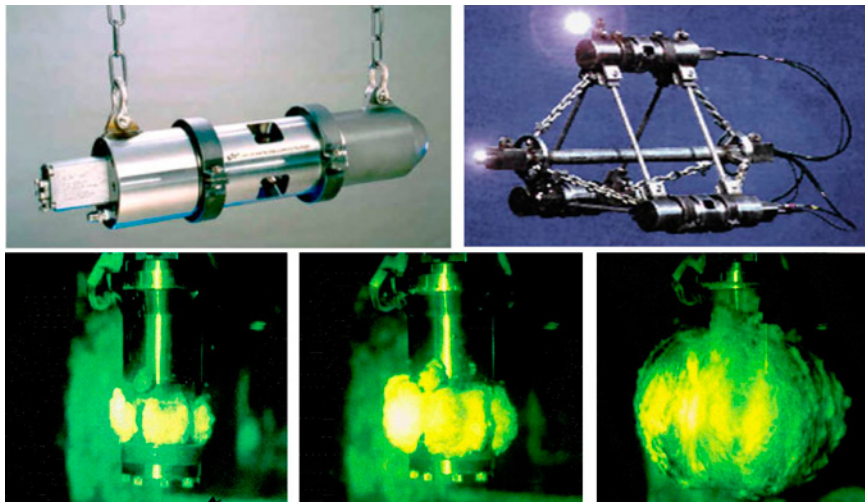
Here, 'dB re 1  $\mu\text{Pa-m}$ ' means decibel value peak-to-peak relative to the reference pressure one micropascal at a reference distance of one metre. Confusing units? Read Box 1 and we will guide you through the physical principles of air-guns and the basic sound measurement units. Our focus in the present article is on the vertically downward travelling 'far-field' signature of an air-gun array as this signature provides a quantitative measure of the array's performance.



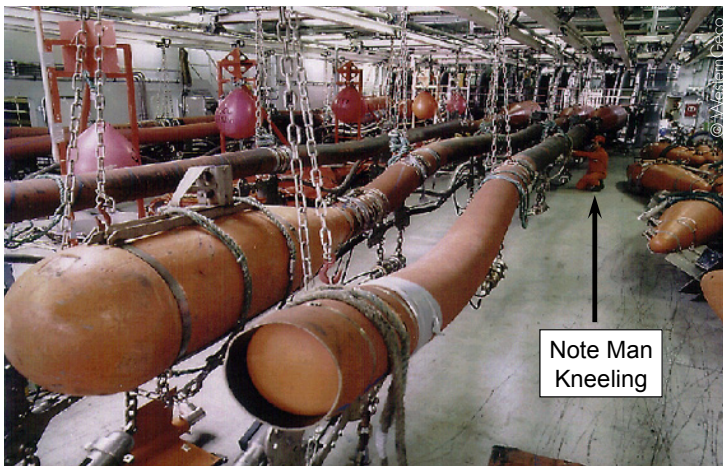
Lasse Amundsen is Chief Scientist, Geophysics, at Statoil.



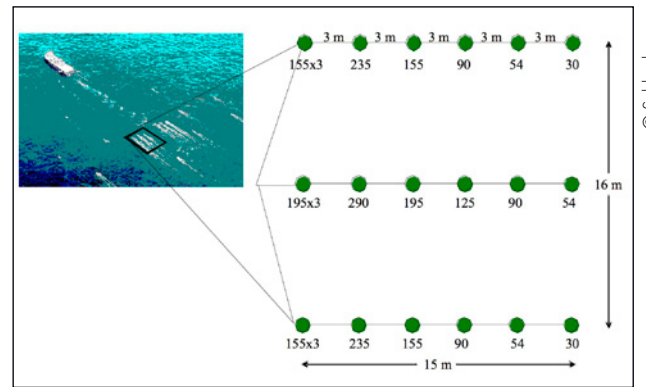
Martin Landrø is professor in Applied Geophysics at NTNU, Trondheim, Norway.



Top: Single air-gun and three-gun cluster (www.bolt-technology.com). Bottom: Pictures of air bubbles 1 ms, 1.5 ms, and 7 ms after firing a small air-gun in a tank (Langhammer 1994).



Part of an air-gun array onboard a vessel.



Seismic vessel towing two air-gun arrays at 6 m depth. One array, consisting of three strings with in total 24 guns, is sketched in plan view. It measures 15 m x 16 m (inline x cross-line). The numbers are gun volumes in in<sup>3</sup>. The total volume is 3,397 in<sup>3</sup>.

## BUBBLE OSCILLATIONS

When compressed air is suddenly released into the water an oscillating bubble forms. This process is described in Parkes and Hatton (1986):

*Initially, the pressure inside the bubble greatly exceeds the hydrostatic (external) pressure. The air bubble then expands well beyond the point at which the internal and hydrostatic pressures are equal. When the expansion ceases, the internal bubble pressure is below the hydrostatic pressure, so that the bubble starts to collapse. The collapse overshoots the equilibrium position and the cycle starts once again. The bubble continues to oscillate, with a period typically in the range of tens to hundreds of milliseconds.*

The oscillation is stopped due to frictional forces, and the buoyancy of the bubble causes it to break the sea surface. If we could stop this cyclic motion immediately after the first expansion of the bubble, the air gun would create an ideal signal close to a single spike and similar to a dynamite explosion. However, due to the cyclic bubble motion, the signal from a single air gun is far from ideal.

As explained in Box 2 on bubble motion, the dominant frequency of the bubble oscillations decreases with increasing gun volume, or with increasing gun pressure, or with decreasing source depth. Therefore, small guns emit higher frequencies and big guns emit lower frequencies – like a bell choir. The geophysicist wants a broad band of frequencies.

However, as we will explain, the source ghost (see Box 3) has a detrimental effect on broad-band spectrum.

## THE SOURCE GHOST

The time domain pressure pulse that is emitted by the single air-gun in the vertical direction is called the

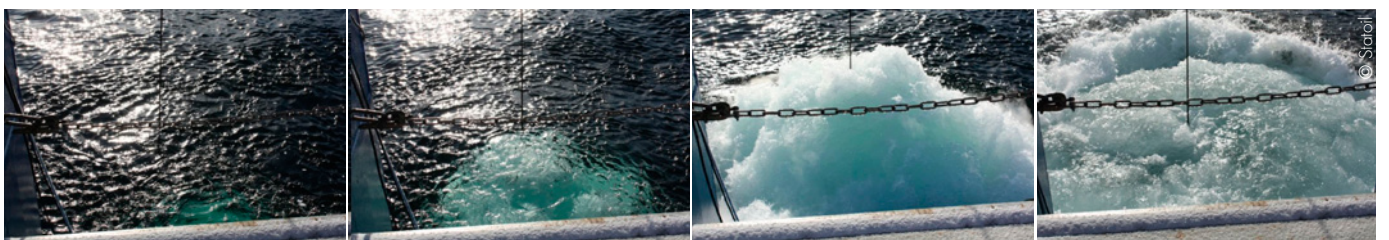
pressure signature. However, another pulse simultaneously travels upward from the source, is reflected down at the sea surface and joins the original downward-travelling pressure pulse. This delayed pulse, reflected at the sea surface, is called the source ghost. From a data processing point of view, the source ghost is considered to be an intrinsic feature of the source wavefield, and therefore often included in the definition of the source pressure signature.

As illustrated in Box 3, the effect of the source ghost on the frequency content of the source signature is substantial. Therefore, like gun size, the gun depth is an important parameter in source and survey design.

The useful frequency band of seismic data is between the first (always at 0 Hz) and the second zeroes in the amplitude spectrum of the source signature. The zeroes in the spectrum, caused by the source ghost and therefore called ghost notches, implies that there is no signal at these particular frequencies.

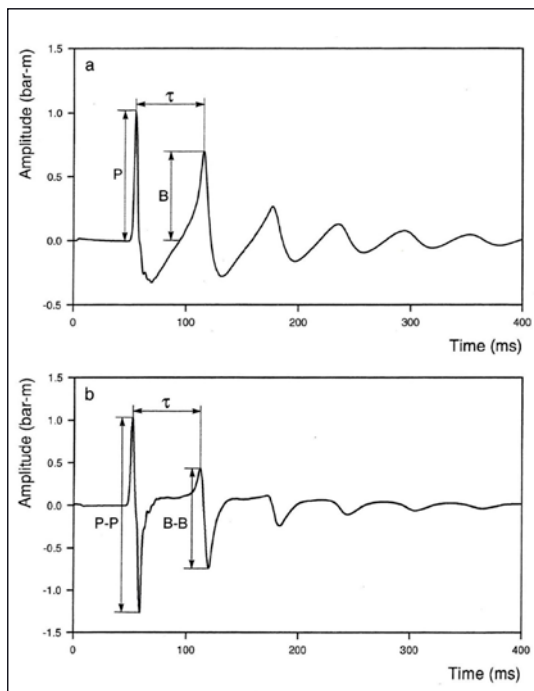
If high-resolution seismic of the shallow subsurface is the objective, it is important to extend the high-frequencies as much as possible. For a source at a depth of 3.75 m, the second ghost notch is at frequency  $f_1=200$  Hz. But the low-frequency amplitudes are much lower than for a source depth of, for example, 15 m. As low frequencies improve penetration into the subsurface, a shallow source is not recommended for a dee-looking survey. By comparison, a 15 m source depth has nice low-frequency characteristics for good penetration, but the ghost notch at  $f_1=50$  Hz has a detrimental effect on resolution. A survey with both low-frequency and high-frequency objectives is difficult to realize. It can be seen from this that the survey objective dictates the source depth.

The air bubble from a 600 in<sup>3</sup> gun at 3 m depth. The released air produces a steep-fronted shock wave that is observed as ripples on the sea surface (pictures 1 and 2) before the bubble breaks the surface.





Pressure signature of the sound pulse of a single 40-in<sup>3</sup> air-gun. The near-field signature (upper trace) shows the measurement of the released air producing a steep-fronted shock wave followed by several oscillations resulting from the repeated collapse and expansion of the air bubble. The signal strengths of the direct wave and the first bubble are P and B, respectively. The near-field peak-to-bubble ratio is  $PBR=P/B$ . The far-field signature (lower trace) shows the effect that the source ghost has on the near-field signature. The peak-to-peak amplitude P-P (the distance between the positive peak of the primary and negative peak of the ghost) is 2.3 bar-m. The far-field peak-to-bubble ratio is  $PBR=P-P/B-B=1.9$ . The bubble period is  $\tau=60$  ms (Langhammer 1994).



**THE AIR-GUN SIGNATURE**

The air-gun ‘signature’, recorded by a hydrophone below the gun, has three characteristic features: the direct arrival produced when the gun fires; the source ghost; and the bubble pulse caused by the expansion-collapse cycle of the air bubble. The signature is characterized by two parameters: the primary pulse peak-to-peak (P-P) amplitude, or “strength”, the useful part of the signal, and its bubble period. These two characteristic parameters depend on the air-gun’s size, initial firing pressure, and depth.

**SOURCE ARRAYS**

Two important parameters of an air-gun array signature are its peak-to-peak (P-P) strength and primary-to-bubble ratio (PBR). The PBR should be as high as possible so that the air-gun array signature is close to an ideal pulse. To find the P-P strength of an array, its signature is measured at a distance from the source known as the far-field point, a point where the output signals of the individual guns interfere constructively, typically 250-300m beneath them. This far-field signature is then

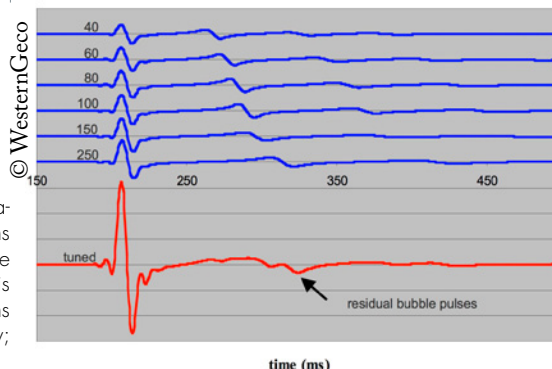
**Acknowledgment**

We thank WesternGeco for providing useful illustrations to this article.

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Farfield pressure signatures of individual air-guns vary with gun volume. The tuned pressure signature is obtained when the six guns are fired simultaneously;  $PBR=8.6$ .



**BOX 1**

**Definitions**

Hydrophones are sensitive to sound pressure, which is measured in micropascals ( $\mu$ Pa). By tradition, the geophysicist uses a different pressure unit, microbar ( $\mu$ bar). One bar is equivalent to  $10^{11}$   $\mu$ Pa.

The far-field signature of an air-gun array, measured vertically beneath, is used to define the nominal source level. This is the acoustic pressure 1 m away from its hypothetical point source equivalent that would radiate the same amount of sound in the far-field as the actual source. Units are in bars at 1 m, abbreviated as bar-m. For example, 100 bar-m means that if the array were a point source and a hydrophone were 50 m away, then the hydrophone would detect a pressure of 2 bar.

In presenting sound measurements, acousticians use ratios of pressures; in underwater sound the adopted reference pressure is one  $\mu$ Pa. Further, acousticians adopt the decibel (dB) scale so that sound pressure level (SPL) of a sound of pressure S is  $SPL (dB) = 20 \log_{10}(S/S_0)$  where  $S_0$  is the reference pressure. The standard for specifying air-gun signal levels is the peak-to-peak (P-P) level, which is the maximum negative-to-positive measurement of the air-gun signature. The seismic survey literature refers to P-P pressure amplitudes in bar-m. P-P can be converted to source level  $L_s$  in dB re 1  $\mu$ Pa-m as follows:  $L_s (dB \text{ re } 1 \mu Pa-m) = 20 \log(P-P)+220$ . Acoustic pressures of 10-20 bar-m correspond to 240-246 dB re 1  $\mu$ Pa-m<sub>P-P</sub>.

The source amplitude spectrum level gives source amplitude strength versus frequency. It is common to normalize the amplitude spectrum in dB relative to 1  $\mu$ Pa/Hz at 1 m, abbreviated as dB re 1  $\mu$ Pa/Hz-m. Because the reference pressure 1  $\mu$ Pa is a small pressure, a moderately sized air-gun array will have a spectrum that peaks above 200 dB above this reference level.

used to define a nominal point-source level, at 1 m from the centre of the array, by multiplying the signature by the radial distance from this point to the hydrophone. This nominal point-source level is a theoretical sound pressure level. Because of partial destructive interference between the signals of the individual guns, the actual level at this point in reality tends to be 10 times (20 dB) lower than the nominal level.

The P-P strength (related to this nominal source level) is defined as the difference in absolute amplitude between the peaks of the primary and ghost arrivals. The P-P amplitude of, for example, the 3,397-in<sup>3</sup> array is 102 bar-m, corresponding to 260 dB re 1  $\mu$ Pa-m. Typical arrays tend to produce levels of 243-249 dB re 1  $\mu$ Pa-m, corresponding to 14-28 bar-m. The seismic industry sometimes gives output levels in root-mean-square (rms) peak-to-peak amplitudes (rms P-P). The dB reduction of rms P-P compared to P-P is around 3 dB since the maximum peak and trough amplitudes are approximately equal.



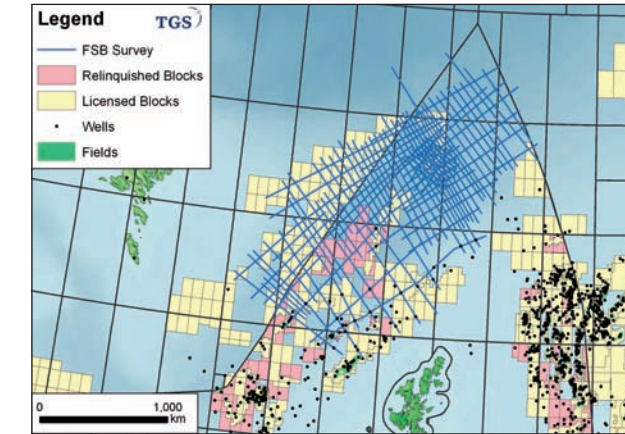
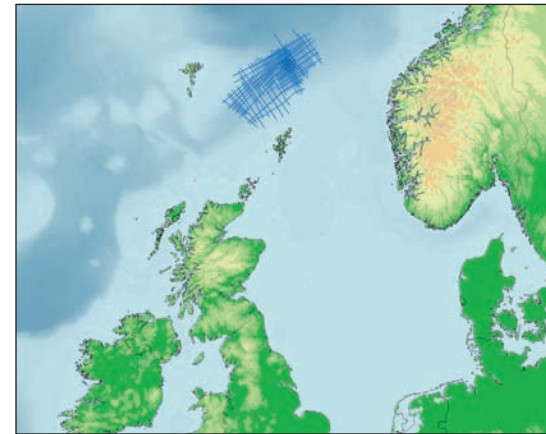
# SHETLAND ROCKS!

## Improved Sub-Basalt Structural Imaging

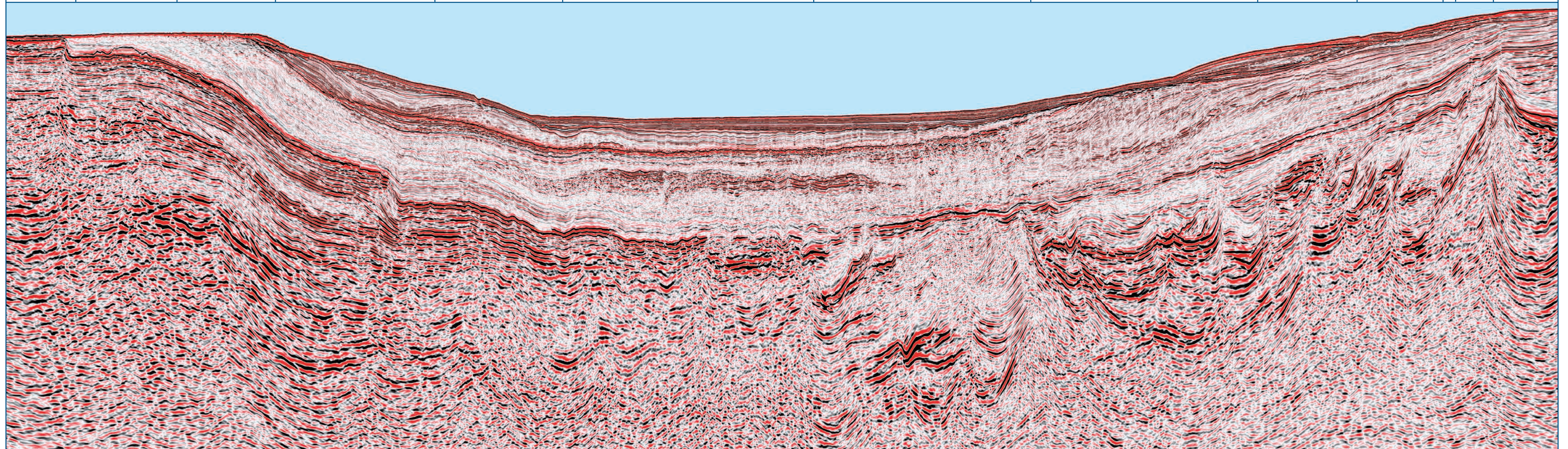
Extensive thick sequences of basalt dominate the northwest flank of the Faroe Shetland Basin. Recent reprocessing of this long offset data dramatically improves the interpretability of the sub-basalt structures.

*See full story starting on page 39.*

Location of the Faroe Shetland Basin (FSB) dataset



FSB dataset line location map





# WEST OF SHETLAND: Improved Sub-Basalt Imaging

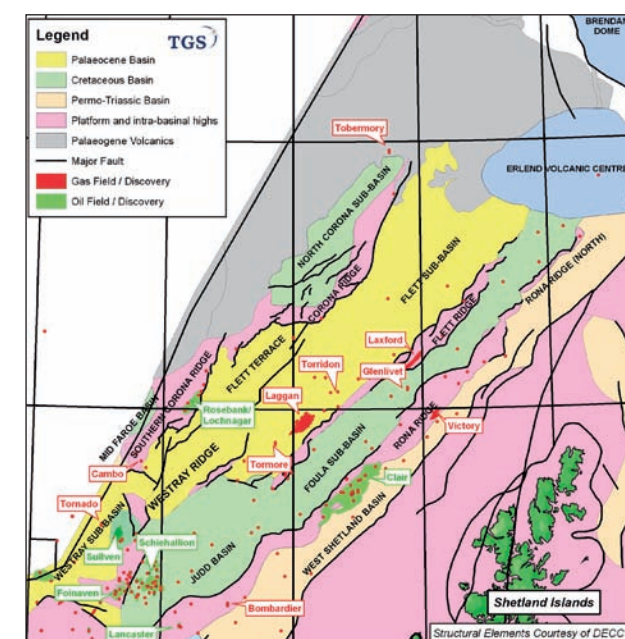
Newly reprocessed long offset seismic data from the Faroe Shetland Basin now provides a tool to enable interpreters to produce meaningful correlation in the sub-basalt section and raises some exciting geological questions for the West of Shetlands.

BENT BAUMBACH, PROJECT DEVELOPMENT, TGS - BEDFORD, UK

TGS has successfully completed the reprocessing of the first 6,500 km of a large 10,000 km long offset regional dataset in the Faroe Shetland Basin (FSB). The remaining 3,500 km is due to be finalised by February 2010. The objective of the reprocessing was to improve overall imaging with particular emphasis on the sub-basalt section.

The fold out profile heading this article shows an example of the sub-basalt imaging achieved by methodical analytical processing using TGS' latest processing software.

To observe the dramatic improvements achieved in the 2010 reprocessed data, a comparison between the original processing and the newly processed profile is shown. The recent reprocessing has brought out significant improvements of key importance in the understanding of the sub-basalt geological setting, allowing meaningful correlation across the West of Shetlands area.



Structural Elements West of Shetland, with main basins, fields and discoveries. The same features are annotated at the top of the FSB profile.

## GEOLOGICAL DISCUSSION

This summary, built on past and current exploration ideas highlights some new geological questions for the West of Shetlands.

Looking at the West Shetland Basin area, the stratigraphic section known to be present in this basin consists of a full column of Tertiary section overlaying an Upper Cretaceous section resting unconformably on the Lewisian basement.

Moving northwest the profile traverses the Rona Ridge. The Clair oilfield further south is hosted on the Rona Ridge complex, with oil accumulated in a Devonian Sandstone reservoir overlain by a Carboniferous formation. This gives an indication of what might be present within the Rona Ridge in the Victory area. None of the wells drilled in the Clair area penetrated into basement. The overburden section deposited on top of the apex of the Rona Ridge consists of a nearly full Tertiary section with a late Palaeocene formation resting on the ridge apex.

The sediment section thickens dramatically immediately west of the Rona Ridge into the Foula Sub-basin. Deep seismic imaging is observed in the basin. Note the rollover feature observed in the Palaeocene section right next to the ridge – a possibly similar feature to the recent gas discovery Glenlivet. Good control on the anticipated stratigraphic column within the basin is provided, based on data available from wells drilled further south.

A near full Tertiary section rests unconformably on Late Cretaceous and Late Early Cretaceous. A hiatus unconformity separates the Cretaceous from an underlying Late Jurassic section which is known to contain the Kimmeridge source rock. Several prospective sandstone reservoirs are present within the Cretaceous-Jurassic section. The Jurassic rests unconformably on Permo-Triassic, potential Carboniferous (another possible source) and Devonian section.

West of the Foula Sub-basin the FSB Profile crosses into the Flett Ridge area. The seismic data hints at the Flett Ridge being a composition of fault blocks forming the ridge caused by transpressural/transensional movements within the fault block components. The stratigraphic composition within each of these fault blocks has hitherto been unknown.

Further to the west the profile traverses the Flett Sub-basin

where compressional features within the Early Palaeocene section are evident. Within this area it seems possible to correlate a deep reflection sequence representing a Devonian/Lewisian basement horizon across to the Rona Ridge area.

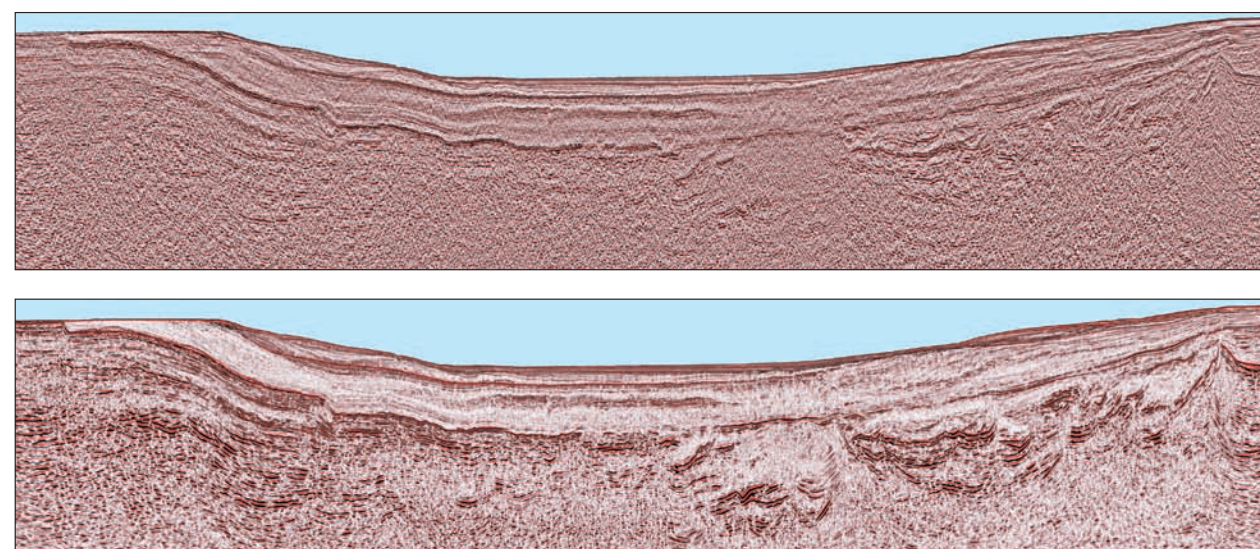
To the northwest the profile traverses the very interesting Corona Ridge feature containing a section imaged down to great depth. Could the Corona Ridge be formed of a set of fault block elements which as a whole constitute an inverted basin?

The Rona, Flett and Corona Ridge features all trend in the mainly NE/SW direction through this area each of them showing offsets caused by movements along the NW/SE transfer fault system active along the whole of the Atlantic Margin.

Northwest of the Corona Ridge the profile traverses a feature named the North Corona Sub-basin. It is founded on a set of fault block elements. It is possible to correlate reflector horizons across the basin even at depth. The Eriboll well 213/23-1 drilled to the southwest of the profile encountered a carboniferous section underlying a Tertiary-Mesozoic section however the knowledge of the stratigraphic section within this sub-basin is still incomplete.

Note the anticline feature at depth located within the area named the Faroe High.

The profile traverses further into the Faroese Continental Shelf (CS) across the Faroe-Shetland Escarpment and on to an area where the sub-basalt section rises dramatically to a position with the top volcanic horizon near the water bottom. Further observe the dramatic thickening of the individual basalt sequences into the Faroese CS and the much improved resolution achieved within the basalt sequences particularly in the shallow, where seismic sequence analysis now seems to be possible. Looking at depth in this section the immediate impression is that one is looking at a major set of fault blocks initially positioned at depth, but then from late Palaeocene/Early Eocene to present was subjected to severe compression mainly in a WNW – ESE direction.



A comparison between new (2010, below) and original (1999/2000, above) processing illustrating a dramatic increase in quality.

## REPROCESSING DISCUSSION

What were the main processing elements which led to this improvement?

- Three key approaches were used:
  - Preservation and enhancement of low frequency signal
  - Noise Attenuation in multiple domains
  - Full Sequence Migration Velocity Analysis

Careful attention to the preservation and enhancement of low frequency signal, multiple and noise removal are seen to be crucial to improving signal-to-noise beneath the basalt. There is no need to compromise the frequency content of the overlying Tertiary section when reprocessing shallow towed datasets for sub-basalt targets.

The third approach, Full Sequence Migration Velocity Analysis, is seen to be the key to improving the structural interpretability of concealed Mesozoic and Palaeozoic structures. Recent advances in compute power mean that this procedure can now be run within the time frame of a quick turnaround large scale production project. It permits the early involvement of interpreters, to whom the choice of a range of alternative structural images may be presented. Each alternative has the processing and signal-to-noise characteristics of a final section and allows a 'composite' image to be built. The final time domain migration velocity field should provide an excellent reference model for initial passes of pre-stack depth migration and tomography-based velocity updates.

## CONCLUSION

The West of Shetlands contains three of the largest producing fields on the UKCS today yet it still has vast tracts of open acreage. It is clear that this reprocessed dataset now gives the interpreter the ability to carry out evaluation, correlation and mapping within the prospective sub-basalt interval.

## Further Information

TGS have submitted an abstract with further details of the reprocessing to the forthcoming EAGE conference in Barcelona.

## BOX 2

### Bubble motion

The physics of air bubbles from marine air-guns is complex. The temperature inside the bubble can drop to around minus one hundred degrees Celsius, causing ice crystals to form. There is also evidence that the bubble comprises a number of small bubbles rather than one large one.

Nevertheless, to a first approximation, the parameters that govern the time behavior of the bubble oscillation are surprisingly "simple":  $T = C_1 P^{1/3} V^{1/3} / P_0^{5/6}$ . Here, P and V are the initial internal pressure (firing pressure) and volume of the air before it is released and  $P_0$  is the hydrostatic pressure.  $C_1$  is a constant that depends upon the air gun details.

The dominant frequency of the bubble motion,  $f=1/T$ , then decreases with increasing gun volume, or with increasing gun pressure, or with decreasing hydrostatic pressure (and thus, source depth).

By tradition, the seismic industry quotes firing pressure in pound force per square inch, psi (psi=6894.76 Pascals; a Pascal is a Newton per square meter).

### Air-gun strength

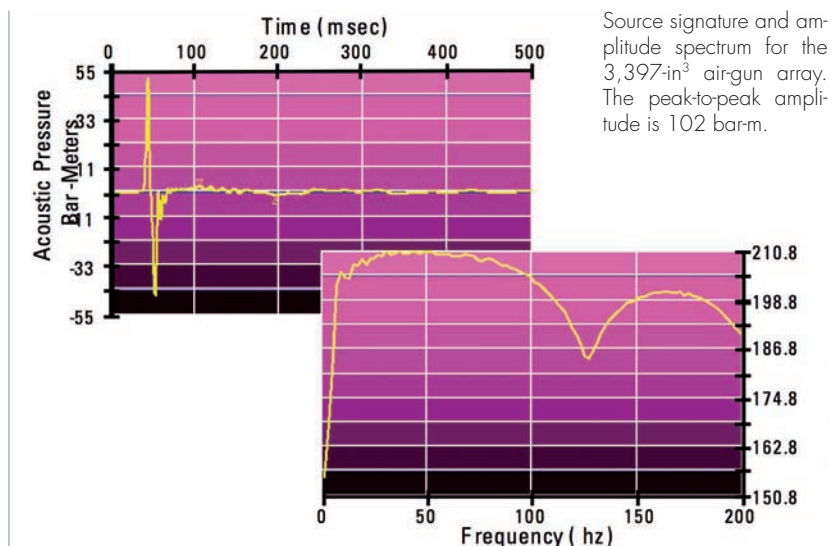
The strength of an array is:

- (1) Linearly proportional to the number of guns in the array. All else being equal, a 40-gun array generates twice the amplitude of a 20-gun array.
- (2) Close to linearly proportional to the firing pressure of the array. A 3000-psi array has 1.5 times the amplitude of a 2000-psi array.
- (3) Roughly proportional to the cube root of its volume.

The number of guns provides the greatest influence on the array strength, not the firing pressure nor the total volume.

It is important to remember that the time-domain specifications of P-P strength and PBR depend strongly on the frequency bandwidth of the array's signature. When high frequencies are cut the P-P strength and PBR both decrease.

There are several reasons for deploying air-guns in arrays. The first is to increase the power of the source. The basic idea is that a source array of n single sources produces n times the power of the single source. The second is to minimize the PBR by tuning the array: Guns with different volumes will have different bubble periods, leading to a constructive summation of the first (primary) peak and destructive summation of the bubble amplitudes.



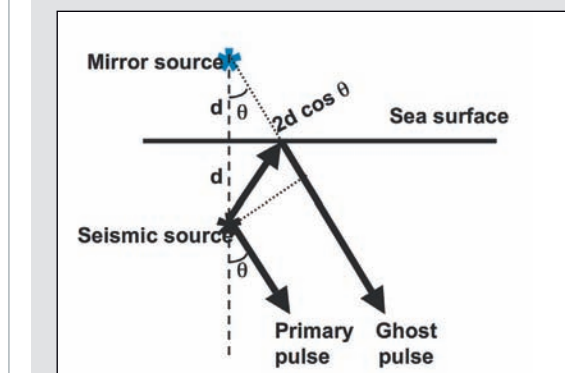
## BOX 3

### Source ghost

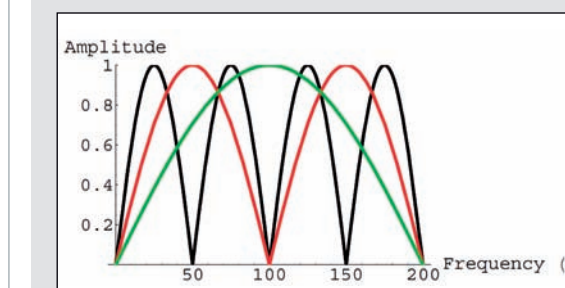
The physics of the source ghost related to marine sources is simple. The upward travelling part of the source signal cannot escape into the air, as the sea surface acts as a mirror, and reflects the signal downwards with opposite polarity. This source ghost pulse is delayed in time with respect to the initial downwards primary pulse from the source. Geometrically, the source ghost appears to originate from the mirror image of the seismic source. The time delay therefore is given by  $\tau = 2d \cos\theta / c$ , where d is the source depth, c is the sound of speed in water, and  $\theta$  is the offset angle of the initial downwards primary pulse measured from the vertical axis.

The frequency spectrum of the composite signal (primary and ghost) is  $|G(f)| = 2 \sin(2 \pi f d \cos\theta / c)$ .

This spectrum has zeroes called 'ghost notches' at frequencies  $f_n = n c / (2 d \cos\theta)$ , where n is zero or positive integer. The first notch (n=0) is always at  $f_0=0$  Hz. The useful frequency band in seismic is inside the first and second notch frequencies (inside  $f_0$  and  $f_1$ ) of the spectrum of the composite signal.



The source ghost reflects at the sea surface to join the primary downwards pulse from the source. The ghost appears to originate from a virtual source at the mirror location of the physical source.



Frequency spectra of the composite signal travelling in the vertical direction ( $\theta=0$ ) for source depths at 3.75 m (green), 7.5 m (red) and 15 m (black).



# The Qatar Oil Discoveries

In January 1940 (now 70 years ago), with the discovery of the onshore Dukhan oil field, Qatar joined the Middle East's oil club. In 1960 (50 years ago), Qatar's first offshore field was discovered. Today, this country, smaller than the state of Connecticut, possesses the world's third largest gas reserves, and about 25 billion barrels of oil.



A satellite image (taken on 18 February 2003) of the southern Persian Gulf showing the Qatar Peninsula and phytoplankton boom in the nearby waters.



# of 1940 and 1960

Qatar is relatively a small peninsula, 160 km long and 55-90 km wide, that extends from Saudi Arabia into the Persian Gulf. It is an Arab emirate ruled by the Al-Thani family since the 1870s. From 1872, to the beginning of World War I in 1914, Qatar was under the Ottoman Empire. Qatar gained its independence in 1971, after being a British protectorate since 1916. The early twentieth-century history of oil exploration in Qatar is associated with British players in the region.

## 1920S ...

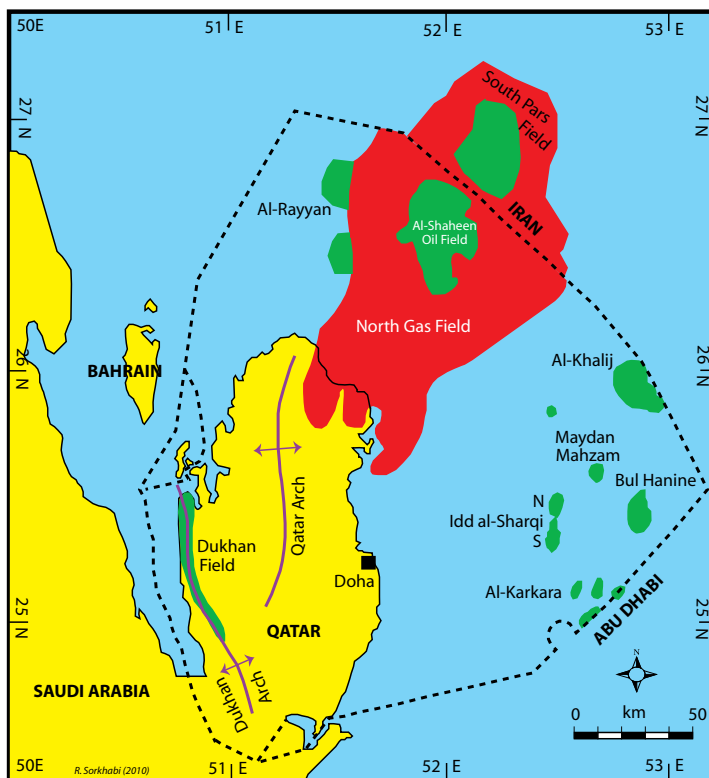
As early as 1922, Major Frank Holmes (also called “Abu Naft,” or Father of Oil in the Middle East) had his eye on Qatar’s oil resources. Holmes was a New Zealand-born British miner, army officer, and oil businessman who represented the London-based Eastern and General Syndicate’s ventures in the Middle East, and helped obtain oil concessions in Saudi Arabia, Kuwait and Bahrain in the 1920s (see “The Emergence of the Arabian Oil Industry,” *GEO ExPro*, 06/2008). However, Holmes, who also managed to meet with Qatar’s ruler Shaikh Abdullah bin Jassim al-Thani in Doha in 1923, did not proceed with his ideas because the British Colonial Office had prohibited oil ventures in Qatar.

By 1925, however, such restrictions appear to have eased, for in early 1926, George Martin Lees, a geologist with the Anglo-Persian Oil Company (APOC, later British Petroleum), visited Doha and made a one-day trip to a few outcrops of Qatar, which he rightly identified as Eocene limestone exposed on the crest of a gently-dipping anticline. Before leaving, Lees also obtained permission from the Shaikh for exploring the emirate for the following two years.

## 1930S ...

What renewed the British interest in Qatar’s oil was the 1932 discovery of oil in Bahrain by the Standard Oil Company of California. Alarmed by the American company’s success in the region, APOC sent C. C. Mylles to Doha to negotiate an oil concession with the Shaikh. In August of that year, APOC was granted a two-year exploration license in Qatar. This venture, however, posed a problem for APOC, as the company had signed the 1927 “Red Line” with a consortium of oil companies called the Iraq Petroleum Company (IPC) to the effect that no member of the consortium would be engaged, on its own, in any exploration activity in the former Ottoman empire of the Middle East, and Qatar was part of the Red Line Agreement. APOC thus informed IPC of its option in Qatar, and IPC permitted APOC to act as its nominee in Qatar.

Late in 1932, APOC dispatched two geologists, E.W. Shaw and P.T. Cox, to Qatar. After a survey during January-March 1933, the team found out that the Dukhan anticline in southeastern Qatar shared similarities with the discovery field in Bahrain: Its surface rocks were Eocene limestone and hence good potential for a Cretaceous reservoir rock (like that of Bahrain). The Dukhan anticline was nothing but the highest hills in Qatar, which the natives called Jabal Dukhan (“Hill of Smoke”) for its oftentimes hazy weather. ▶



Onshore geology and the Qatar’s major oil and gas fields.



Outcrop of the Dukhan anticline displaying the Middle Eocene Dammam Formation.

In 1933-34, APOC dispatched W.E. Browne and D.C. Ion to precisely map the Dukhan anticline. After this mapping, APOC entered a negotiation with Qatar, and on 17 May 1935, it was granted a 75-year oil concession covering all of Qatar's land to explore and produce oil. In return, the Qatar government was to receive a royalty of 2 Indian rupees per ton of oil produced, a payment of Rs. 400,000 on signature, and an annual sums of Rs. 150,000 (after five years, Rs. 300,000) in addition to the royalty. Two years later, APOC on behalf of IPC created a new company called Petroleum Department

of Qatar, which took over the concession and its operations. This new company included BP (23.75%), Royal Dutch Shell (23.75%), Cie Francaise des Petroles (23.75%), Standard Oil of New Jersey (11.87%), Mobil (11.87%), and Paratex (Glubenkian Foundation) (5.0%).

During the winter of 1937-38, a new group of geologists, Norval E. Baker, T.F. Williamson, and R. Pomeyrol, visited Dukhan to locate a drilling site. They examined the Dukhan anticline, which was 80 km long with 90 meters of structural closure in the Middle Eocene limestone, and recommended a location for the first well.

**Qatar at a Glance**

**Land area:** 11,437 sq. km (4,416 sq. mi)  
**Population:** 860,000 (largely immigrants from other parts of the Middle East)  
**Proven oil reserves:** 25.41 billion barrels  
**Oil production:** 843,000 bopd  
**Producing oil wells:** 421  
**Crude oil exports:** 703,000 bopd  
**Refinery capacity (Umm Said built in 1953 with an initial capacity of 600 bopd):** 80,000 bopd  
**Proven natural gas reserves:** 25.466 trillion cubic meters (891 Tcf, world's third largest after Russia and Iran)  
**Gas production:** 76.98 billion cubic meter (Bcm)  
**Natural gas exports:** 56.78 Bcm  
**OPEC member since 1961**

Source: OPEC Annual Statistical Bulletin 2008



Qatar flag

**The Story of Shaikh Mansour**

All historical oil discoveries in the Middle East included local guides, some of whom contributed no less than their bosses to the success of expeditions although these men have often gone nameless or little known. In the case of the Dukhan field, however, we are fortunate to have a report about a man named Shaikh Mansour, who helped the Shaw-Cox survey in 1933 and the Williamson-Baker survey in 1937-38. Williamson later remarked that Shaikh Mansour "appeared to have a mental picture of the whole of Qatar and had a quite uncanny capacity for knowing exactly where he was under all conditions - in clear weather, in fog, or even in darkness." He ensured that the field work proceeded smoothly among the local inhabitants; he was also quick to learn geology, especially for locating the outcrops of Eocene-age *Alveolina* (a large foraminifer fossil) limestones in Qatar. During World War II, Mansour went blind from trachoma. Despite this, in 1946 he joined N.E. Baker and F. E. Wellings, geologists working for Petroleum Development of Qatar, to examine outcrops outside the Dukhan field. For this new field work, Mansour took his nephew as his "seeing eye," and still proved to be an excellent guide. He lived in a village near Dukhan until his death in 1972.

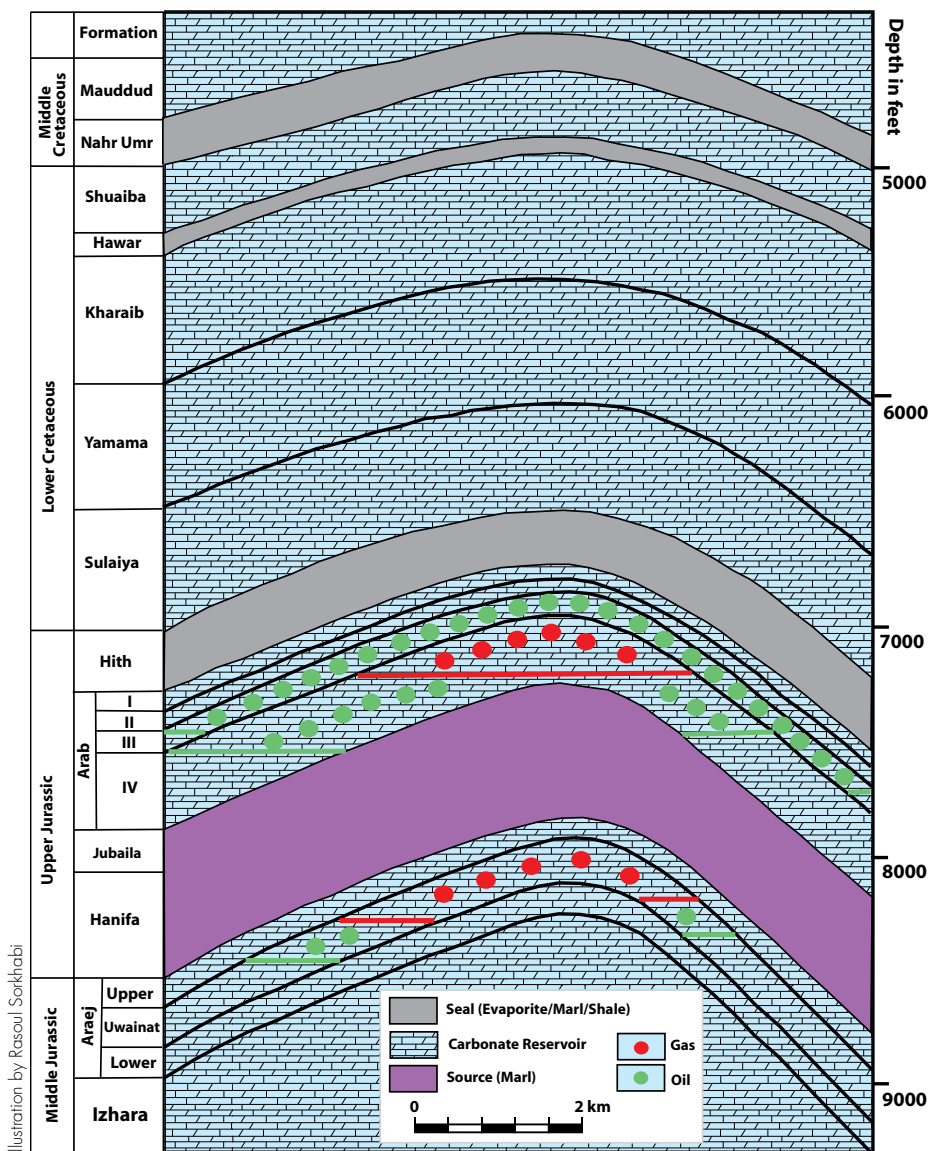


Illustration by Rasoul Sorkhabai

Stratigraphy and structural cross-section of the Dukhan oil and gas field drilled in 1940 (Source, Frei, H.P., 1984, Proceedings of Seminar on Source Habitat of Petroleum in the Arab Countries, OAPEC, Kuwait, pp. 115-123.). The Dukhan field is about 80 km long and up to 8 km wide. At the surface, the limbs of the anticline dip 2-10°. At the Jurassic reservoir level, the anticline comprises four culminations along strike. Structural closure at the Jurassic horizon is 488 m which increases to 640 m at the level of the Permian Khuff formation. The deepest well in the field is the 1990 Dukhan DKG-27 which penetrated the Ordovician sandstone at a depth of 4,975 m.



## THE DISCOVERY WELL

Drilling of Dukhan No. 1 began in October 1938. In the last weeks of 1939, the well hit oil shows, not in the Cretaceous limestone (as had been expected with comparison to the Bahrain field) but in the Upper Jurassic limestone, similar to Saudi Arabia's Dammam field discovered in 1936. In January 1940, Dukhan No. 1 was completed at a depth of 1733 m, and was then producing about 4,480 barrels of oil per day (bopd).

The producing reservoir rock, the Upper Jurassic **Zekrit** Formation, was similar to the **Arab** Formation of Saudi Arabia, even having the same number of limestone payzones which had been named A, B, C, and D of Arab Formation in the Dammam field. However, N. T. Langham, the well site geologist, unaware of these payzones discovered two years earlier, called the Zekrit limestones as No. 1, 2, 3 and 4. (Zekrit Formation is named after the port of Zekrit, northeast of Dukhan, where a jetty had been built by the drilling team for unloading materials.)

### 1940S ...

In March 1941, Dukhan No. 2 was drilled about 16 km south of the first well. It discovered oil in the No. 3 limestone and gas in the No. 4 limestone. In May 1942, Dukhan No. 3 was drilled about 5 km east of the first well. However, World War II (1939-45) put an end to field operations in Dukhan. Indeed, Dukhan wells and installations were stripped or destroyed in 1942; therefore, after the war ended, the field needed reconstruction.

Renewed operations began in late 1947. During the following three years, three drilling rigs were continuously employed to drill 25 wells. Meanwhile, a 120-km pipeline was built from the Dukhan field to the port of Umm Said in eastern Qatar where terminal facilities also were put in place. On 31 December 1949, the first shipment of the Dukhan crude was made from Umm Said (Mesaieed) where the tanker S.S. *President Manny* carried 80,000 tons of oil to Europe.

### 1950S ...

By 1950, Qatar was producing 33,800 bopd. The production increased threefold by 1954. In 1950, Qatar's revenue from oil was \$1 million; it amounted to \$23 million in 1954, mainly because in September 1952, Qatar had signed a new agreement with the Petroleum Department of Qatar calling for 50-50 profit-sharing.

The Dukhan field is comprised by three oil reservoir sectors, **Khatiyah**, **Fahahil**, and **Jaleha/Diyab**, respectively, from north to south. Early production was from the



A view of Halul Island (an area of 1.5 sq. km) from where the first shipment of oil produced by Shell from the Idd al-Sharqi field was exported on 1 February 1964. Today, the island is home to 11 large oil storage tanks with a total capacity of 5 million barrels; it also has pumping stations and modern loading terminals for tankers. In 2008, oil exported from Halul was about 90 million barrels transported by 137 tankers; operations are managed by the Qatar Marine Crude.

Khatiyah sector. Production from Fahahil began in 1954 and from Jaleha in 1955. In 1955, Dukhan No. 1 began producing water so much so that the provincial government designed a man-made oasis. But many other wells continued producing oil from. By 1957, 58 wells had been drilled in the Dukhan, of which 48 wells were producers. In 1959, pro-

duction averaged about 169,000 bopd.

During 1959-60, deeper wells in the Dukhan field discovered non-associated gas from the Permian Khuff formation (*GEO ExPro* 04/2009) at a depth of 3,000 m, and this new play added to the hydrocarbon wealth of the Dukhan oil and gas field. The top of the Khuff formation lies at depths of

Reservoir	DUKHAN Onshore field	IDD AL-SHARQI NORTH DOME
Shuaiba	No Cretaceous payzone	Aptian, 99 m thick Porosity 22-30% Permeability 0.2-200 mD Oil 27° API, 2.8% sulfur
Kharabi		Barremian, 174 m thick Porosity 15-30% Permeability <12 mD Oil 27° API, 2.8% sulfur
Arab-3 (C) Zekrit	Kimmerdgian-Tithonian, 27 m thick Porosity 15-20% Permeability 30 mD Oil 37° API, 1.8% sulfur	Kimmerdgian-Tithonian, 30 m thick Porosity 10-23% Permeability 50-200 mD Oil 27° API, 3% sulfur
Arab-4 (D) Zekrit	Kimmerdgian-Tithonian, 56 m thick Porosity 19% Permeability 70 mD Oil 42° API, 1.1% sulfur	Kimmerdgian-Tithonian, 102 m thick Porosity 10-38% Permeability 1-300 mD Oil 32° API, 1.7% sulfur
Upper Araej		Callovian, 46 m thick Porosity 5-20% Permeability 0.1-20 mD Oil 36° API, 1.2% sulfur
Uwainat	Bathonian, 60 m thick Porosity 19% Permeability 16 mD Oil 43° API, 0.8% sulfur	Bathonian, 55 m thick Porosity 5-20% Permeability 1-1600 mD Oil 36° API, 1.2% sulfur

Illustration by Rasoul Sorakhabi

Comparison of oil payzones in the onshore Dukhan field and the offshore Idd al-Sharqi North Dome field (data after Frei, 1984).

2835-3262 m, and its thickness varies from 448-564 m. Gas production from the Khuff commenced in 1978.

## OFFSHORE QATAR 1960S: ENTER SHELL

In August 1949, the new ruler of Qatar, Shaikh Ali ibn Abdullah al-Thani (the elder son of the former Emir), gave a concession to the International Marine Oil Company (a subsidiary of the Superior Oil Company and Investment Corporation) to explore for oil offshore Qatar (in waters beyond the 3-miles line); but the company could not locate any suitable structure for drilling, and thus relinquished the concession in 1952.

Qatar, in turn, granted a new offshore concession to Shell Overseas Exploration Company; the concession was transferred in 1954 to a new subsidiary called Shell Company of Qatar. The concession, covering 25,900 sq km (the equivalent of 4 North Sea quadrants), was for 75 years and included an initial payment of £260,000 to the Shaikh, and a fifty-fifty profit sharing after production; field operations were bound to start within nine months and drilling within two years. Shell started seismic survey in the Qatar waters in the spring of 1953 and drilled two exploratory wells in 1955 and 1956; both wells were dry. It was only in May 1960 that Shell discovered the **Idd al-Sharqi** oil and gas field, some 85 km east of Doha. This field consists of two elliptical domes; the larger North Dome (which was discovered and produced first) and the smaller South Dome.

In 1963, Shell discovered another major offshore field, the **Maydan Mahzam**, with payzones at Arab-D, Arab-C, and Uwainat. Production from this field started in 1965. In 1969, the Idd al-Sharqi was producing 35,000 b/d and the Maydan Mahzam 100,000 b/d. By then, Qatar's total oil production had increased to 17 million tons (293,000 bopd), earning its government \$115 million in 1969.

Production from the Idd al-Sharqi in 2006, according to a report by Qatar's Ministry of Foreign Affairs, was close to 144,000 bopd from the North Dome and 10,000 bopd from the South Dome. Production from the Maydan Mahzam in 2003 averaged 38,800 bopd.

Crude produced from these offshore fields were (and are) stored at facilities on the island of Halul (located about 80 km northeast of Doha), which also has pumping stations and loading terminals for tankers. The first shipment of oil produced from the Idd al-Sharqi North Dome field was exported from this island on 1 February 1964. ■

## Qatar Petroleum

In 1952, Petroleum Department of Qatar together with Petroleum Department of Oman and Dharrur and Petroleum Department of Trucial Coast States (small shaikhdoms between Qatar and the mouth of the Persian Gulf) merged to form the Petroleum Concessions Ltd under the general-manager of G. Heseldine.

In 1953, with further organizational changes, Petroleum Department of Qatar was named Qatar Petroleum Company.

In 1972, the government of Qatar established the Qatar National Oil Company to manage its oil operations. In 1973, the government took 25% share each of Qatar Petroleum Company and Shell Company of Qatar. In 1974, the government established the General Petroleum Corporation (later called Qatar Petroleum), and signed new agreements with the two oil companies giving 60% share to the state-run Qatar Petroleum. In 1977, Qatar fully nationalized onshore and offshore operations and gave service contracts to the former concessionaries.



## The Dukhan Field Today

Dukhan, Qatar's only onshore oil and gas field, is located about 84 km west of Doha. Its oil production capacity, according to Qatar Petroleum, is up to 335,000 bopd but the actual production is subjected to reservoir management. The total number of wells in the Dukhan field is 605, including 300 oil-producing wells, 182 water injection wells, 58 gas-producing and injector wells; the remaining are shut-in, observational or abandoned wells.

Oil and gas from the Dukhan field are separated in four degassing stations: Khatiyah North, Khatiyah Main, Fahahil Main and Jaleha. (The Khatiyah, Fahahil and Jaleha stations were built in 1949, 1954, and 1955, respectively.) The crude is then pumped to the Umm Bab Booster Station where its pressure is boosted for transportation by pipeline to the Umm Said (Mesaieed) port, about 100 km east of Dukhan.

In 1989, water injection in the Dukhan field was started to maintain reservoir pressure. In 1998, a gas recycling plant was started to process 800 million cubic feet per day of Arab-D gas cap to recover 38,000 bopd of condensate and 750 tons per day of NGL. In 2008, Qatar Petroleum awarded a \$140 million deal to French firm CGS Veritas for a 3D-seismic survey of the Dukhan field. This project is expected to be completed by the end of 2011. A new reservoir study of the Dukhan field is also underway and will be completed in 2012.



A view of the new Qatar Petroleum corporate training facility at Dukhan



## The Cape Peninsula:

# An Ancient Beauty

Photo: Jane Whaley

Table Mountain dominates the city of Cape Town. It is one of the oldest mountains in the world and is made up of great thicknesses of Ordovician sandstone overlying the Precambrian shales and granite, the unconformity between them identified by a clear break in slope. It is cut by many deep gorges, the result of erosion along fault and joint planes. It is possible to hike to the top in a couple of them.





Spectacular, extraordinary, awe-inspiring: Table Mountain and the Cape Peninsula are more than just a list of superlatives, with much of interest to offer the visiting geologist.

It is surely one of the most iconic views in the world, and yet never fails to impress the visitor: Table Mountain rising steeply and dramatically from the very centre of the city of Cape Town. To the south, the land narrows rapidly towards the famous Cape of Good Hope, constantly battered by wild seas and fierce winds. The whole area is one of fascinating diversity in flora and fauna as well as scenery, and at the root of this is, of course, the geology.

With the exception of some Quaternary and Holocene deposits, the rocks of the Cape are all very old. They comprise three main groups; the Cambrian-Carboniferous Table Mountain Supergroup, predominantly sandstones; the Cambrian Cape Granite; and the Precambrian Malmesbury Group, composed of dark grey mudstones and lighter sandstones. Although originating in ancient times, the way these rocks and the landscape appear today is the result of millions of years of constant erosion, deposition, earth movements and transformations.

#### PRECAMBRIAN TURBIDITES

Much of Cape Town and the coastal plain is underlain by the 560 million year old Malmesbury Group of rocks, which are ancient slump and turbidity current deposits. They still exhibit classic features such as graded bedding and ripples, despite their great age and the subsequent metamorphism and tight folding they have undergone. They form the base of Table Mountain and rarely outcrop at the surface, but can be seen along the rocky Sea Point shoreline on the western coast of Cape Town.

The Malmesbury Group also contains volcanics, seen as reddish-brown rocks among the usually dark slates and sandstones, indicating that the sediments probably accumulated on a tectonically active margin, with volcanoes developing as oceanic crust was pushed down into the earth under lighter continental material.

At one time Nelson Mandela and fellow inmates of the prison on Robben Island, 10km north of Cape Town and easily seen from Table Mountain, had a chance to view



Hout Bay, 15 km south west of Cape Town, is presided over by the impressive peak of Sentinel Mountain, composed of Ordovician Table Mountain Group Rocks. Whales are commonly seen basking in the calm waters of the bay.



these rocks at close quarters. The core of the island is a Malmesbury Group anticline, smoothed to a platform by Pleistocene wave action, and overlain by wind blown sand.

**DARWIN'S EYE-OPENER**

During the early Cambrian, Malmesbury Group sediments were disturbed by the intrusion of magma, the result of the continental collision which eventually formed the super continent of Gondwanaland. The magma cooled and crystallised slowly, in the process melting and deforming the surrounding sediments. Although this occurred at great depth, subsequent erosion exposed the granite at the surface, forming a base for the deposition of the rocks which produced the dramatic cliffs of Table Mountain and Cape Point.

The effect of hot magma intruding into Malmesbury Group shales can be clearly seen near Sea Point, south-west of Cape Town. Over a mere 150m of coastline, the transition from undisturbed Malmesbury Group, through a complex mixed rock known as migmatite, to homogenous granite, is beautifully exposed on a wave cut platform. In 1836, Charles Darwin visited this location, and it had a major impact on his thoughts on the origin of rocks, as the initially fluid nature of the granite is hard to deny.

**NINE KILOMETRES OF SAND**

The intrusion of the Cape Granite marked the beginning of the uplift and erosion of the Cape Town area, as the deeply buried Precambrian rocks and granite were forced to the surface. The hiatus between these and

the thick layers of mudstones and sandstones which make up the overlying Table Mountain Group lasted over 30 million years, and the resultant unconformity is very clear, particularly along the spectacular Chapman's Peak Drive, south of Cape Town.

The Table Mountain Group, part of the Cape Supergroup, was deposited between 510 and 340 million years ago, and the oldest rocks, the Graafwater and Peninsula Formations, form the 600m high sandstone cliffs of Table Mountain. The Graafwater, up to 60m thick, is composed of fining-up cycles of interbedded iron-rich maroon mudstones and lighter sandstones, passing conformably into the more massive, relatively iron-free sandstones of the Peninsular Formation, which are 700m thick in this area.

These are the only Cape Supergroup rocks found in the Cape Peninsula, except at the highest point of Table Mountain, where there is a very small remnant of the Late Ordovician Pakhuis glacial tillite, left by the tail end of a melting glacier. At one time, however, the Group probably covered a large percentage of Southern Africa, with up to 9,000m of sandstones deposited on a passive continental margin. Tectonism in the Permo-Triassic caused them to buckle and fold, forming the Cape Fold Belt, which extends 600 km from the eastern side of False Bay.

This folding exposed softer layers at the surface, and extensive erosion removed much of the once continuous Table Mountain Group layer. The nearly horizontal sandstones of Table Mountain are the sole remnant of the Fold Belt in the Cape Peninsula, probably rep-



Photos: Jane Whaley

Boulder Beach on the west coast of False Bay is a rare mainland nesting site for the African Penguin. At this location the characteristic round shape of the granite boulders, the result of preferential weathering along



Photos: Jane Whaley

The hard, horizontally bedded sandstones of the Ordovician Graafwater and Peninsula Formations, sitting on a bed of Cape Granite, have withstood the pounding of these churning seas for millions of years, but have been eroded to form cliffs rising over 200m from the sea. Contrary to popular opinion, the dramatic Cape of Good Hope is not the most southerly point of the continent of Africa.



Photos: Jane Whaley

The unconformity between the hard Table Mountain Group and the underlying weathered granite is clearly seen on Lions Head (left peak), as viewed from the top of Table Mountain. To the right of Lions Head are the softer outlines of the Malmesbury Group Signal Hill, with Robben Island in the far distance.



Photos: Jane Whaley

Chapman's Peak Drive from Noordhoek to Hout Bay follows the contour of the sharp non-conformity and break of slope between the Cape Granite and the more resistant overlying Table Mountain Group, with weathered granite clearly seen at the discontinuity. Current and cross-bedding features are frequently seen in the Lower Table Mountain Group formations





Photo: Val Taylor

The King Protea (*protea cynaroides*) is the national flower of South Africa and is only found in the Western and Eastern Cape. It takes four or five years to flower for the first time and the flowers can be 30cm in diameter.

### A Unique Flora

The distinctive geology of the Cape Peninsula has brought a unique biodiversity and ecosystem to the region. Table Mountain National Park, covering 250 km<sup>2</sup> of Table Mountain and the Cape Peninsula, is home to 2,285 different plant species, and in 2003 it was nominated as a UNESCO world heritage site. Table Mountain alone has almost 1,500 species in a mere 57 km<sup>2</sup> – approximately the same number of species as the whole of the UK.

The special vegetation of the Cape is known as fynbos, from the Afrikaans meaning ‘fine bush’, and consists of a diverse range of plants, with a large number of heathers, reeds, bulbs and large vibrantly flowering protea bushes, many of which are only found in the Western Cape - nearly 70 species of protea are found in the coastal region of Cape Province alone. Fynbos plants are well adapted to the thin, nutrient-poor soils and strong seasonal rainfall and dry summers of the area.

The unique ecosystems also extend offshore into False Bay, where the influence of the warm east coast Agulhas current and the cool, west coast Benguela current means that over 31% of marine animals and 40% of seaweeds are found no where else in the world.

representing the trough of a deep fold, where the horizontally lying beds were less easily eroded.

### RUGGED GLORY

Prolonged periods of uplift and erosion mean that there is a huge gap in the geological record of much of the Cape area, from the end of deposition of the Table Mountain Group in the early Carboniferous right up to the present day. Igneous activity about 130 million years ago (Early Cretaceous) resulted in a number of black dolerite dykes which cut through the older rocks, but there was little further sedimentation on land until fluctuating sea levels during the Pliocene and Pleistocene ice-ages resulted in the deposition of weakly cemented marine sands over

parts of the Peninsular and the Cape Flats area. Evidence of these sea level changes can be seen as wave cut terraces along the coast around Cape Town.

Much of the Cape Town landscape has been altered to accommodate the demands of man, and the unique biota of the region has also suffered major changes. But stand in the incessant wind at Cape Point, looking over the gloriously rugged landscape towards Table Mountain, and you realise that over much of the Cape Peninsula, geology and nature still have the upper hand.

*Acknowledgement: Thanks to Prof John Compton of the University of Cape Town for assistance with this article*



Photo: Jane Whaley

The Ordovician Graafwater and Peninsula Formations were deposited either in a rapidly flowing braided river system or as multiple stacked beach deposits over muddy lagoonal sediments, and current and cross-bedding features are frequently found in these rocks.

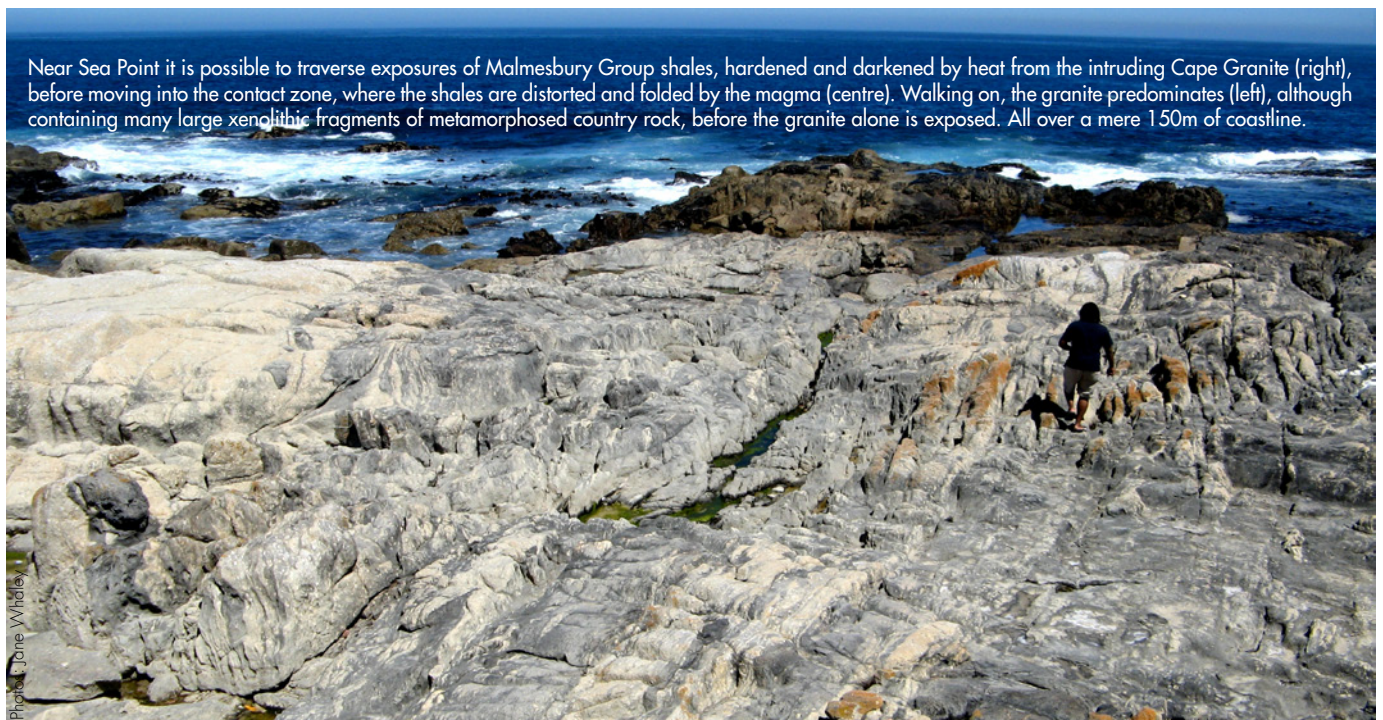


Photo: Jane Whaley

Near Sea Point it is possible to traverse exposures of Malmesbury Group shales, hardened and darkened by heat from the intruding Cape Granite (right), before moving into the contact zone, where the shales are distorted and folded by the magma (centre). Walking on, the granite predominates (left), although containing many large xenolithic fragments of metamorphosed country rock, before the granite alone is exposed. All over a mere 150m of coastline.





# Does Exploration Create Value - in a Mature Province Like Norway?

Exploration activity was at an all time high on the Norwegian Continental Shelf (NCS) in 2009, with 67 exploration wells, 45 of which were wildcats and 22 appraisal wells. Total pre-tax spending was USD 5 billion. However, the amount of money at risk after tax for the companies was only USD 1.1 billion, since the government is picking up 78% of the bill through the cash-back rule implemented in 2005.

Is there a risk that the government is sponsoring a G&G playground for the oil companies? In particular, does the new APA-regime (Awards in Predefined Areas; a yearly round of re-circulated acreage) actually create value?

Rystad Energy has investigated these issues, and has concluded that exploration on the NCS actually creates value with a good margin. For every dollar put into exploration in the area in recent years, you get three dollars back. For APA rounds seen separately, the return is slightly lower, with every dollar invested yielding 2.5 dollars in return. For regular concession rounds, which primarily include frontier acreage, the return has been 1:3.5 in recent years.

*So, how have we reached this conclusion?*

One challenge has been to find a good indicator of the value of recent discoveries. There are few transactions, and terms and conditions are rarely revealed. However, Wintershall's USD 740 million acquisition of Revus last year is one indication. Revus' portfolio consisted of discoveries like Luno, Astero, Jordbær, Oselvar, Vega South and Yme. Technical resources for these discoveries were 110 MMboe. Thus,

value per boe for undeveloped discoveries was USD 2.6 per boe for this portfolio of 3 unappraised and 3 appraised discoveries.

Statoil's USD 213 million acquisition of 15% of the high quality Goliat field corresponds to a value of USD 6.2 per boe if the Norwegian Petroleum Directorate resource estimate of 245 MMboe is used. This analysis came after 5 wildcat and appraisal wells were completed, giving a likely pre-tax cost of USD 600 million, after tax finding and appraisal costs of USD 0.55 per boe. Another "appraised" transaction was Lotos' acquisition of 10% of the Yme Field from Det norske for USD 56 million in 2008, corresponding to USD 8.2 per boe.

A second method of valuing discoveries is to look at current pricing of pure play Norwegian exploration companies, of which Det norske is the obvious candidate. Det norske currently has a market value of USD 740 million. The company holds 115 MMboe in six primarily unappraised discoveries, corresponding to 45% of the value of portfolio. This corresponds to a value of USD 2.9 per boe.

The third method is to do

Discounted Cash Flow (DCF) analysis for each discovery, which we have done using current forward curve. Results ranged from negative values to USD 6.4 per boe, with an average of USD 3.1 per boe when using the forward oil price. We found oil fields close to existing infrastructure, like Fulla and Marihøne, or fields with stand alone potential like Grosbeak (USD 4-5 per boe), had the highest value. Lowest value per boe was for small, deep and/or distal gas fields like Gro in the Norwegian Sea (USD 0.5-1.5 per boe).

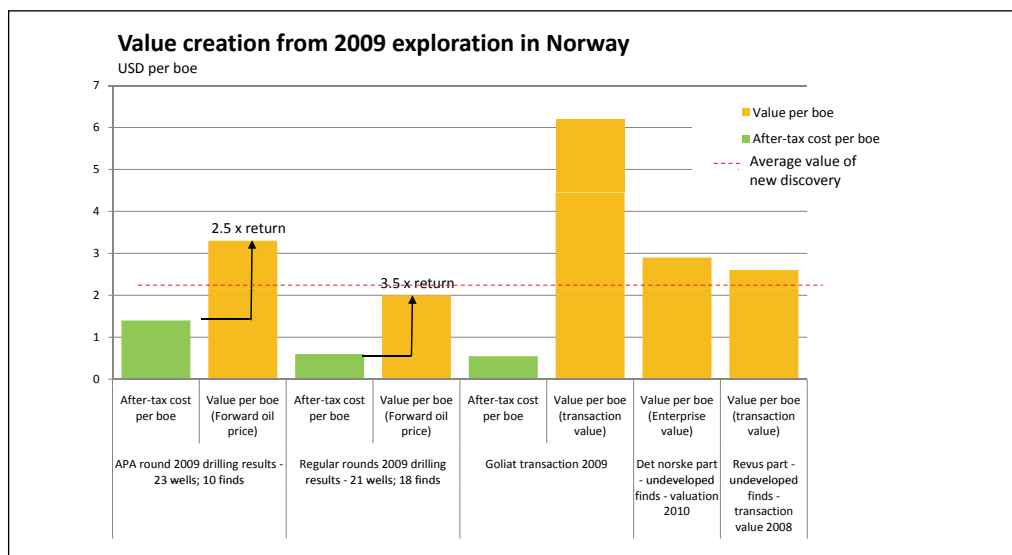
Combining these methods would indicate that unappraised discoveries on the NCS probably have an average value of USD 2.8 per boe. This is the after-tax value as companies see it, and should be compared with after-tax finding cost of about around USD 0.9 per boe. Pre-tax value is USD 12.7 per boe, which could be compared with pre-tax finding cost of USD 4.0 per boe.

Discovered volume at NCS in 2009 is uncertain since the Gro gas discovery field could be small, large or very large. However, assigning 530 MMboe to Gro, we

get in total 1.35 billion boe. The corresponding value was USD 3.4 billion when using DCF based on the forward curve and USD 1.7 billion when using the conservative USD 50/boe oil price assumption. With after-tax exploration cost of USD 1.1 billion, we can confirm the overall picture that one dollar in gives three dollars out.

For APA licenses, 23 wildcat wells were drilled with 10 finds grouped into six discoveries; Grosbeak, Corvus, Gygrid, Luno basement, Ragnarrock SW and Harepus. Total volumes are 250 MMboe and the DCF cash flow based on the forward curve USD 800 million. After-tax finding cost was USD 1.4 per boe, and value of the discoveries USD 3.3 per boe, confirming our numbers above.

Another 21 wildcats were drilled on acreage from regular rounds, of which only 5 of the wildcats were in acreage award after 2005, resulting in a surprisingly high success rate of 85% or 18 finds with a total volume of 1.1 billion boe, worth USD 2.24 billion. Finding cost for these volumes was only 0.6 per boe, again confirming our numbers above.

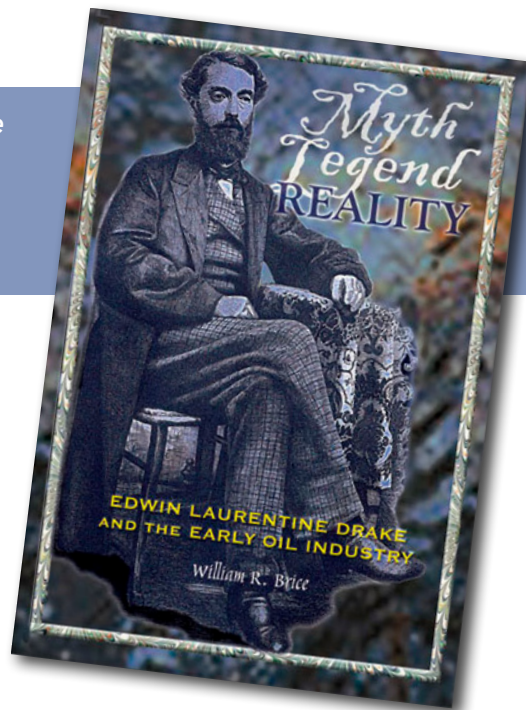


# Edwin Drake's Life and the Early Oil Industry

This well-written book offers the full story of a pioneer oilman, a historic discovery well, and all the players who gave birth to the modern oil industry.

*Myth, Legend, Reality - Edwin Laurentine Drake and the Early Oil Industry:*

William R. Brice. Published by Oil Region Alliance, Oil City, Pennsylvania



On 27 August 1859, a 21-meter well that “Colonel” Edwin Drake had drilled into a thin Devonian sandstone bed in the Oil Creek near Titusville, Pennsylvania, hit crude. This discovery well, a famous piece of history (“The Birth of the Modern Oil Industry,” *GEO ExPro*, 03/2009), ushered in the modern oil industry in the USA and around the world. Nonetheless, our knowledge of Edwin Drake’s life and well has long remained fragmentary.

Now 150 years later, we have a definite book on the life and career of this pioneer man and event. I say “definite” because this new book is a detailed, comprehensive, research-based, and well-documented work; it is also profusely illustrated. Its author, William R. Brice, professor emeritus of geology at the University of Pittsburgh at Johnstown and editor of the *Oil-Industry History*, devoted several years to researching and writing this 675-page volume.

The book begins with an informative overview of the history of oil in the ancient times (chapter 1) and in the Americas (chapter two), thus placing the Drake story in a historical and geographic context. The remaining eight chapters (the “meat” of the book) takes the reader on a vivid journey through Drake’s life, the nineteenth century Pennsylvania, and all the players who had a role in founding the

oil industry in that region, including chemists Samuel Kier and Benjamin Silliman, and entrepreneurs George H. Bissell, J.G. Eveleth, Francis B. Brewer, Asahel Pierpont, W. A. Ives, James M. Townsend and others who founded the Pennsylvania Rock Oil Co. in 1855 (later called Seneca Oil). At the end of the book, important historical documents and correspondences are given in appendices, and the Endnotes and Bibliography further enhance the value of the book for interested scholars and researchers.

Edwin Drake was born to a farmer family in Greenville, New York, on 20 March 1819, but grew up near Castleton, Vermont, where his family finally settled. Shortly after his mother’s death, Edwin, then aged nineteen, left the family farm in search of wealth. He did various jobs including working on a steamer, in a hotel, in a store, and more importantly as a conductor on the New York & New Haven Railroad. The latter job gave him a free train pass, and it was partly because of this privilege that Drake was hired by the Seneca Oil Company to drill into the oil seeps in Pennsylvania. Drake was then in his late 30s, a tall, bearded man who wore a black hat and long coat (his well-known image from photographs of that time).

Of all folks described in the book, one who practically

helped Drake in this venture was a less-known blacksmith and water-well driller by the name of William Smith (“Uncle Billy”) who put together the first mechanical engine to drill a well exclusively to extract oil from underground. The discovery well was successful because of Drake’s resilience and commitment.

Drake, however, did not profit from the oil wealth he had created for his bosses (nor did Uncle Billy). Overall, Drake lived as a poor man both before and after his oil discovery well. Only in 1873, the Pennsylvania Legislature granted an annual payment of \$1,500 to support Drake’s and his wife Laura’s life. Even then, his last years were spent in illness and he eventually died in Bethlehem, Pennsylvania on 8 November 1880.

Drake has been honored in various ways in the past, including a monument at Woodland Cemetery in Titusville (where Edwin and Laura Drake were buried), the 1952 movie, *Born*

*in Freedom: The Story of Colonel Drake*, by the American Petroleum Institute, and the Drake Well Museum and Park in the Oil Creek. Now this book takes Drake’s heritage to bookshelves around the world.

This new book is a chronicle of the pioneer efforts in a region and a period ripe for oil discovery. Petroleum (“rock oil”) replaced whale oil for lamps (and thus saved whale population), fueled vehicles to replace horse carts and eventually dominated the world’s energy production and consumption. Published by the Oil Region Alliance ([www.oil150.com](http://www.oil150.com)), the book will remain a cornerstone of our knowledge about this fascinating subject. The low price tag of \$40, obviously subsidized by grants, should encourage not only libraries, universities, and oil companies but also individuals (petroleum geoscientists, engineers, economists, and historians) to get a copy of this well-written book. ■



# CHINA: Deep water gas discovery

Calgary based Husky Energy is one of the largest foreign holders of exploration blocks offshore China and has been exploring in the area since 2002. In 2004 it signed a contract for the relatively unexplored Block 29/26, which covers nearly 3,000 km<sup>2</sup>, of the Pearl River Mouth Basin, approximately 300 km south-east of Hong Kong. The company was rewarded in 2006, when **Liwan 3-1-1** found significant quantities of gas. At the time this was the deepest water well drilled offshore China, in depths of 1,345 m.

In December 2009 Husky announced another discovery, 23km north-east of Liwan. Well **LH 34-2-1** drilled to a total depth of 3,500m and flowed at a restricted rate of 55 MMcfcpd, although eventual production rates are estimated to be in the region of 140 MMcfcpd of gas or more. Husky plans to drill an appraisal well on the new discovery early this year to determine its potential further.

Little further information about the latest well has been made available, but it extends the trend confirmed by the Liwan discovery, which targeted objectives in the Upper Oligocene Zhuhai Formation and Lower Miocene Zhujiang Formation.

Based on interpretation of the 3D seismic data, the Liwan discovery is estimated to contain a contingent resource of 4 - 6 Tcf (700 - 1,000 MMboe). Liwan is reported to have found 56m of net gas pay in two Tertiary reservoir zones, and recent

appraisal wells confirmed that it ultimately could produce more than 150 MMcfcpd. Production from the field is expected to commence in 2013.

The area around the Pearl River Mouth Basin experienced two major episodes of rifting along the South China margin from the late Cretaceous to the early Oligocene. This caused regional normal faulting, with

the formation of major sub-basins characterised by horst and graben structures. Regional subsidence since the Late Oligocene resulted in a tilted continental shelf with thick sequences of fluvial sedimentation in the Pearl River Mouth basin, ideal conditions for the accumulation of hydrocarbons in multiple reservoirs.



Photo: GeoPublishing

More gas has been found in the South China Sea.

# 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 Basin has identified a significant hydrocarbon column, confirming Tweneboa as a 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, deposited in an extensive turbidite fan system. The field lies in over 1,300m of water, 50km from the coast and close to the border with Cote D'Ivoire.

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

(*GEO ExPro* No. 5, 2009, p. 66). The country is rapidly pushing towards its first oil production from the offshore, anticipated possibly later this year.

Tullow operates the Deepwater Tano licence and is partnered by Kosmos Energy Anadarko, Sabre Oil & Gas, and the Ghana National Petroleum Corporation.





# BRAZIL: Billion Barrels Post-salt Discovery

Amongst all the hype about pre-salt discoveries in Brazil, it would be easy to overlook the largest Brazilian private sector offshore exploration campaign, which has been remarkably successful in the post-salt of the Campos Basin. Brazilian company OGX Petróleo e Gás Participações S.A. only entered the industry in June 2007, but since then has acquired 7,000 km<sup>2</sup> of what it described as 'high potential offshore acreage'.

This analysis seems to be bearing fruit, as drilling on OGX blocks in the southern part of the Campos Basin, which only started late last year, has already lead to a number of interesting discoveries.

In October 2009 OGX announced that **1-OGX-1-RJS**, the first well of a seven well programme, had discovered recoverable reserves of between 500 MMbo and 1.5 Bbo in block **BM-C-43**. The well is located approximately 85 km off the coast of the state of Rio de Janeiro, close to the border between the Campos and Santos Basins, in relatively shallow water of 140m. It was followed by **1-OGX-2-RJS**, on a separate prospect about 15km further north in **BM-C-41**, which reached a depth of 3,550m, and found high quality reservoir intervals, predominantly carbonates, in the Eocene, Upper

Cretaceous, Albian, Aptian and Barremian. Preliminary analysis suggests recoverable reserves across these reservoirs are between 1 and 2 Bbo.

The next well, **1-OGX-3-RJS**, about 6km from its predecessor in the same block but targeting a different prospect, also found hydrocarbons, recording an oil column of more than 180m and net pay of around 50m in carbonate reservoirs of the Albian, Aptian and Barremian sections, with some intervals presenting porosities in excess of 30%.

Based on recently released final test information on this well, combined with the 3D seismic data interpretation, OGX estimates that recoverable oil from for all reservoirs in this prospect alone is between 500 and 900 Mmbo. Potential production rate of the 20° API oil is thought to be in the region of 3,000 bopd. And finally, in January wells **1-OGX-4** and **1-OGX-5**, in blocks **BN-C-42** and **BN-C-43** respectively, have both reported the presence of hydrocarbons. OGX-4, the southernmost of these five wells, encountered an oil column of approximately 90m with around 17 ms of net pay in Eocene sandstone reservoirs, characterized by excellent levels of permeability, while OGX 5, which lies close to the

first well, OGX-1, found about 30m net pay of oil-bearing Albian carbonate reservoirs.

Both these wells are still drilling so the final analysis has yet to be undertaken, but the company believes it is working a very promising new play. Overall in the Campos Basin OBX has seven blocks, five of which it has started working on. Within these it has identified 24 prospects with prospective resources of 2,562 MMboe.

OBX is part of the industrial group EBX, founded by Brazilian entrepreneur Eike F. Batista, who has a very successful track record in developing new enterprises in the natural resources and infrastructure sectors.



Photo: Diamond Offshore

The 1-OGX-5-RJS in the Campos Basin is being drilled by Diamond Offshore's semi-submersible rig, Ocean Ambassador.

# USA: Treasure in Davy Jones Locker

The rocks buried at great depth beneath the waters of the USA Gulf of Mexico continue to reveal exciting discoveries. New Orleans based company McMoRan Exploration focuses on the Lower Miocene sub-salt and the 'deep gas' post-salt plays in the shallow waters of the northern Gulf of Mexico, and recently struck lucky with a well on the large Davy Jones ultra-deep prospect on **South Marsh Island Block 230**, about 10 km south of the coast of Louisiana, in only 6m of water. Spudded in June 2009, the well has already reached over 8,500m, with a proposed depth of 8,840m, and is targeting the Eocene Wilcox formation, the Paleocene, and possibly Cretaceous Tuscaloosa formation sands below a listric fault.

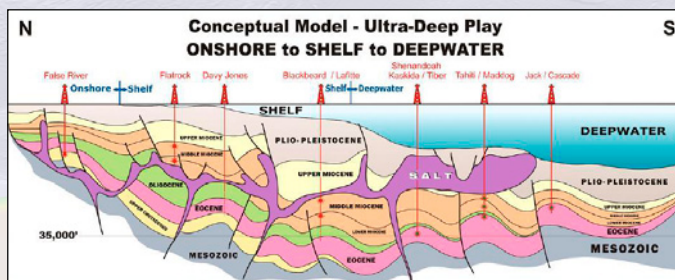
In mid January 2010 the company announced that the well had encountered 41m net of hydrocarbon-bearing sands in four zones in the Wilcox Formation of the Eocene/Paleocene. The reservoirs have yet to

be flow-tested, but the company reported that the sands logged below 8,321m appeared to be "of exceptional quality". As drilling continued the well found a lower hydrocarbon pool with an estimated 20m net pay.

While no reserve estimates have been announced yet, McMoRan Exploration has described the prospects it is chasing in the Gulf Coast region as having over 30 Tcf (840Bm<sup>3</sup>; 5.7Bboe) gross unrisks potential. The company believes that the Cretaceous section, productive onshore in the Tuscaloosa trend

north of Baton Rouge in Louisiana, extends offshore in deep horizons on the shelf, and this discovery would appear to bear out that hypothesis.

The Davy Jones discovery well will be followed by an appraisal well to the southwest to test similar sections at slightly shallower depths. The company also owns the Blackbeard prospect, on South Timbalier Block 168, about 100km to the south-east, which was drilled to over 9,400m and found Miocene-aged sands at that depth. In total, McMoRan has identified about 15 promising prospects on large structures on the Gulf of Mexico shelf, with ties to the deepwater.



It is hoped that the Davy Jones well will provide evidence to link deepwater shelf discoveries to the onshore fields.

McMoRan Exploration Co.



# Possible Oversupply in Ten Years Time

Peak oil will happen, eventually, but possibly not before the 2030s. In the meantime, we may be faced with oversupply, partly driven by increased production in Iraq.

## Rystad Energy

Rystad Energy is an independent E&P advisory and business intelligence data firm offering global database applications, stand-alone research products and strategy consulting services. From this edition onwards, Rystad Energy will provide analyses for our new column "Energy Statistics" (page 54).

*Rystad Energy has just entered its seventh year of operation, meaning that establishing the company was a success. How did it happen in the first place?*

I had conducted a lot of strategy work for international oil companies during my years with McKinsey. Often I felt that we spent too much time on data gathering and modelling, and thought that we could be even more efficient as consultants by reusing data through our own global information infrastructure. Most people thought that it would be totally unrealistic, so I decided to do it on my own. My old friend Per Magnus Nysveen, previously with DNV, also shared this vision, and we started up in my basement six years ago.

*So, what is the main product today? Or should we say products?*

First and foremost, we are a consulting company providing advice on E&P strategy, transactions and oil service markets for our clients.

*But you are not only offering consulting services. You are also marketing data bases?*

Yes, and this is the new thing for 2010, namely that we are now officially launching our global upstream database – our **UCube** – with production profiles and financial profiles for all fields, exploration blocks and E&P companies globally.

*Based on the number of people I can see around your office, you have grown into a substantial company. Tell me about your staff, locally and international!*

We have 32 people here at Lysaker, just south of Oslo, including my six fellow partners, consultants, analysts and technology developers. We have been recruiting only top academic people from Norway and abroad – half of our staff are non-Norwegian. In addition we have teams in Asia and Trondheim supporting us on scouting, with focused scouting tasks for companies and regions.

*In this edition of GEO ExPro, we are focusing on the Middle East. How do you foresee the future for the international oil industry in this region?*

According to our field-by-field forecasts, we see that Middle East growth might be 6 million bopd towards 2020. This is less than some other prognoses, but still more than any other region globally, just ahead of Brazil and North America. On the gas side, Middle East growth is even stronger, and Russian levels could be reached in 2020 if markets and politics allow it.

*Lately, Iraq has come into focus because of ten new contract areas. How will their efforts to boost production from 2.2 MMBopd today to possibly more than 6 MMBopd in 7 years affect the petroleum industry?*

If they succeed in this aggressive ramp-up, despite security and political issues and oil service constrains, we might actually go from a tight supply situation to temporarily global oversupply around 2016–2018, since oil sands, Brazil, the Caspian and deep water also will come in with significant volume additions. Majors will control part of this ramp-up, and might be tempted to prioritize high profit projects elsewhere, while Chinese players would push for progress.

*Finally, Mr Rystad, you sit on a huge data base concerning oil and gas reserves, what are your thoughts about Peak Oil and the future of fossil energy?*

Eventually we will see peak oil, and in our database this will be in the 2030s. New unconventional hydrocarbon resources will have more flexibility in terms of turning activity on and off according to the macro environment. Oil prices will see a long term increase in real terms, but we should expect large fluctuations given the dynamic forces in the economy. We will need 20 years of high oil prices to get sufficient investments and technological breakthroughs in renewable energy and "clean coal", and this will gradually take over from the 2030s. ■

Jarand Rystad, who holds a M.Sc. degree in physics from the Norwegian University of Science and technology, founded the Norwegian company Rystad Energy in 2004, having gained extensive experience in oil and gas strategy work through his long career with McKinsey & Company. His areas of expertise include exploration strategy, concession policies, asset transactions, corporate M&A, macro analysis, upstream technology and gas infrastructure.



Photo: Rystad Energy as



# Paleozoic Tight Gas Plays in Jordan

Compared to the other Middle Eastern countries, Jordan does not have a significant position in terms of conventional oil and gas resources. According to *Oil & Gas Journal* (21 December 2009), the kingdom's known oil reserves are only one million barrels and that of natural gas is 213 billion cubic feet.

Indeed, Jordan spends one-fifth of its gross domestic product to import 96% of its energy needs predominantly from Iraq (*Jordan Times*, 26 October 2009). Against this backdrop, it is interesting to learn that recently British Petroleum (BP) signed a deal with the government of Jordan to explore and develop the natural gas resources of the **Risha Basin** in eastern Jordan.

According to the agreement, signed by Jordan's premier Nader Dahabi and BP's exploration chief Michael Day last October, in the first phase of the project, BP will explore the area totaling about 7,000 sq. km (the equivalent of a North Sea quadrant) along the Jordanian-Iraqi border for 3-4 years at a cost of \$237 million. If the exploration yields successful results, BP will then invest US\$8-10 billion to produce between 300-1,000 million cubic feet (mcf) per day. Currently the Risha gas field produces 21 mcf from 20 wells.

Exploration of the Risha basin began in the mid-1980s with seismic shooting (9,057 km) and exploratory drilling by Jordan's Natural Resources Authority. Seismic images showed horst and graben structures in the Paleozoic section. The Paleozoic sediments dip and thicken eastward while the overlying Mesozoic sediments thicken toward west and dip under the Basalt Plateau. The total sedimentary thickness in the Risha basin exceeds 7,000 m. Risha-1 (3177 m total depth) and Risha-2 (3314 m) were drilled in 1984 followed by Risha-3 (4204 m) which discovered gas in Ordovician sandstones. Since then, dozens of wells have been drilled; many are dry but some wells produce gas. The Risha field delineated to be 1500 sq. km in area produces from Ordovician tight sandstone at depths of 2425-2575 m with thin beds (2-12 m each) in faulted glacio-fluvial channels. Its proven gas reserves are 180 billion cubic feet (Bcf) (equivalent of 34.2 MMbo) (*Oil and Gas Journal*, 2 July 2007). However, estimates of total gas reserves in the field range from 400 bcf (*Jordan Times*, 12 March 2000) to

Jordan covers a land area of 89,342 sq. km, with Amman as its capital



Illustration: Rasoul Sorkhabi

2-3 Tcf (15 September 2008, quoted from Abdulelah Rousan, then director-general of Jordan's National Petroleum Company, NPC).

If all goes well, the Jordanian government will receive 50% of the produced gas, with the other half going to BP and NPC. This will significantly boost Jordan's natural gas and electricity production. Currently there is an electric power plant in the Risha field.

In 2000, an international consortium headed by BP negotiated with Jordan to build a gas pipeline from Jordan via Syria to Lebanon. But the proposal was suspended after the government decided to focus on further exploration of the Risha basin. In the same year, the NPC in collaboration with Geoquest (a division of Schlumberger) conducted a detailed study of the Risha gas field.

The Risha gas field is located 270 km northeast of Amman. What amplifies the importance of the Risha field is that it shares a similar geologic history with the little-developed Akkas gas field, some 200 kilometers further east in Iraq. Indeed, the Paleozoic section thickens eastward up to 6,500 m. It appears that the deserts of eastern Jordan and western Iraq have a great potential for Paleozoic tight gas plays awaiting systematic exploration.

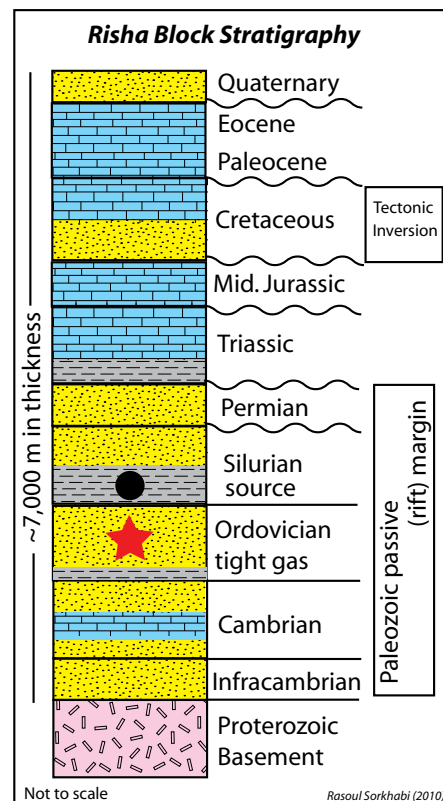


Illustration: Rasoul Sorkhabi

## Acknowledgements:

I thank Nicola Dahdah for helpful geologic information.



# More oil to come in war-torn Iraq

In less than 10 years Iraq's oil output may increase 3 or 4 times from today's level, thanks to contracts with major international oil companies that will now start redeveloping existing fields.

## CONVERSION FACTORS

### Crude oil

1 m<sup>3</sup> = 6.29 barrels  
 1 barrel = 0.159 m<sup>3</sup>  
 1 tonne = 7.49 barrels

### Natural gas

1 m<sup>3</sup> = 35.3 ft<sup>3</sup>  
 1 ft<sup>3</sup> = 0.028 m<sup>3</sup>

### Energy

1000 m<sup>3</sup> gas = 1 m<sup>3</sup> o.e.  
 1 tonne NGL = 1.9 m<sup>3</sup> o.e.

### Numbers

Million = 1 x 10<sup>6</sup>  
 Billion = 1 x 10<sup>9</sup>  
 Trillion = 1 x 10<sup>12</sup>

### Supergiant field

Recoverable reserves > 5 billion barrels (800 million Sm<sup>3</sup>) of oil equivalents

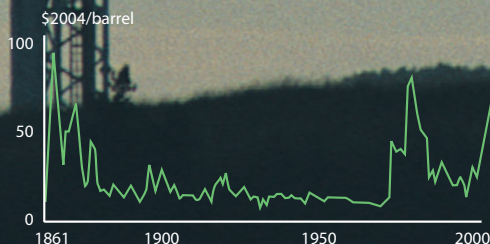
### Giant field

Recoverable reserves > 500 million barrels (80 million Sm<sup>3</sup>) of oil equivalents

### Major field

Recoverable reserves > 100 million barrels (16 million Sm<sup>3</sup>) of oil equivalents

### Historic oil price



Iraq's petroleum industry remains in tatters following many years of war. This is about to change, and in order to take full advantage of the huge (!) potential, it has been necessary to invite foreign oil companies to assist both financially and technically.

Two petroleum licensing rounds held in Iraq last year will almost certainly turn the country into an oil power nearly on par with Saudi Arabia within the next 5 – 10 years. The outcome of the rounds was 10 contract areas that may eventually result in more than 10 million barrels of oil produced every day. Saudi Arabia for its part produced 10.8MMbpd in 2008.

Despite its rich petroleum resources, violent events in Iraq over the past three decades have hampered the country's exploration and production. Iraq's maximum production of oil was about 3.5MMbpd in 1979, a year before President Saddam Hussein started his war with Iran. The "all time low" in 1991 was about 240,000bpd. Since then, Iraq's daily output has risen to 2.4MMbpd in 2008, up from 1.34MMbpd in 2003.

The licensing process started last summer when Iraq's government hosted an auction for 8 oil and gas fields (Iraq's First Petroleum Licensing Round). Only one bid succeeded. BP and CNPC laid their hands on the super-giant Rumaila field (discovered by BP in the

1950s!) close to Basra in southern Iraq. It may contain as much as 65Bbo and as such is one of the world's largest oil fields. The commitment is to increase production until it reaches a plateau of 2.85MMbpd.

We have to get used to big numbers when talking about this "oily" country.

Later, in November, the government made deals with both Eni and Exxon Mobil/Shell to develop Zubair and West Qurna, respectively. Together these fields are expected to produce 3.3MMbpd after having reached the targeted plateaus.

In December, we were informed of the results of the next auction (Iraq's Second Petroleum Licensing Round). The combined oil reserves in the fields were estimated at about 41 Bbo, of which West Qurna, phase 2 (a super-giant field in southern Iraq, discovered in 1973) and Majnoon (another supergiant in south-east Iraq, discovered in 1976) were the largest.

Seven contract areas were then awarded, with Petronas, Sonangol, Lukoil, Statoil, Japex, Gasprom, Kogas and TPAO as additional players. The target plateau production for these areas totals close to 5MMbpd. West Qurna (Lukoil, Statoil) and Majnoon (Shell, Petronas) both have targets of 1.8MMbpd.

*Please refer to GEO ExPro No 3, 2009, pp. 28-34, for in depth knowledge of Iraq's petroleum resource base.*



Photo: Ailo K. Abrahamsen

In 2003, the Rumaila oil field was set on fire in the early stages of Operation Iraqi Freedom. The field will now be redeveloped with the assistance of BP and CNPC.

### 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