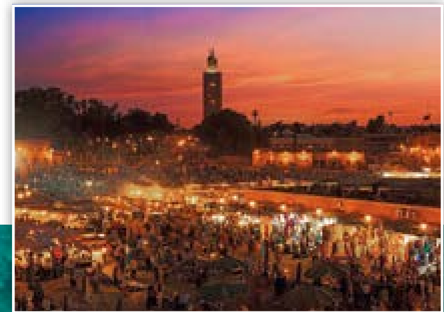
VOL. 13, NO. 1 – 2016

# GEOExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED



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EXPLORATION

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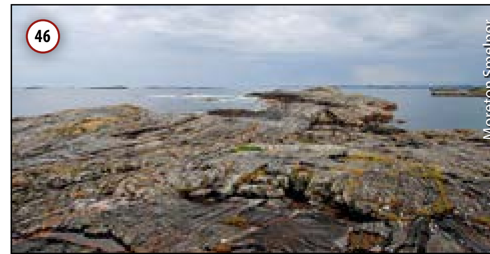


*The Atlantic Road, one of the National Tourist Roads of Norway, offers great scenery all year around.*

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This edition of *GEO ExPro* magazine focuses on North Africa, the Middle East, carbonate reservoirs and non-seismic geophysics

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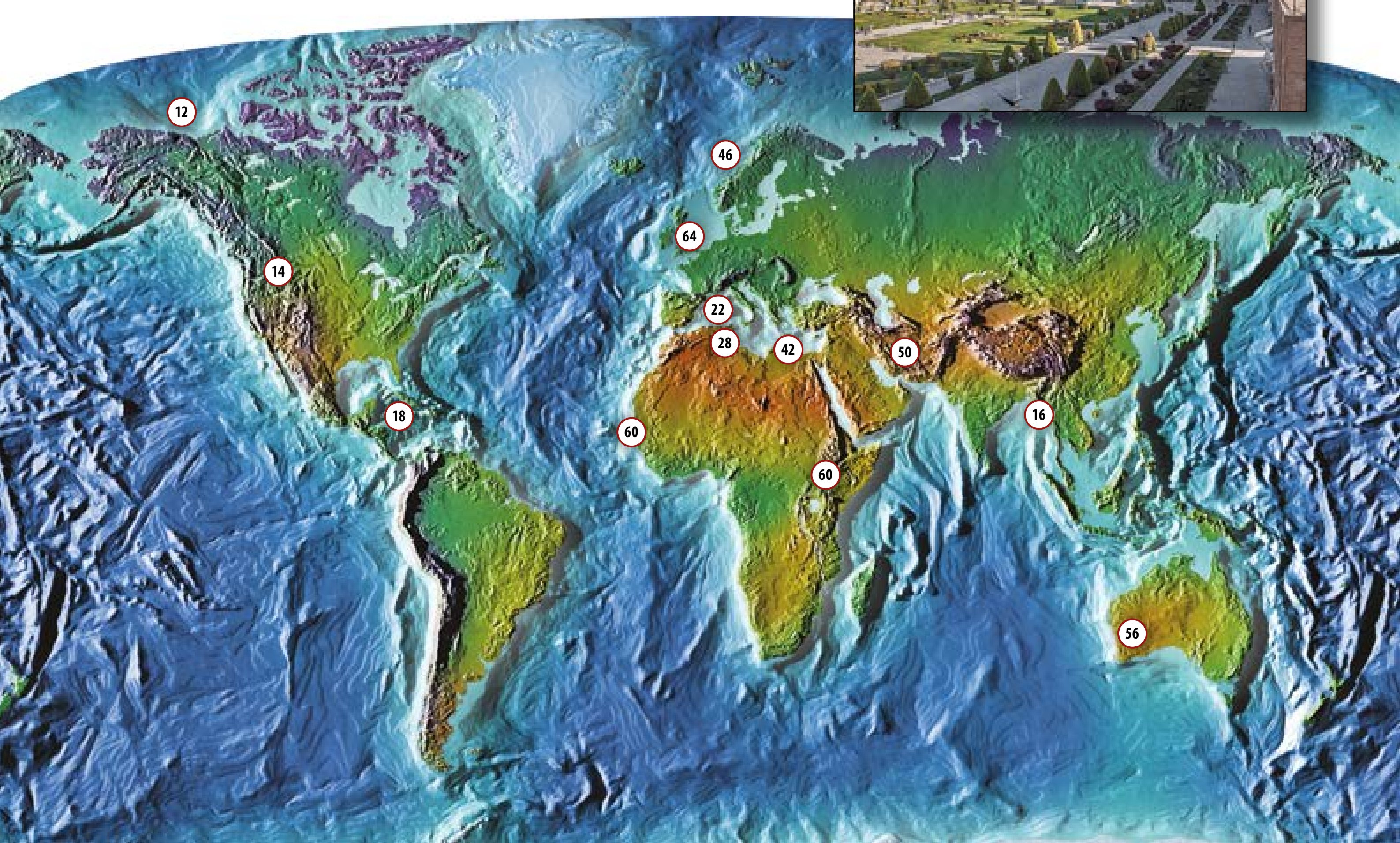
*With the removal of sanctions, Iran could provide a significant opportunity for the right companies.*

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KNOWLEDGE IS OPPORTUNITY

C&C Reservoirs

# A Wind of Change?


According to analysts Morgan Stanley, the climate change deal signed in Paris in December 2015 is another nail in the coffin of the oil industry. Under the accord governments agreed to limit global warming to below 2°C, aiming for 1.5°C, and each participating country must outline how this will be achieved. Will this mean that some already found and indeed yet-to-find reserves will be left in the ground? And how should the already rather embattled industry react?

It would appear that in the short term, at least, the agreement may have little impact, partly because while the overall agreement is legally binding, much of it is not, including individual pledges to curb emissions and means of financing change. Substantial action is not expected until 2020, so the industry can expect to concentrate on the immediate issues surrounding the low oil price, watching until this induces consumption to rise sufficiently for the supply/demand imbalance to redress itself.

However, industry is beginning to look at climate change issues on a longer term basis. For example, the International Petroleum Technology Conference in Qatar, coincidentally held concurrently with the Paris talks, included a forum on the topic, which was in itself evidence of how importantly it is viewed. Senior industry leaders discussed how $CO_2$ emissions should be addressed by the industry, how they thought the Paris discussions would affect the business and how they were approaching the subject in their own organisations. There was much talk of cross-company collaboration on the development of technically possible and commercially feasible emissions-reducing technologies and the need for a consistent set of global priorities for the industry to sign up to.

There is definitely a wind of change in industry thinking, possibly as a result of a simple realisation that the topic has to be addressed and we should have a major role in influencing and guiding developments, rather than just letting them happen. ■

***Jane Whaley***
*Editor in Chief*


DRONE MAGIC

UAV-acquired photos 50m above the exposed Pleistocene reef on West Caicos Island enable detailed mapping of outcrop exposures that include fault, fracture and facies analysis. The entire 7.5 km shoreline was photographed in three days and it took approximately 50 photos to make this composite.

Inset: The vibrant Djemma el Fna, Marrakech. Morocco's 2016 elections will be another power-sharing test in North Africa.



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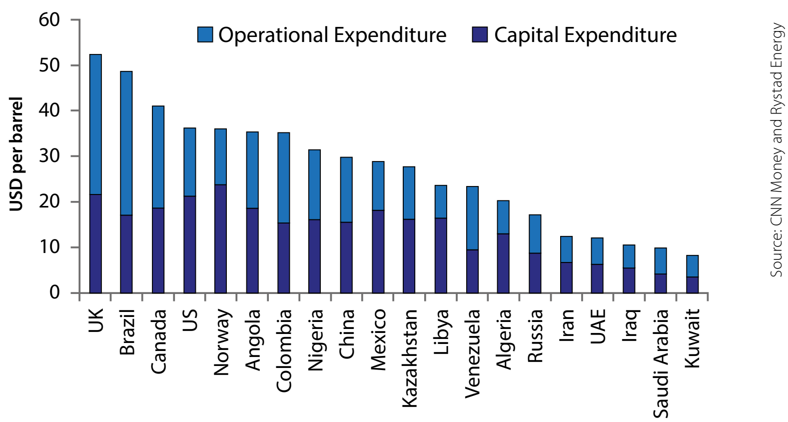
# Tough Times Still Ahead

## Six factors suggest the oil price will remain low in 2016.

Oil prices fell markedly in December and still further in January, dropping below $30/barrel for a short time. The average Brent 2015 price was $54/barrel and it is expected to be lower in 2016, influenced by six factors which will add to the current supply glut and postpone the time at which the market might be expected to balance.

1. **OPEC: No new target – no new strategy:** At OPEC's meeting in December the cartel completely dropped a new quota, citing the uncertainties surrounding Iran's future production volumes. Collaboration appears to be failing. There is political disagreement over how the quota should be distributed among member countries and Saudi Arabia is not yet happy with the results of the strategy change. The lack of a quota means low oil prices for longer, as OPEC floods the market with cheap oil to squeeze out more expensive producers.




***Overall cost to produce a barrel of oil in different countries.***

2. **The US Federal Reserve increased rates:** The US hiked interest rates for the first time in almost a decade at the end of 2015, indicating that rates will rise further in 2016 and 2017. Higher rates will keep US economic growth moderate and dampen oil demand. This also strengthens the dollar, making oil traded in dollar terms more expensive to large oil importers.
3. **COP21 environmental targets:** Exactly how and how fast the UN climate agreement in Paris will influence the oil balance is still uncertain, but there will clearly be a significant impact on both production and consumption of oil. Higher carbon costs and stricter regulations on emissions from oil and gas production may be imposed in some oil-producing countries, which should make oil less cost competitive compared to lower emission/green alternatives.
4. **US crude export ban lifted:** The lifting of the 40-year ban on US crude oil exports in late December 2015 could lead to a further increase in US oil production, and environmental groups have reacted with fury. However, the export of large volumes of US light tight oil into a saturated global market are unlikely in the near future, and US shale producers have already cut output in response to lower prices. Lifting the export ban is expected to lead to increased competition and less pressure in the Brent market and thus lower Brent prices.
5. **Libya's peace deal:** Libya's two rival factions signed a UN-backed deal to form a unity government in December, hoping to end four years of chaos in the oil-rich North African nation. Before the downfall of Gaddafi in 2011, Libya produced around 1.6 MMbopd, but fighting has stopped operations at strategic oil terminals and production fields, and output is down almost 80%. With a lasting peace agreement Libya can ramp up production, adding to the large supply glut.
6. **A mild winter:** Unusually warm weather at the start of the winter season reduced heating oil demand and increased the downward pressure on crude oil prices. ■

**Thina Margrethe Saltvedt**

### ABBREVIATIONS

**Numbers**
**(US 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$^3$ gas
MMscmg: million m$^3$ gas
Tcfg: trillion cubic feet of gas

Ma: Million years ago

**LNG**

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

**NGL**

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

**Reserves and resources**

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

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

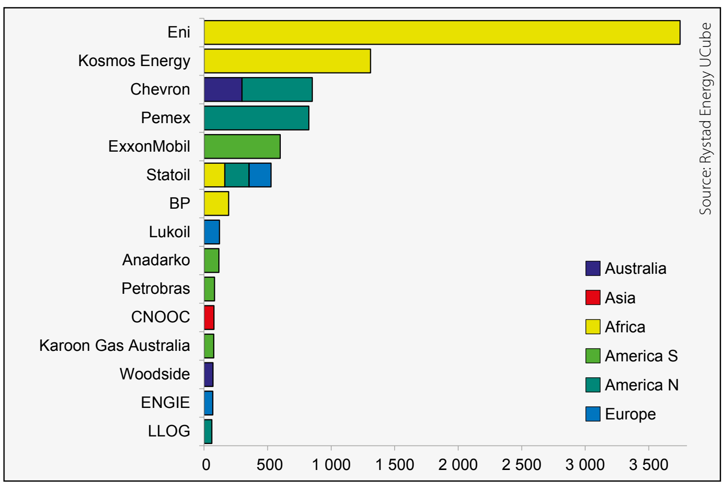
**P3 reserves:**
Quantity of hydrocarbons believed recoverable with a 10% probability

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

# 2015 Exploration Results: Eni Best in Class

Prior to official results, the speculation for the year was that discovered hydrocarbon volumes would continue their downward trend. The results now in show that offshore-discovered volumes were 8.5 Bboe, of which 2.6 Bboe were liquids. This is slightly lower than the results in 2014, and considerably lower than the 18 Bboe discovered in 2010.

In terms of activity, about 600 offshore exploration wells were drilled through the year, resulting in total investment of US$55 billion, 25% lower than 2014 values.



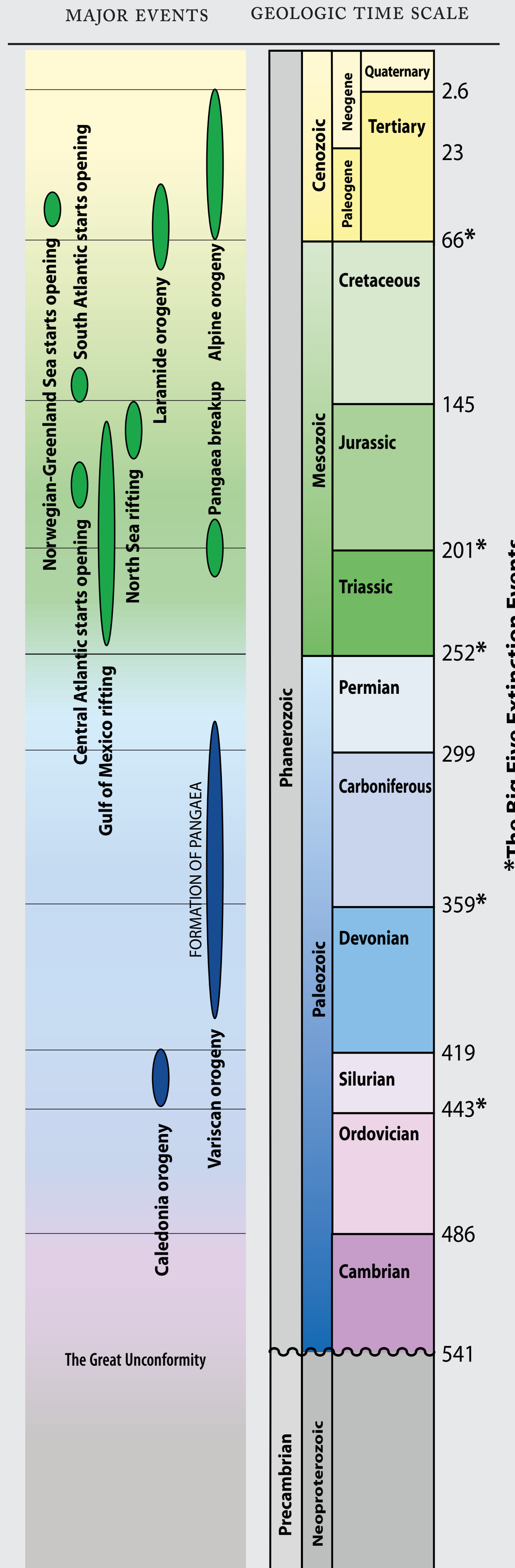

***Global 2015 offshore-discovered volumes for the 15 largest operators (excludes volumes added from successful appraisal exploration), Million boe.***

The chart above shows the 15 largest operators in terms of discovered offshore volumes in 2015. Topping off the list is Eni, with 3.7 Bboe of discovered resources last year. Most of these volumes are related to the Zohr discovery, located in the Egyptian part of the Mediterranean. Kosmos Energy takes second place with its discoveries in Mauritania. These discoveries may contribute to a new gas province on the western side of Africa – similar to what has happened in Mozambique and Tanzania, where the teams of Anadarko/Eni and BG/Statoil are both planning large LNG developments. Another important discovery was Exxon's Liza discovery in Guyana; the resource estimate of 600 Mboe makes this the largest oil discovery in 2015.

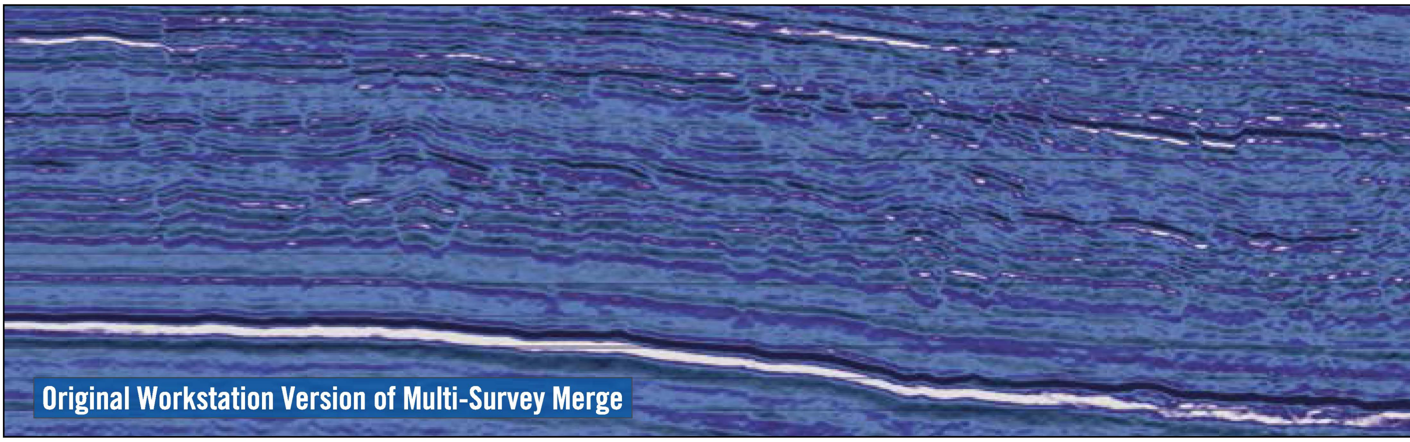
In many ways, 2015 is similar to preceding years, with discoveries dominated by large African gas finds. Other regions had more disappointing results. Offshore Europe discovered 500 Mboe, with the Romanian Lira discovery as the main driver. In Asia, around 300 Mboe were discovered, while there were no significant discoveries in the Middle East.

If we compare 2015 discovered offshore volumes with 2015 production, it is obvious that we would not be able to replace the volumes we produced during the year. In 2015, total offshore production was 16 Bboe, of which 9.7 Bboe was liquids, considerably lower than the amount discovered. In the long term, this implies that it will become difficult to keep up offshore production volumes. ■

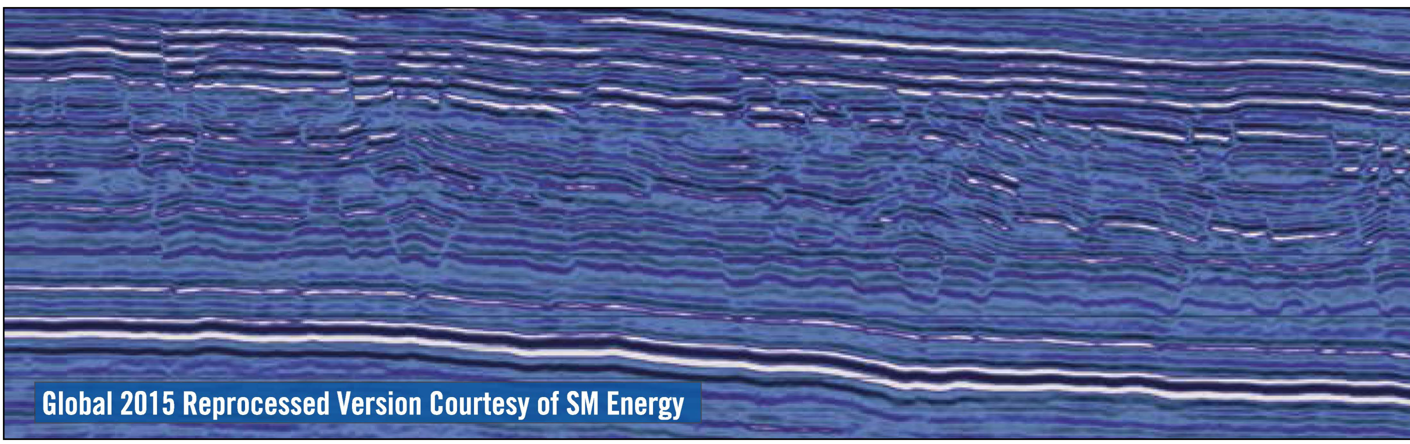
**Espen Erlingsen, VP Analysis, Rystad Energy**



# OLD DATA, NEW RESULTS.



Original Workstation Version of Multi-Survey Merge



Global 2015 Reprocessed Version Courtesy of SM Energy

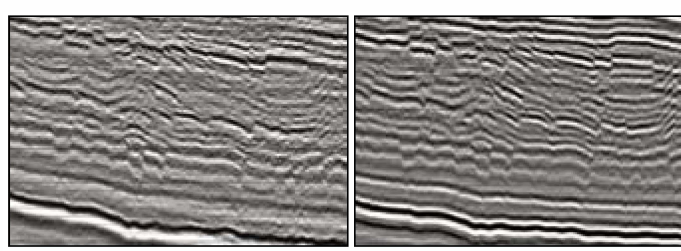
# REVEAL NEW VALUE IN YOUR DATA

Recent innovations in technology and understanding have started a quiet revolution in seismic processing. Reprocessing vintage 3D seismic using Global's new work flows can bring new life to your old data in a fast, affordable, and actionable way. To the geoscientist, this means:

- Increased bandwidth and higher resolution
- Better imagery; sharper, crisper, better positioned fractures and faults
- Insanely flat gathers in both offset and azimuth, out to 50 degrees of incidence angles
- More accurate offset amplitudes in the final gathers, producing true "Inversion Ready Gathers"
- New and interesting azimuthal characterizations of the seismic data producing new attributes which correlate nicely to well production data

These "Inversion Ready Gathers" produce more accurate traditional rock properties and lithology predictions, and when combined with the new azimuthal attributes, ambient seismic, and also existing well production and engineering information, allow for predictions of hydrocarbon production at both existing and proposed well- and even stage-level locations. The ability to predict production away from the well in an accurate fashion enables optimization of all phases of your field development program in both conventional and unconventional reservoirs.

Our integrated seismic solutions include autonomous nodal acquisition, ambient seismic time lapse recording and processing, data processing producing truly "Inversion Ready Gathers", reservoir analytics and production predictions, interpretation, and consulting services. Our objective as a service company is to help oil and gas companies reduce field development cost through optimized well placement and completion programs.



*Proprietary workstation version of final stack (left) compared to Global 2015 reprocessed version (right). Note improved imagery in the reprocessed version, especially the fault clarity. What is not shown is the interval HTI attribute, a very intriguing by-product of the reprocessing and good predictor of hydrocarbon production. South Texas Eagle Ford example courtesy of SM Energy.*

**For More Information:**
**www.globalgeophysical.com/REPROCESS or**
**Contact REPROCESS@globalgeophysical.com**

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# Finding A&D Opportunities in the Fog

## Global upstream exploration deal flow in a declining commodity price market.

**MIKE LAKIN**, Envoi Limited

When assessing opportunities for successful acquisition and divestment of upstream assets, looking into the future can be compared to driving in the fog, en route to catch a ferry. Even when familiar with the road, the risk of serious accident can only be reduced by slowing down to a safe speed, but one is likely to get to the port after the ferry has departed. One could find an alternative route with less likelihood of fog, even if this involves a long detour; or follow the normal route and take the next ferry, or not go at all. When the fog might clear is unpredictable – like the current oil price!

In a low or declining oil price environment, the industry generally knows where it is trying to go but whilst uncertainty continues few decisions are made and new funding becomes largely unavailable until the bottom has been reached and confidence returns. How long will it take this time? Predictions range from six months to over three years.

### The Oil Price

Although oil demand has declined recently, global demand long term is expected to continue to increase with population and associated industrial growth. There is a huge gap in technical experience (due to previous downturns) which will severely hit the ability to find new resources in more subtle and complex hydrocarbon plays. Even the world's largest and most influential oil producers could only sustain such a continuing price drop for a limited period before a global recession. Perhaps the latest decline, exacerbated by the prospect of Iran opening the taps and increasing oversupply even more, will hurt enough of the big producers that they will agree quotas that ensure their share of production, in order to stabilise supply and demand, thus leading to a price increase.

Survival of the world's upstream sector in the immediate future now depends on available cash flows, cost management and preservation of available resources, with the inevitability that a long, drawn-out return to oil price stability will see more businesses struggle or even disappear.

For some, this may be the first experience of a severe downturn, but I suspect that for most it is just another one to endure and survive with cuts and downsizing, trusting that the price will come back up and the industry will rebalance at whatever price is sustained for confidence to return. The graph below shows the oil price since the early 1980s and various key influences since. Interestingly, the price changes with the most damaging effects all seem to be clearly linked to industry-driven factors – and specifically to the dominant producers causing the current price war. One therefore wonders how much this is connected to the change of power in Saudi Arabia since the death of the old king in late 2014.

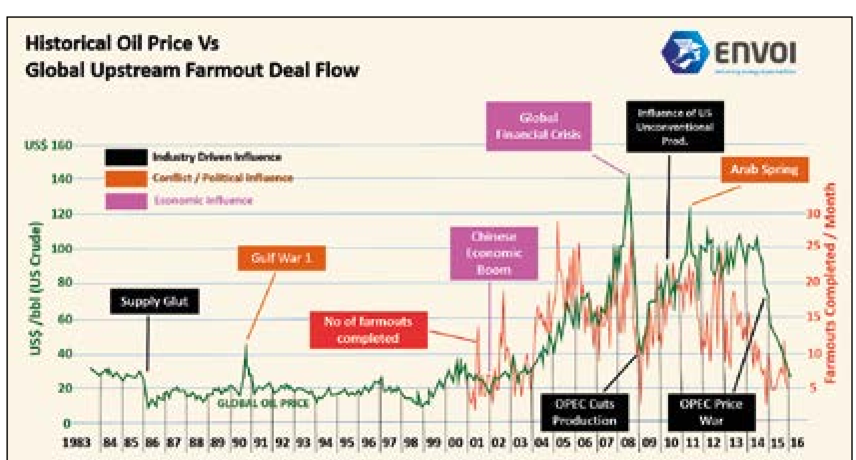
### The Opportunity

Although the majority of the upstream sector suffers in such a dramatic global price decline, the old saying, *'One man's loss is another's gain'*, comes to mind. Arguably, those investors with resources, and confidence that the price will rise up in the next 5+ years, now have a fantastic window of opportunity to invest at the lowest price point (wherever that might be) without much competition, to cherry pick the best upstream deals at the cheapest price from distressed companies trying to survive.

Looking at the number of global upstream exploration deals (farmouts, excluding North America) that have been concluded since 2000 (source JSI Services Ltd), we see a close match between deals per month and the oil price: they decline together. The fact that the same number of deals tends to be available, regardless of the price cycle, and that since 2000 the JSI Global Upstream Deals database shows an average 20% commercial success rate for farmout wells, clearly suggests that now is the right time to invest if one believes the oil price will increase within the next five years. Companies struggling to hold onto their longer term exploration may call these opportunists 'vultures', but buying low and selling high is what drives most free market sectors.

The statistics show that during dramatic oil price declines, exploration deal flows track the price, only increasing when exploration costs also go down, until the rate of decline slows and bottoms out. Much lower costs for exploration work programmes then coincide with a return of investor confidence and the ability to invest in future exploration deals on very favourable terms.

As when trying to catch the ferry in the fog, the best option is to accept that the journey may take longer and the initial ferry missed. Making the right decisions in the current low price climate, based on a longer term view and using the best upstream E&P expertise, can undoubtedly unlock high value opportunity at lower cost and with limited competition. ■



# What Next for the Arctic?

## Arctic waters hold vast undiscovered hydrocarbon reserves, but will they ever be exploited?

JANE WHALEY

The US Geological Survey estimates that the Arctic holds undiscovered reserves of about 90 Bbo, 1,669 Tcfg, and 44 Bb of natural gas liquids, the majority of it offshore. When the oil price held steadily at over US$100 per barrel, a number of countries and companies were eyeing these northern riches, but in the present price environment, things look very different.

### Pulling Out

Exploring offshore in the Arctic is very expensive: a very short ice-free weather window for drilling; massive safety issues; hugely expensive specialised technology; and major environmental regulations. With the present oil price all these add up to make exploring in Arctic waters very unattractive at the moment.

After spending a number of years in litigation and in discussions with environmental authorities to gain permission to restart drilling in the US Arctic Chukchi Sea, super-major Shell finally drilled the Burger J well in the summer of 2015 – to find only a few traces of hydrocarbons. The company promptly announced that it would withdraw from the region completely, despite reportedly having spent an estimated $7 billion on its Arctic efforts.

Shortly afterwards, in October 2015, the US Department of the Interior cancelled two Arctic offshore lease sales, in the Chukchi and Beaufort Seas, both part of the US current five-year offshore oil and gas leasing programme for 2012–17. The department claimed that its decision was prompted by Shell's disappointing well, plus the fact that companies had shown very little interest in the sales. The US authorities also turned down requests from Shell and Statoil for lease extensions that would have allowed them to retain their Arctic leases beyond the primary 10-year term, claiming that the companies "did not demonstrate a reasonable schedule of work for exploration and development".

Then in November Statoil announced that it would be pulling out of all its leases in Alaska's Chukchi Sea, saying that "given the current outlook we could not support continued efforts to mature these opportunities".

Environmental activists rejoiced. But does this spell the end of exploration in Arctic waters?

### Time to Consider and Plan

Unlikely. The US is only part of the story: Russia, Canada, Norway, Greenland and Iceland all have Arctic coastlines too. Statoil is drilling in the Norwegian Arctic and gas is already coming ashore from the Snøvit fields, about 450 km north of the Arctic Circle. With the enthusiastic backing of President Putin, Russia is actively exploring its Arctic waters, and in April 2014 announced the shipment of its first tanker of Arctic offshore oil, from the Prirazlomnoye offshore field, in the Pechora Sea, less than 100 km from coastal and island wildlife reserves.

Many people not involved in the oil industry consider the hazards involved in Arctic exploration, particularly from the environmental viewpoint, not worth the potential prize. A major – or even minor – oil spill could have very far-reaching effects on the fragile ecosystems of the Arctic. Even with the very strict regulations in place in the US, it is doubtful if such a spill could be easily contained. Although to undertake further offshore exploration Russia probably needs technical help from US multinationals, unavailable at the moment due to sanctions, the lower regulatory regime there makes exploration in these waters disquieting.

Cheaper oil is for the moment driving people away from offshore Arctic exploration. Maybe this will give us time to step back, undertake detailed research, and analyse the pros and cons in a more informed and less intense manner. More discussion and cooperation between the Arctic nations is needed, particularly to look at technological solutions which could make drilling there reliably safer, both for the people involved and for the environment.

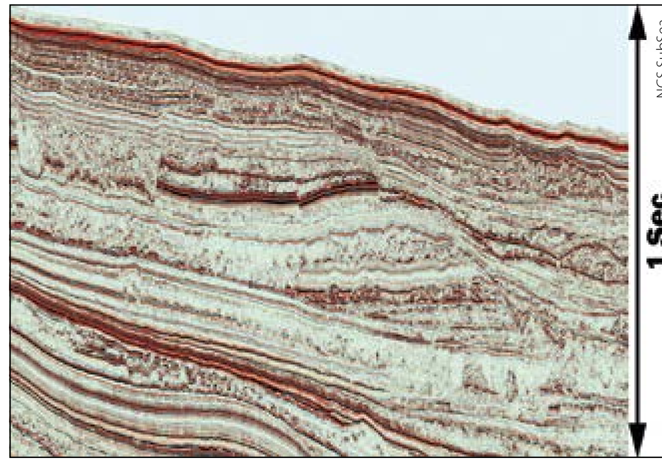
At some time, the oil price will go up again. When it does and Arctic drilling becomes more economically feasible, we must have information available to know whether we can do it safely – and if we should do it at all. ■

Harald Pettersen – Statoil ASA

*The LNG plant at Melkøya in the Norwegian Arctic processes gas from the Snøvit field, 170 km to the north.*

# Breaking UHR3D Barriers

As **ultrahigh-resolution 3D seismic** methodologies have become more prevalent in the marketplace, consumers of this technology have started to look towards broadening the sphere of applicability of this, now proven, niche portion of the seismic acquisition industry. Recent innovations in acquisition hardware and methodologies have allowed companies such as **NCS SubSea** to overcome limitations in record length and water depth. Specifically, adapting the UHR3D system to continuous recording allows for the collection of longer records without sacrificing fold in situations of greater water depth or subsurface target depth. Also, the implementation of multiple source acquisition strategies allows for greater optimisation of systems, such as the P-Cable, for the collection of data in shallow water situations where near zero offsets are necessary to properly image the seafloor and shallowest subsurface. Further improvements are currently underway, and as demand dictates, UHR3D acquisition methodologies will continue to break barriers as we move further into the 21st century. ■




# Creative Data Solutions

In an effort to access and visualise all geoscience data, **Neuralog** recently introduced **Neuralog Desktop**, a standalone ESRI GIS-based interface which enables geoscientists to create, organise and visualise data and projects across platforms and datasets within a single application. Logs, documents, seismic data and all ancillary well data can easily be organised by well, field, lease or any user-defined entity. The map interface and area tree enable users to quickly navigate and access critical data and documents in a couple of clicks. With the inclusion of **NeuraSection** it is possible to correlate logs, create cross sections, contour maps and create project montages directly from the GIS map. You can also capture, edit and save log and map data directly into the project database. Whether digitising a log or evaluating prospects, data can be quickly accessed, analysed and then updated into the database for future interpretation through Neuralog or other products.

Neuralog was founded in 1991 to find creative solutions for exploration and production problems through the application of advanced computer science technologies and client direction. Today its solutions are recognised around the world as the best for digitising, exploration and production valuation, and log scanning and printing; over 1,000 customers from super-majors to small independents in 70 countries use Neuralog products. ■

# Record Speaker Interest for ACE 2016

A record number of abstracts – 1,830, representing a 6% increase on the previous year – have been submitted for **AAPG ACE**, to be held on **19–22 June, 2016** in **Calgary**, suggesting that this event will continue the century-long tradition of delivering exceptionally strong, juried technical programmes and a highly successful conference. The technical programme features more than 900 technical and poster presentations in eight concurrent sessions, and field trips, short courses, luncheons and the International Core Conference are also available.

With a global audience of some 7,000 professionals from more than 72 countries, ACE is one of the most prestigious events for the geosciences community, with a tradition of delivering scientific excellence and professional camaraderie. The **Canadian Society of Petroleum Geologists** hosts AAPG's flagship event, which returns to Calgary for the first time in 10 years. A global energy centre with the Canadian Rockies in its backyard, Calgary is home to a strong local crowd of geoscientists.

Exhibition space and sponsorship opportunities are also available and registration is now open at ACE.AAPG.org. ■

*AAPG ACE 2016 will be held in Calgary.*

# Largest Man-made Moving Object

Polarcus Amani


Dubai-based seismic company **Polarcus** is breaking records! The ***Polarcus Amani*** is currently acquiring an ultra-wide 3D marine seismic project offshore **Myanmar**, towing an in-sea configuration that measures 1.8 km wide across the front ends. With each of the ten streamers separated by 200m, the total area covered by the spread is 17.6 $km^2$, making this the largest in-sea configuration ever towed by a single seismic vessel, as well as the largest man-made moving object on earth. With this spread, Polarcus is also setting new acquisition performance records. The acquisition plan in Myanmar will deliver up to 190 $km^2$ per day, a production rate that is currently unrivalled in the seismic industry. The survey is being undertaken for Shell Myanmar Energy PTE Ltd. ■

# Africa Independents Forum

As recent discoveries show, despite the industry downturn Africa still has plenty to offer, and the **14th Africa Independents Forum 2016**, hosted by **Global Pacific & Partners** and **ITE Group plc**, is the place to go to learn more. The forum, to be held on **25–26 May** in **London**, will showcase independent companies with acreage and portfolio assets in the Gulf of Guinea, North West Africa, Maghreb-North Africa, Central Africa, Eastern and Southern Africa and in landlocked and littoral frontier states. A wide range of expert speakers will provide unparalleled insights into current and emerging exploration plays and capital development projects, current corporate strategies in-place, winners and losers, and the unlocking of Africa's large hydrocarbon reserves, as well as the state of Africa's geo-economics and the key issues shaping the future funding of companies and ventures in Africa's upstream.

Running alongside the Forum are the 18th Scramble for Africa Strategy Briefing; 75th PetroAfricanus Club Reception; 6th Global Women Petroleum and Energy Club Luncheon on Africa; and the 2nd Africa Oil & Energy Investor Forum. ■

# Recent Advances in Vibroseis Technology

While improvements in systems and sensors grab the headlines in terms of land seismic product development, vibroseis technology has also seen some exciting progress. **INOVA Geophysical** is at the forefront of this development, stemming from a long heritage in this technology space.

Increasing interest in low frequency recording resulted in the AHV-IV 364™ Commander vibrator. With a full drive of 61,800 lbs, frequency range of 1–250 Hz and peak force from 5 Hz, this is one in a series of vibroseis vehicles specifically designed for broadband acquisition. Constructed for reliability, it included major improvements designed for better low and high frequency performance. For greater peak force (up to 80,000 lbs) there is the 380 heavy vibrator. Broadband requirements and the need for a smaller vehicle to access difficult or environmentally sensitive areas propelled the recent development of UNIVIB®, which provides flexible hold-down weight variable from 18,000–26,000 lbs and a frequency range of 1–400 Hz.

Source control is an integral part of INOVA's vibroseis technology. Earlier this year, in partnership with Seismic Source, Inc., the new Vib Pro™ HD controller was released, delivering class-leading performance on a modern digital platform. This technology forms a critical part of INOVA's CLARITY Broadband™ solution, which includes broadband MEMS sensors (AccusSeis/VectorSeis) and high performance cable (G3i HD) and cableless acquisition systems (Hawk). ■

# Benchmark for Success

Given the current state of the industry, it is important that E&P decisions be de-risked as much as possible. There will always be subsurface uncertainty, there are typically multiple options to consider, and for some projects, there are practices you simply want to avoid – but do you know what they are? Unfortunately, we often rely only on our individual or company experience to tackle these problems. What's really needed is a olution that aggregates knowledge from the entire industry and makes it easy to use.

One approach to addressing these issues is through **benchmarking** using **global analogues**: finding projects with similar characteristics that exhibit superior performance. Comparing expected performance against these demonstrated best practices and success cases can help to validate project assumptions, identify knowledge gaps, and improve understanding of what might work, and what might not. A global analogues database, covering more than 500 geological and engineering parameters for global reservoirs and fields, along with the tools to quickly analyse and capture proprietary knowledge, can help benchmark for success. Visit **C&C Reservoirs** at GEO 2016 for more information. ■

# Drone Magic

THOMAS SMITH

**Photographs acquired through unmanned aerial vehicles are revolutionising digital outcrop models, allowing geoscientists unprecedented insight into subsurface reservoirs.**

"When developing an oil field or, for that matter, any subsurface resource, geoscientists see only a small fraction of what is actually there through bore hole data," says Christopher Zahm, a research associate at the Bureau of Economic Geology (BEG), University of Texas at Austin. "From this limited data, they determine what rock features will impact the extraction of those resources. Outcrops provide an analogue the geoscientist can use right at the outset of a project for predicting what can be expected underground."

A digital outcrop model (DOM) is a digital, 3D representation of an outcrop surface. These models enhance conventional fieldwork, particularly in areas that are difficult or dangerous to access. The geological interpretation can be performed on a computer screen. The interpreter can use the models to accurately measure different geological features such as the spatial distribution of rock types, fracture orientation and density, layer thicknesses, and surface orientations. The accuracy of the interpretation and identifiable geological features is highly dependent on the outcrop model resolution, but is generally known to within 25cm or less.

The use of commercial unmanned aerial vehicles (UAVs), when coupled with photogrammetry, provide a unique opportunity for improved DOM development. This method is relatively inexpensive and, when used in combination with differential GPS, the end results are very precise, and informative outcrop models can be developed with minimal effort.

"The process of drone acquisition can be broken down into four major steps," says Josh Lambert, a research scientist associate at the BEG. "Those four steps are acquisition, development, exportation, and finally, interpretation." Josh explains these steps below.

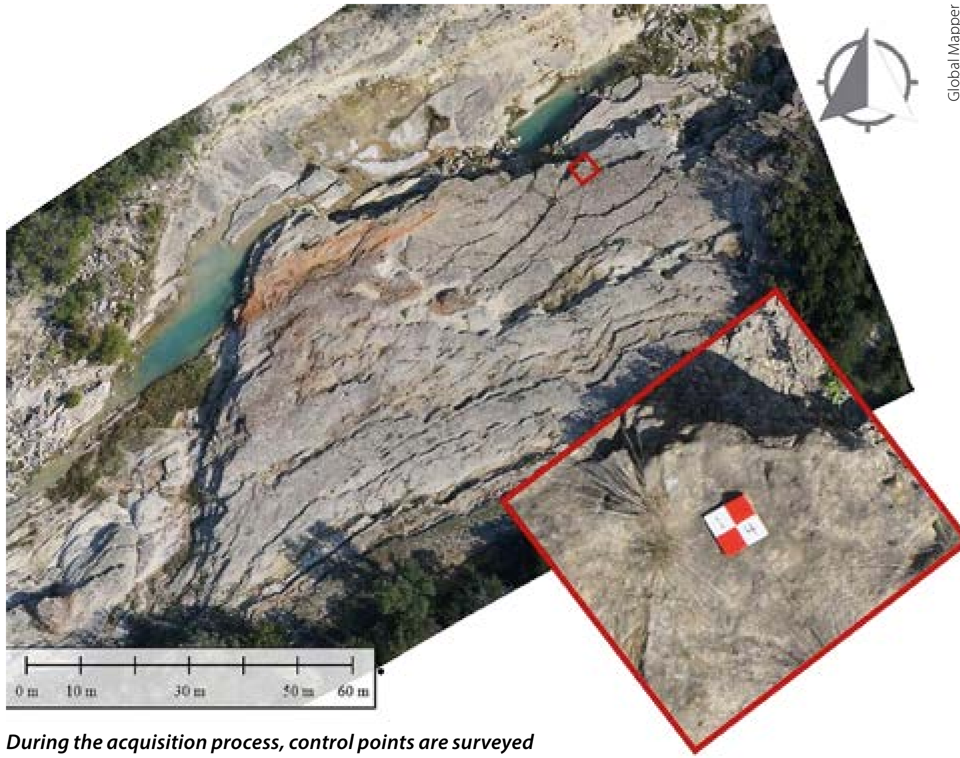
### Acquiring, Developing and Exporting Data

"The acquisition process includes pre-photo shoot planning, the actual photo shoot, and surveying of control points. Acquisition planning is accomplished in person during fieldwork or through interpreting Google Earth or other satellite imagery. This allows for the delineation of an acquisition area and also gives an idea of the time it would take to shoot. Surveying-in control points consists of getting some form of GPS data from either features or markers that are placed on the ground. Ideally, this GPS data is collected with a highly accurate (centimetre resolution) real-time kinematic GPS and base station, although data could be collected with less accurate results with some form of handheld GPS if need be. We use ground markers to act as targets that we can see easily on

Christopher Zahm, BEG

*Drone surveying on West Caicos, Turks and Caicos Islands, BWI.*

photographs and then input GPS data (latitude, longitude, altitude) to have a geographic reference for the photograph. We then fly a drone over the area and collect photographs in a roughly equal interval based on either time (one photograph every few seconds) or on the distance that the drone travels (one photograph every few metres). Depending upon the area that is being surveyed this could result in hundreds, if not thousands, of images. The goal here is to have a series of photographs that are overlapping. The more overlap the better, aiming for 60% is a fair assessment."



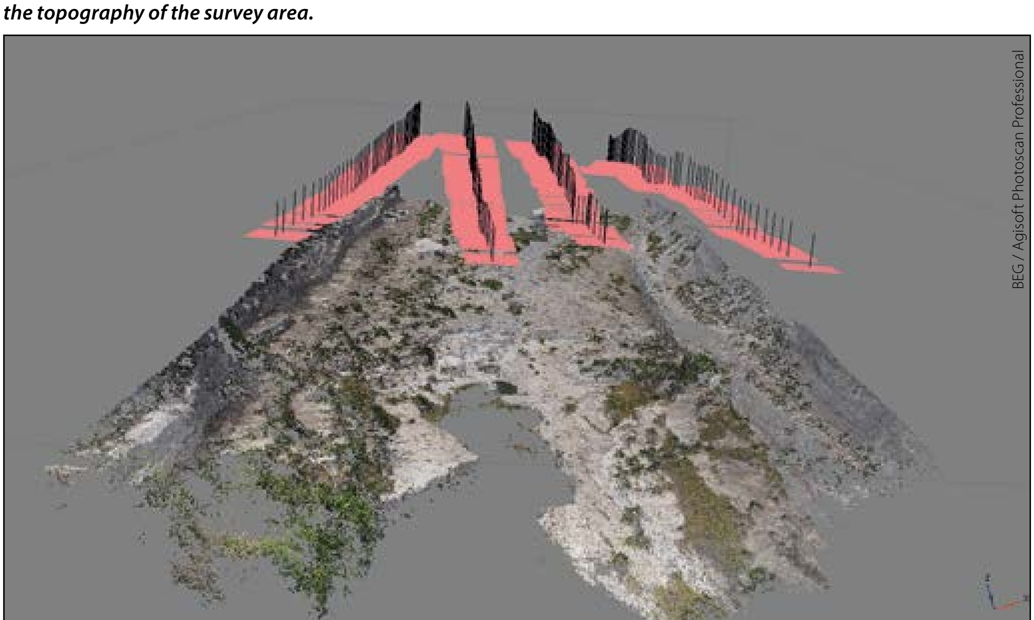

*During the acquisition process, control points are surveyed and hundreds of photographs are taken from the UAV.*

The development aspect involves pumping the GPS and the photographs into a photogrammetry software. "The photogrammetry software that we use is Agisoft Photoscan Professional," Josh continues, "however, there are other good photogrammetry software packages out there. The software processes photographs under the assumption that they are each taken from a different perspective and that the images are overlapping. It also finds the position of the camera used for each image and takes into consideration the camera calibration parameters (shape of lens, etc.) This image alignment process can be optionally constrained with the use of GPS data.

"Part of the development process is the insertion of GPS data into the photographs. I would say 10 ground control points would be an adequate starting point for providing GPS data over a survey area. This process simply means going through photographs, finding a location where you know the latitude, longitude and altitude (hence the ground control marker) and inputting that data into the photograph. For example, over a survey area that has 500 pictures, you might have 10 ground control markers, which might be represented on 50 or so (~10%) of the images. Having this GPS data allows either the GeoTIFF, point cloud, or digital elevation model to be exported into a visualisation tool or a geographic information system (GIS) software package and be able to drop into a coordinate system so measurements can be made. The software that we use estimates errors in metres so at times it can be easy to follow up if a point is causing problems with a particular model.

"The exportation step is rather simple: just exporting the model into whatever format that would best suit the users' needs. The GeoTIFF works great for a planar type exposure as it is just an image file (tif) with GPS inputs so it can be projected into a coordinate system. Digital elevation models can also be created through the

*A 'stitched' point cloud is rendered in the photogrammetry software. Shown are the drone flight path, location of the cameras, and the position the photograph was taken (pink squares). Below these is a point cloud that shows the topography of the survey area.*



photogrammetry process for spatial analysis and 3D representations of the area."

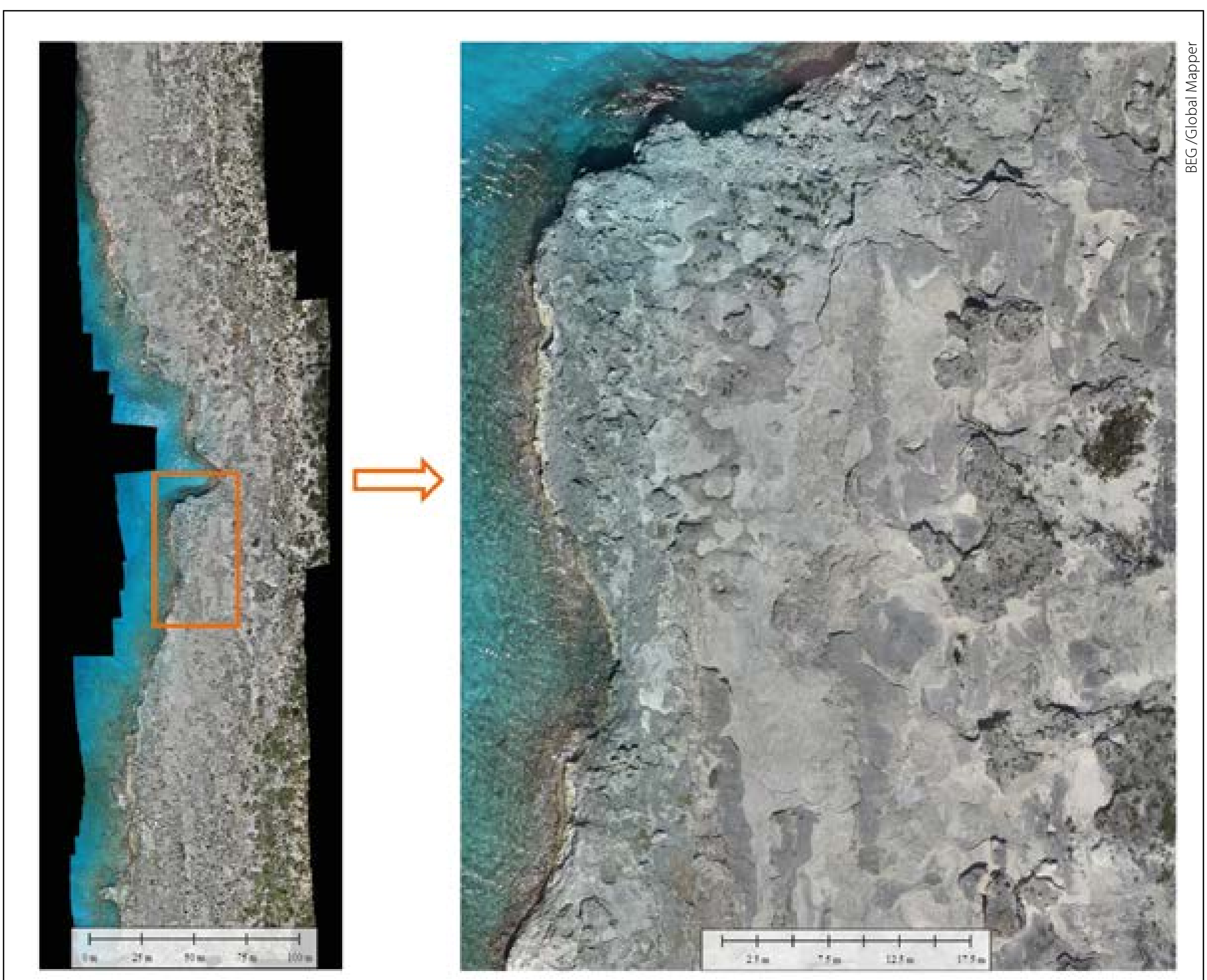
### Interpretation is the Star

"All this data is well and good but the analysis and interpretation being drawn from these models are the real stars of the show," says Josh. "The interpretation of these 2D images and 3D outcrop models give us a perspective that can't be understood merely by conducting fieldwork on foot and at a scale that can't always be captured by aerial or satellite photography. These outcrop models provide a great utility for reference and for analysis in geographic information systems. Geoscientists determine orientation, distribution and frequency of fractures as well as the slope or dip of outcrops from the model products. Specific rock characteristics or facies can be mapped on these products to aid in understanding the geologic settings and stratigraphy. Measurements can be conducted to determine lengths or the areas of exposures as well as volumetric information in regard to channels or other geologic features. Statistics can also be applied to the model to determine and quantify trends in the geology that are exhibited on the images."

Chris Zahm explains it this way: "The process of georegistered photogrammetry allows for two different types of data – high resolution geotiffs (2D) and 3D point clouds where points spaced millimetres apart are referenced with real-world X,Y,Z locations and contain colour information (RGB). GeoTIFFs are useful for mapping key geologic contacts such as facies boundaries, faults, fractures and unconformities. The geoTIFFs are imported into a GIS-based software (e.g., ARC or Global Mapper) where the lines can be drawn for the geologic feature of interest. After the interpretation is complete, data and statistics about the features can be queried; for example, the orientation and length of a fracture or the area of an exposed facies. A more complex interpretation is performed when the photogrammetry data is exported to the 3D environment. In this case, geologic interpretations are queried for volumetric analyses and an exposure can be coloured by the interpretation to provide the interpreters or others with insight into what is interesting or useful within the 3D data."

### Understanding Geospatial Relationships

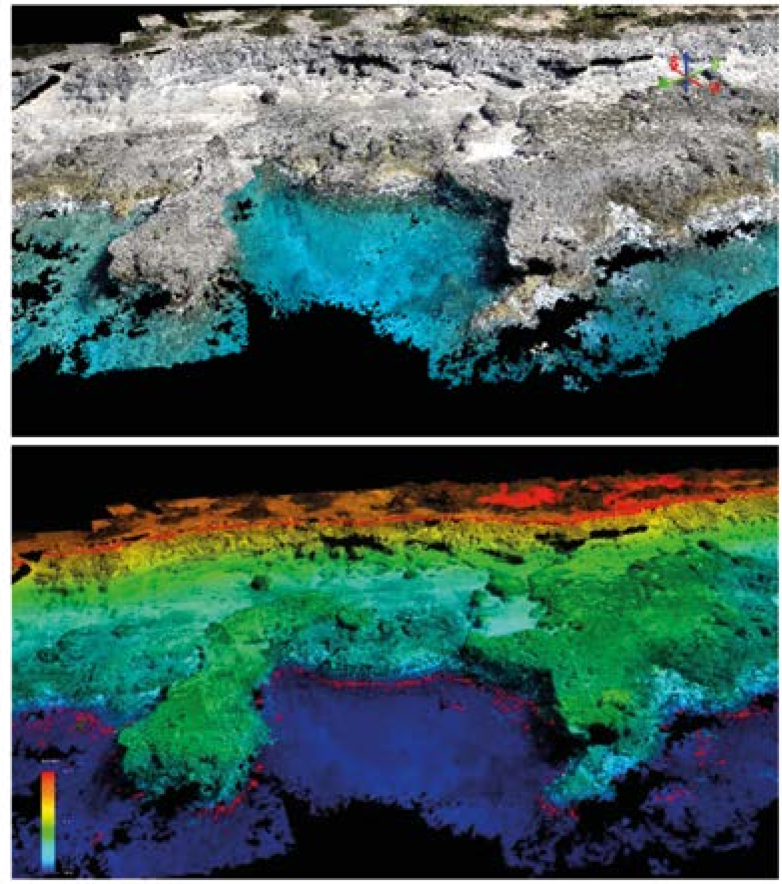
An excellent example of how this process can help the geoscientist understand geospatial relationships, and better understand what is happening in the subsurface, comes from the BEG's work on a 7.5 km exposure along the western coast of West Caicos, British West Indies. The area displays well preserved depositional facies and extensive early fracture development in this Pleistocene carbonate strata. "UAVs and real-time kinematic GPS were used to generate an integrated map




*GeoTIFF 2D images can be created from, in this case, over 300 individual images and (right photo) zoomed in for more detail.*

and 3D model of fractures within a framework of depositional facies," says Chris. "The results from this study have demonstrated a critical link between facies and fracture style, intensity, and orientation. Early formed fractures occur in both the margin parallel and perpendicular to the direction and the longest features developed in the grainstone facies. In addition, fracture systems play a fundamental role in the orientation of easily identified spur and groove systems preserved in the outcrop exposure."

"The mobility the UAV provides allows us to get a better perspective of the areas that we are surveying by positioning the camera to take pictures at different vantage points. The software puts it all together to make the models, which ties back to the broader goal of understanding reservoir environments and using outcrops as analogues for the subsurface," concludes Josh. ■


Chris Zahm, BEG

***UAV-acquired orthophotographs enable facies mapping and quantification of the spur and groove geometry at the South Reef locality, West Caicos, British West Indies. This image is a point cloud that is depicting an oblique angle over the outcrop. The lower image shows elevation, blue being the lowest altitude with red being the highest represented in the model. Surface field mapping is plugged into these 3D elevation models to create a 3D analogue that can be applied to understanding similar formations in the subsurface.***

# Mediterranean Carbonate Potential: Lessons from Existing Discoveries

RAFFAELE DI CUIA & ALBERTO RIVA
GEPlan Consulting

**The opening of new areas and the changing regional political and economic situation, together with innovative technologies, new seismic data and improved imaging, have revitalised exploration activity in the Central and Western Mediterranean. Analysing the characteristics of previous carbonate discoveries can help future exploration activity.**

Intense, mainly shallow water exploration activity in the Central and Western Mediterranean Sea during the last two decades of the 20th century led to the discovery of some important oil and gas fields, with gas (mostly biogenic) found mainly in the deepwater deposits such as turbidites and oil in carbonate units that span in age from Triassic to Miocene. In the early 21st century, exploration tapered off, but in recent years the changing political landscape in North Africa, coupled with innovative new technologies, has resulted in explorers renewing their interest in the area.

### Dominated by Thrust Belts

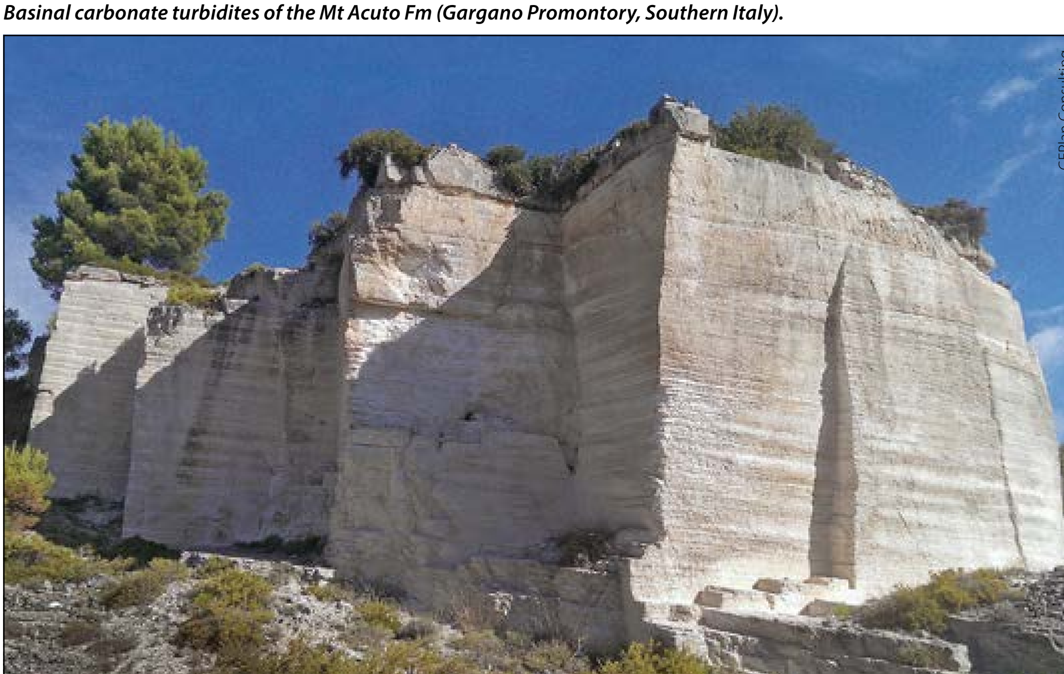
The Western and Central Mediterranean area is geologically very complex because it is characterised by a combination of rifting systems surrounded by thrust belt systems, which have had a very dominant influence on the petroleum potential of the region and which still impact on it to this day. Several Neogene rifting systems are found in the Western Mediterranean between Spain, France and Italy, which is surrounded by the Atlas, Apennine, Pyrenean and Alps fold and thrust belt systems, while further east the Neogene extensional basin centred on the Greek islands is similarly encircled by the thrusts of the Anatolian plate.

Back in the Lower Jurassic, however, this area lay on the western edge of the Neo-Tethys in an area of shallow water deposition, mainly consisting of carbonates. At this time a first, well-extended rifting stage started, which controlled the deposition of potential source rock deposits. This stage lasted for different lengths of time across the basin but there is evidence that it continued discontinuously until the end of the Cretaceous. The first effects of the collision between Africa and Europe are recorded in Early Tertiary sequences. By the Miocene the Central and Western Mediterranean area had taken on more of its present shape.

Comparing the stratigraphic successions of the different basins of the Central and Western Mediterranean Sea, it is evident that the entire Mesozoic interval is predominantly characterised by carbonate units while the Tertiary sequences are more lithologically heterogeneous, even if carbonate rocks are still abundant.

As a result, hydrocarbons have been discovered in carbonate lithologies in this area in units that are from Triassic to Miocene in age, but in many cases the real potential of these carbonate units is still to be understood. By looking at the previous carbonate discoveries with new 'eyes' and with the use of innovative technologies available to the modern explorer, it could be possible to delineate the key characteristics of carbonate fields, identify errors made in the past and learn and extrapolate from them. ▶

*Basinal carbonate turbidites of the Mt Acuto Fm (Gargano Promontory, Southern Italy).*



## Lessons from Exploration

Here we review the main carbonate discoveries in the Central and Western Mediterranean Sea, identifying the chief characteristics of the reservoirs, and discuss how each discovery can be used to learn specific technical aspects for exploration activity targeting similar reservoirs in the future.


## Casablanca (oil field, 1982)

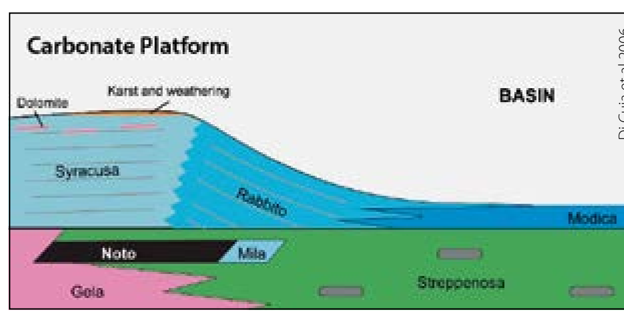
Hydrocarbons are reservoired in Cretaceous platform karst carbonates, intensely fractured over a long period of time. They are laterally sourced from Miocene clastics, sealed by Tertiary flysch deposits and trapped by an eroded structural high. The main factors controlling reservoir performance are karst diagenesis characteristics, particularly cement types and variations. This discovery highlights that it is fundamental to understand fracturing through time and the importance of cycles of uplift and subaerial exposure of carbonate sequences in karst development.

## Dougga & Lambouka Discoveries (condensate discoveries, 2009–2010)

These relatively recent discoveries were found in Lower Miocene and Upper Cretaceous platform carbonates, sourced from the Lower Tertiary and sealed by Tertiary flysch deposits. Hydrocarbons are trapped in a fault-controlled structural high, with some of the faults reaching to the seabed.

## Vega (heavy oil field, 1974)

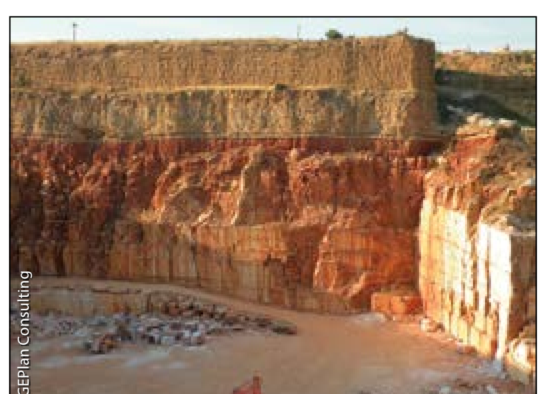
A Lower Jurassic shallow water dolomitised carbonate reservoir, sourced from the north-east from Lower Jurassic basinal carbonates of the Streppenosa and Noto Formations, and sealed by Mesozoic basinal carbonates. The main structure is a tilted platform margin, where the top of the platform was emergent, resulting in a well-developed karst system. Reservoir quality and performance are influenced by the presence of hydrothermal dolomites controlled by the fault network. The main lessons to be learned from this discovery refer to understanding the relationship between the distribution of the fault network and the high porosity and permeability dolomitic bodies, and to the correct assessment of the timing and characteristics of the paragenetic evolution.




*Cross section from the Vega oil field (Siracura Fm.) to source rock (Streppenosa Fm.)*

## Rospo Mare (heavy oil field, 1971)

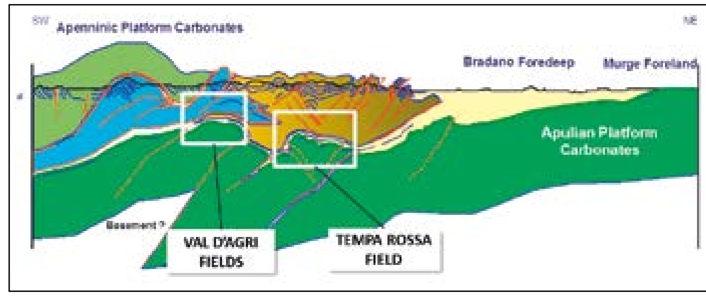
Hydrocarbons are hosted in Lower Cretaceous shallow water karstified carbonate platform sediments, from an Upper Triassic source, sealed by Pliocene shales deposited in the Southern Apennines foredeep. The trap is a fault-controlled structural high. The main factors controlling reservoir performance are the fracture network characteristics and karst diagenesis. The main lessons to be learned from this discovery refer to the importance of understanding the correct timing of subaerial exposure/uplift events and the relationship between the fault and fracture network and the development of karst-related dissolution that can modify the petrophysical properties of the relatively tight carbonate matrix.




*Rospo Mare reservoir analogue, Apricena, Southern Italy*

### Tempa Rossa & Val d'Agri (oil fields, 1989)

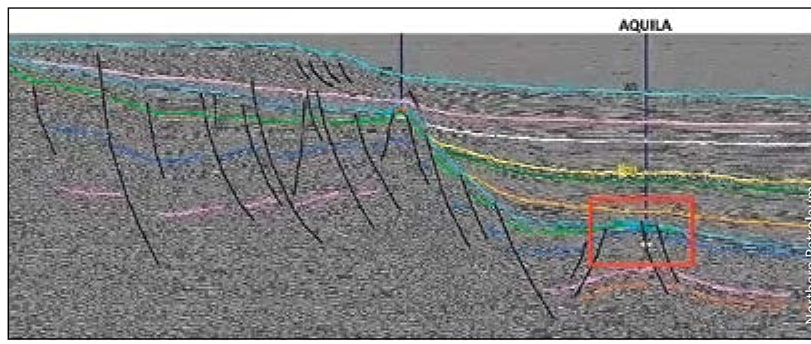
These fields have Cretaceous to Miocene shallow water carbonate reservoirs with low matrix porosity and intense fracturing, hard to image beneath thick thrust units. They are sourced by Lower Cretaceous carbonates deposited in intraplatform depressions and sealed by Pliocene shale. Structures are thrust-related anticlines and pop-up structures and performance is controlled by fracture network characteristics and connectivity, petrophysical properties, HC driving mechanisms, present day stress fields and reservoir thickness. These very large oil discoveries in the core of a thrust belt and in a subthrust position highlight that, given a good understanding of the fault/fracture network and its relationship with the present day stress field, even very tight carbonate matrix sequences can deliver excellent hydrocarbon production.




*Cross-section along the Southern Apennines Thrust Belt System (modified after Turrini).*

### Aquila (oil field, 1981)

*Platform to basin setting offshore southern Adriatic Basin.*




Sourced from Upper Triassic and Jurassic sequences and sealed by Tertiary basinal deposits, the Lower Cretaceous deepwater turbiditic carbonates of the Aquila field are trapped by onlap onto a structural high. The main factors controlling reservoir performance are the distribution and the petrophysical properties of carbonate turbidites in a deepwater setting. From this discovery one learns that, like clastic turbidites, carbonate turbidites can develop good petrophysical properties. A key factor influencing the distribution of carbonate turbidites in this setting is related to the characteristics of the platform margin and slope, which also control sediment input into the basin.

### Sphirag (oil discovery, 2001–2013)

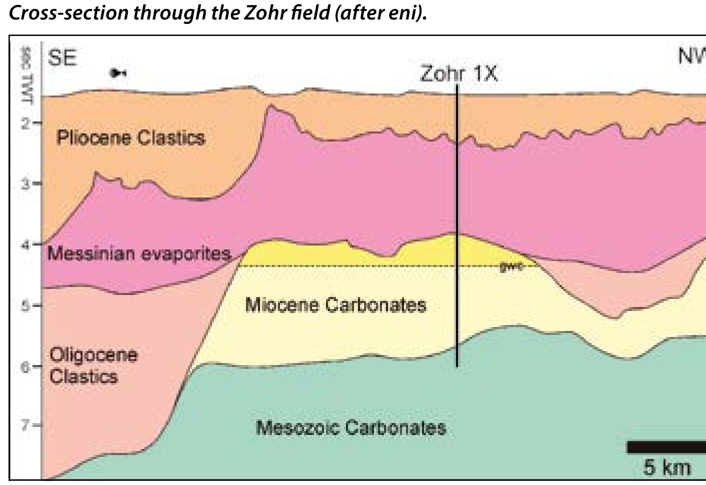
Intensely fractured Paleocene-Eocene basinal carbonates with low matrix porosity form the reservoir in this field, sourced by Toarcian basinal deposits and sealed by Tertiary flysch. The fracture pattern can be seen reflected at the surface, with fault zones occurring at 300m intervals. The structure is dominated by thrust-related anticlines in a subthrust position, making the reservoir difficult to image. Main factors controlling reservoir performance are the fracture network characteristics and connectivity. This discovery shows how deepwater tight carbonate units, if intensively fractured, can be excellent reservoirs.

*Aerial image of the Sphirag area demonstrating the surface reflection of the fault zones.*

### Zohr (gas discovery, 2015)

Lower-Middle Miocene carbonates with good matrix porosity form the reservoir of this field, sourced laterally by Cenozoic clastics. The peculiarity of this field is the stratigraphic trap formed by high-relief isolated carbonate platform, with a very thick (>600m) gas column. Main factors controlling reservoir performance should be the matrix porosity distribution, the porosity enhancement at the reservoir top due to subaerial exposure and the fracture network characteristics and connectivity. This discovery also shows how isolated Miocene platforms could act as reservoir in the Mediterranean area.

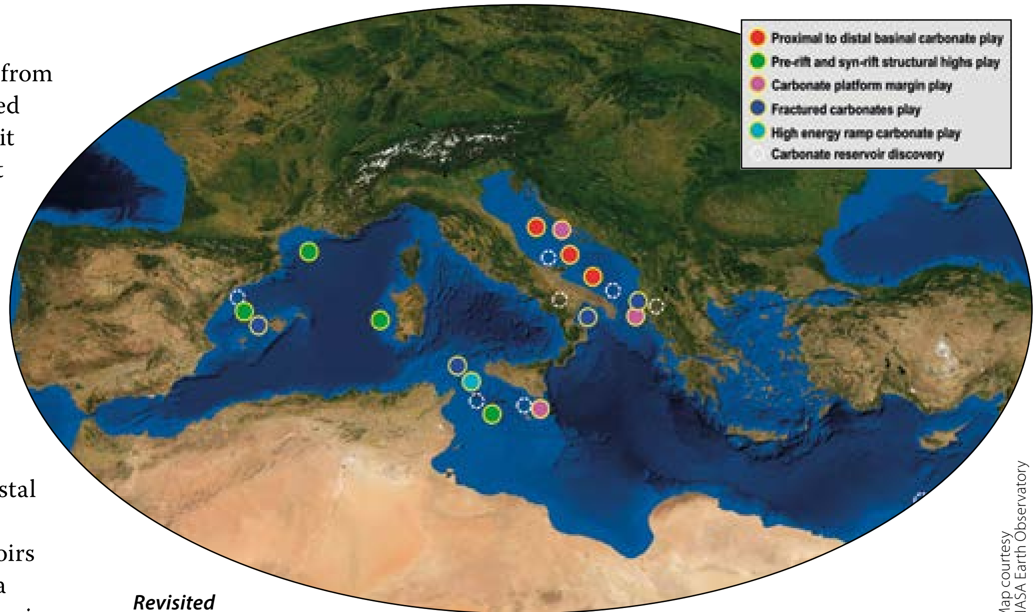
*Cross-section through the Zohr field (after eni).*



## An Integrated Approach

By looking at the lessons learnt from these discoveries in an integrated rather than individual manner, it is possible to develop a different approach to carbonate plays in the Western and Central Mediterranean. Analysis of the main geological domains and the identification of key characteristics have identified several target play types.

***Proximal to distal basinal carbonate play:*** This play is characterised by proximal to distal resedimented shallow water carbonate reservoirs deposited in a basin in front of a fault-controlled platform margin, in high relief platform to basin transition environments. In most cases the source is nearby and the seal is ensured by very fine-grained carbonate and clastic deepwater emipelagic deposits. The traps could be pinch-outs of turbidite flows in distal depositional environments or against structural highs that stop the flows. This type of play can be expected in the Adriatic and Ionian Basins and possibly on the western Sardinia margin and in the Valencia Basin. The Aquila field is an analogue, and for outcrop analogues there are mega-breccias and turbidites in the Maiella mountains of central Italy.




***Revisited exploration plays.***

Map courtesy NASA Earth Observatory

***Isolated platforms play***: Characterised by high-relief isolated carbonate platforms surrounded by basinal deposits, this play is concentrated in the Eastern Mediterranean where Zohr is the first discovery. Reservoirs are karstified shallow water carbonates, sealed by evaporites or fine-grained clastics. Source rocks could be located within the basinal deposits or infills, with lateral migration of hydrocarbons.

***Pre-rift and syn-rift structural highs play:*** Erosion of the top of carbonate platforms and tilted blocks as a result of a rifting event characterises this play. Reservoirs are karstified shallow water carbonates or carbonate reefs on tilted blocks, sealed by post-rift sequences, and source rock could be represented by syn-rift deposits. The distribution of the play is associated with Tertiary rifting areas such as the Maltese and Pantelleria grabens and Western Mediterranean basins. The most typical analogues are found in the Valencian Trough, including the Amposta Marino and Casablanca Fields.

***Carbonate platform margin play:*** This play occurs on high points along Mesozoic and Cenozoic carbonate platform margins. The reservoir is made of shallow water carbonates that can be affected by karst and dolomitisation and which are overlain by Tertiary fine-grained clastics. Reservoir properties, heterogeneity and source rock distribution could be the main uncertainties related to this play type. It is expected to be present along the carbonate platform margins bounding the Adriatic and Ionian Basins and the Sicily/Malta channel. A good analogue would be the Vega field.

***High energy ramp carbonate play:*** Between the Mesozoic and the Tertiary the depositional environment changed from low to high energy, resulting in low angle carbonate ramps, the key characteristic of this play. Fields are expected to be located in the southern Adriatic and Ionian Basins, the Malta Channel, western Sicily and the Tunisia Basin. Analogues can be found in the Nilde and Didon fields and around the Maiella Mountains. Outcrop examples show increased porosity due to the high energy depositional environment.

***Fractured carbonates in thrust belt Settings:*** The main characteristic of this play is that the fault and fracture network controls the hydrocarbon potential and productivity of the tight shallow to deep water carbonate reservoirs. Traps are mainly structural, including 4-way dip closure or fault-bounded anticlines, and the seal is given by Tertiary clastic foredeep deposits. Source rocks may vary according to the location and the type of depositional settings of the reservoir rocks. This play can be found in most of the thrust belts surrounding the Mediterranean Sea, in the Adriatic Basin (both sides), the Ionian Basin, on the north-west side of the Sicily Channel and on the southern part of the Valencia Basin.

## New Perspectives

Carbonates have been proven to be one of the most prolific plays in the Central and Western Mediterranean region, and several large hydrocarbon discoveries have been made in carbonate reservoirs exhibiting varying characteristics. A review of the previous discoveries and an understanding of their main characteristics, together with a regional to basin scale geological understating of the depositional and stratigraphic settings, highlights the fact that in the Central and Western Mediterranean Sea there still exists the potential for large hydrocarbon accumulations in different types of carbonate reservoirs. The acquisition of seismic with new technologies will reduce the exploration risks. ■

# After the Arab Spring: Hopes and Hazards in North Africa

**The outcomes of political upheaval and insecurity in North Africa will be felt in the wider region and beyond, with Europe in particular either contributing to the region's prosperity or continuing to feel its pain.**

**NICHOLAS WADE**
Menas Associates

Commentary about the Middle East and North Africa (MENA) may promise an explanation for what is taking place in this intricate region – but often what it offers instead is an excuse for why we cannot explain it and never will. The MENA region is variously described as too complicated (with so many different factors that 'we', as outsiders, could never possibly comprehend them) or too simple (fuelled by ancient prejudices like tribe and sect that we could never understand). The implication of both arguments is: give up.

But we cannot give up, because the MENA region's challenges cannot be contained within its borders and because solving them will take positive contributions – especially trade and investment – to overcome negative stereotypes. And the region *can* be explained, with the lessons from North Africa being an insightful place to start.

### The MENA Region's Bellwether

The first rule for explaining the region is to not generalise when describing its countries. Borders matter. The Islamic State group (IS) may speak about a Muslim Caliphate, and some commentators still insist on dividing the region into a 'Sunni' and 'Shi'a' world. But, as important as sectarianism or faith may be at a local level, their impact on geo-politics is often exaggerated. This is still a region defined primarily by states: their governments, their rivalries, and their policies.

Rule number two is that, even though we must not generalise about states, they do face common challenges. They deal with them in different ways.

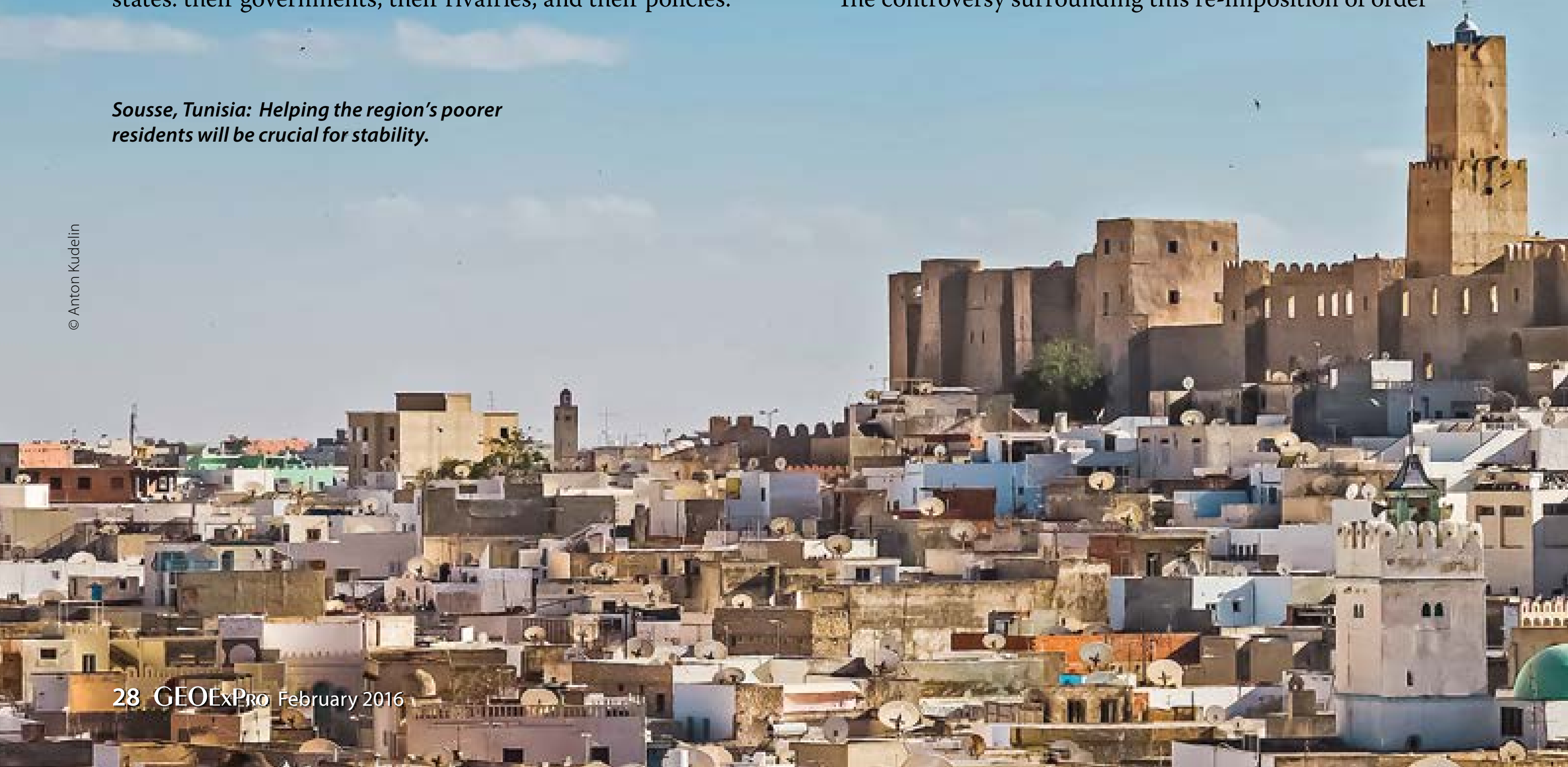
My view is that the governments of North Africa are caught between two powerful forces and the different responses of Morocco, Algeria, Tunisia, Libya and Egypt will be bellwethers for the rest of the region. One force is that of their people's aspirations, and the threat of popular unrest if they are not met. The Arab Spring was the beginning of a process that manifested this sentiment, and we can expect it to be manifested yet again. The second force is the need for economic development, to match the aspirations of booming populations at a time of plummeting energy prices.

The outcomes in North Africa will be felt in the wider region and beyond, with Europe in particular either contributing to the region's prosperity or continuing to feel its pain.

### The Drive For Political Stability

Despite the origins of the Arab Spring being in North Africa, the first important trend to identify in the region's politics for 2016 is that its governments are taking a firmer grip. This is seen in heightened security measures and a more general restoration of law and order, but it also applies to human rights, and the curtailment of free expression.

The controversy surrounding this re-imposition of order



*Sousse, Tunisia: Helping the region's poorer residents will be crucial for stability.*

© Anton Kudelin

should not be taken lightly. The deaths and detentions of anti-government protesters caught the headlines, but the prevention of free political speech and assembly has become pervasive (if less visible) across the whole of North Africa. However, one of the most difficult aspects of this trend to acknowledge is that it has not been universally unpopular.

Among investors, and many ordinary citizens, greater stability has been welcomed despite concerns about the methods through which it was achieved. The energy of the Arab Spring revolutions in North Africa did not simply settle quietly down into the structures of constitutional politics, which were anyway weakly developed across the region after decades of dictatorship. It was also the case that, although the street protesters knew what they were against ('the regime'), they never articulated what they wanted to replace it with in a unified or specific way.

The result was that free speech and expression in the aftermath of these revolutions became associated with raucous street politics, and efforts to force the adoption of views rather than considering compromise. Libya's civil conflict began this way, and both Egypt and Tunisia saw blood on their streets. This instability threatened individual livelihoods, the health of the economy at large, and – sparking international attention – could create a space for extremist militancy. Governments therefore imposed stability, but they need to achieve benefits from it soon.

One test in 2016 is whether power can ultimately be shared between those of different persuasions, or if it will be monopolised by those committed to just one. Tunisia's progress in this respect won it a Nobel Peace Prize, but bitter coalition politics are now giving Tunisians a more unsettling face of democracy. In Egypt, fears that the Muslim Brotherhood would exclude everyone else from power mean that it is now so thoroughly excluded itself as to be illegalised and designated a terrorist group. But Egypt's Islamists will ultimately need a way of engaging with the state other than through prison. Morocco's elections, in late 2016, will be another power-sharing test.

But the issue is that the genie of popular aspiration cannot be put back in the bottle for ever. The main political trend to watch in North Africa during 2016 will be efforts by the governments to keep it there, but the main challenge of 2016 will be whether these governments can meet the economic and political aspirations of their youthful and growing populations. If they fail, then no amount of repression will


***Commerce is key, but North African states look more to Europe than one another for trade.***


*The night-life of Place Djemma el Fna, Marrakech, Morocco, with the minaret of the ancient Koutoubia Mosque in the background.*

save them from what still remains the greatest risk to state stability in North Africa: popular unrest. Riots relating to economic issues have already occurred in Algeria and Tunisia in 2016, and they won't be the last that we see this year if stability does not bring prosperity.

### Terrorism and its Context

Terrorism is a consequence of state collapse, not a cause. Revolutions may provide space for militant extremism, but the equation cannot be reversed. But it is terrorism above all else that will draw international attention to North Africa, and consume the energy of the governments in this part of the world. The coming year will be characterised by efforts to solve the conflicts and failures of governance that give rise to terrorism, with the peace process in Libya and counter-insurgency in the Sinai being the key test cases.

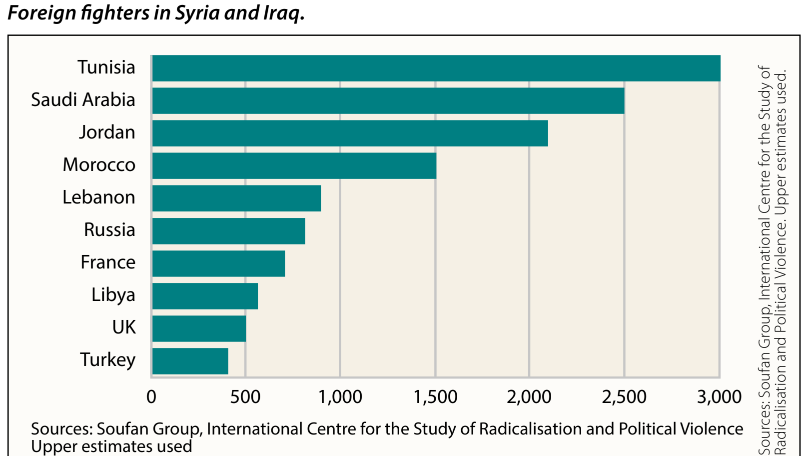
The rise of the Islamic State group (IS) does, in this context, seem to constitute an evolution of jihadism into an even less pragmatic and more pernicious form. Its desire to hold territory, and its determination to kill all who will not obey it, means that even Al-Qa'ida's members are among those who detest and fight IS. But there are encouraging signs to look for in 2016, when it comes to countering IS and other militant groups in the region.

The first is that the zealotry and lack of pragmatism displayed by IS may alienate the group from its local social base. Its emphasis on foreign fighters could be one of the group's weaknesses in this respect. Its lurid atrocities against locals are another.

If IS continues to alienate local communities in 2016, such as it will in the Sinai if it remains determined to disrupt the tourist trade on which they depend, then the self-destructive impetus in IS' brutality and lack of long-term strategy will become apparent. Menas consultants report that a conspiracy theory is already gaining credence in the region that IS is a Western plot to undermine Muslims and, as derogatory as that may be, it could at least serve to discredit the image of a terrorist group that relies on presentation for effect.

A second factor in 2016 will see not only efforts to attack

*Foreign fighters in Syria and Iraq.*



terrorist groups militarily, but also a recognition that this will not work without redressing the context in which they operate. If these terrorist groups seek to take and hold territory, like IS does, then they cannot be defeated by airstrikes: 2016 will see greater efforts to confront them on the ground. If they emerged from civil conflicts, then they cannot be defeated until that conflict is resolved: Libya is the key test case here, as its war has exported terrorism into North Africa. The year 2016 will test the emphasis that the international community has placed on Libya's new unity government to solve that conflict.

But terrorism is where political, economic and security failures converge. Governments need to counter terrorism militarily, while also offering their people positive and compelling economic or political reasons to not join such groups. If the political scale is being tilted towards greater control rather than openness in the region, then the economic stakes will become higher still.

### Economy Remains Key Battle

The future political and security stability of North Africa will ultimately depend on its economies; whether they can address the abundant poverty that exists throughout the region and still create enough jobs to sustain a youthful and growing population.

North Africa is one of the world's least economically integrated regions, and an effective start could be made in 2016 by facilitating trade between states. But the impetus so far has been for these countries to further fortify themselves, building more fences and berms and deploying more troops to their borders as a response to the focus on militancy. Smuggling may be thriving, but licit trade is not, and that is not a problem that is likely to be solved quickly as national road and rail networks are so poorly connected across their international boundaries and there is no apparent political will to redress this. North African states still look to Europe for trade, not each other.

Then there is the issue of the collapse in energy prices, and the reality that – if they stay low for a number of years – states such as Algeria that have become dependent on oil and gas revenues for their state budgets (and generous welfare provisions for their millions of poorer citizens) will be at serious risk of unrest. Algeria is stressing the merits of diversification, while Egypt has emphasised that it wants to use its expanding energy reserves to address booming domestic demand rather than prioritising export. But these are long-term solutions to immediate problems, and time may not be on the side of nervous governments or their restless citizens.

The upshot is that there will be an abundance of investment opportunities in North Africa during 2016, and evolving terms on which business can be conducted. Governments will be eager to attract investment, particularly that which allows them to boost local employment and reduce reliance on imports, while at the same time competing more intensely with one another to do so.

The demand for business is certainly there, as are the opportunities. The ambiguity lies in the environment. There will, in the short term, be a period of greater calm in North Africa as populations remain reluctant to rebel, eager to draw prosperity from stability. The fear of terrorism will always remain greater than the threat, even though that threat will persist. But this window of opportunity must be used to attract trade and investment, and improve the effectiveness of governance. Whether it succeeds or fails, North Africa in 2016 will give us an abundance of signs to look out for.

*Menas Associates is a political and strategic risk consultancy that has been helping multinational companies operate in the Middle East, Africa, and other emerging markets since the late 1970s. Sign up to our newsletter to receive fortnightly insight into the regions we cover and invitations to our free country briefings. www.menas.co.uk.* ■

***Tourist numbers at the Red Sea resorts will be one measure of confidence in security procedures.***

Jane Whaley

# The Digital Oilfield Are We There Yet?

TAHA TAHA
Emerson Process Management

## A complete and integrated workflow for reservoir and production management

The last few years have seen a growing focus on the digital oilfield and a future environment where operators integrate, interpret and action real-time reservoir models and production information to optimise field operations and support production. From remote real-time facility monitoring and control through to real-time production surveillance, advanced wells and production volume management systems, we are closer to this vision than ever before.

Operators are able to evaluate the timings for tie-backs of new reservoirs, phase in or re-route wells, implement pressure boosting and artificial lift, and ensure the effective flow of hydrocarbons from reservoir to refinery – all from the comfort of their control rooms. In the field of production engineering and management, asset team members can monitor the reservoir and its complex production infrastructure of wells, flow lines and flow control devices, such as chokes, pumps/compressors and separators. By utilising measured field data combined with optimisation software, the task of finding optimum operating conditions can be automated, avoiding trial and error procedures and increasing system throughput.

Yet, despite these developments, obstacles still remain in realising the vision of the digital oilfield, in particular in the areas of production and reservoir engineering. These two disciplines share a number of things in common. While production engineering tends to focus on the flow of fluids from the reservoir to production facilities, and reservoir engineering looks in more detail at the subsurface geologies, reservoir mechanics and drainage strategies, they still share the common goal of increasing well production rates and ultimate recovery. Yet, too often, there is lack of integration between these fields. Reservoir, production, completions and operations engineers tend to work in different domains with different workflows and only share information when they have to.

This article argues that the digital oilfield and a future vision of integrated production management can only be solved through a closer software link between production management and reservoir engineering and a fully integrated workflow across the lifecycle of the field.

There is a need for easy-to-use, practical engineering tools, applicable throughout the life of a field, to streamline work processes, improve consistency in data use, and foster multi-disciplinary collaboration.

### Integrating Production and Reservoir Engineering

In May last year, Emerson Process Management acquired Norwegian company Yggdrasil, a provider of flow assurance and production optimisation software. Emerson is incorporating

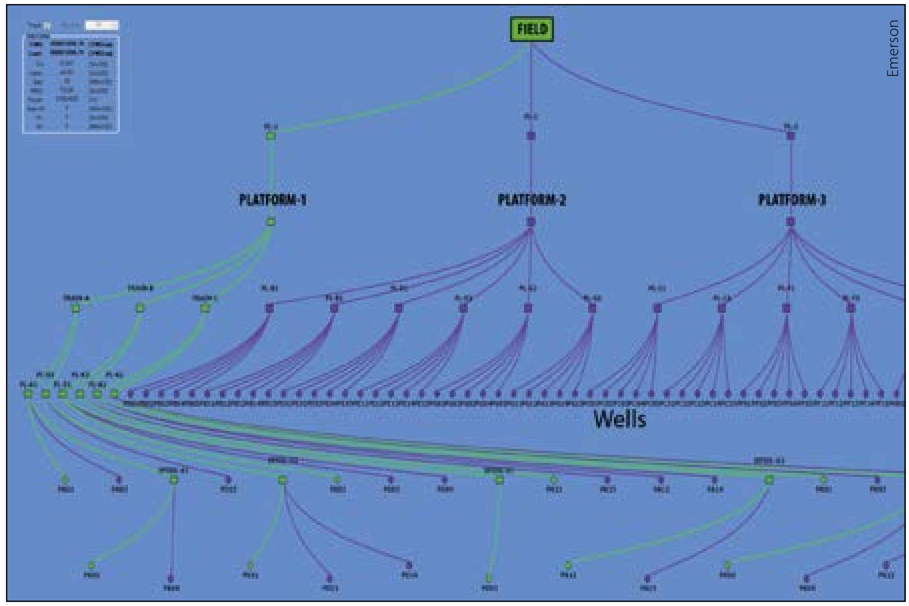

***The production management software was used for planning on the Shtokman field.***

Gazprom

Yggdrasil's production optimisation solution into its Roxar reservoir management software portfolio.

This acquisition is not simply a broadening of the Emerson reservoir management software portfolio. The tie-up will help integrate the disciplines of production engineering and reservoir engineering, where the daily management of oil and gas production is combined with reservoir modelling, uncertainty quantification and simulation data to help operators optimise their field development and production plans.

The new software – known as Roxar METTE – includes network optimisation, well performance, transient simulation and virtual metering capabilities as well as built-in interfaces to reservoir simulators.




*Network simulation: the production management software has a demonstrated capability for handling large and complex networks, either coupled online to one or more reservoir simulators or by using tank type models for well inlet boundary conditions. In this illustration, the purple line represents non flowing/non producing and the green line represents flowing/producing.*

## Four Main Components

There are four key elements to an integrated production management system.

Network optimisation focuses on the surface network and enables the operator to use software to find operating points and calculate network performance data. 'What if' simulations can also be carried out.

Combining known well flow rates with a PID control module also provides the operator with a set of points for active components, such as chokes, pumps and gas lift supply, which can all be used to achieve specific production targets – subject to defined system constraints.

Well performance focuses on the capabilities of the well in delivering oil and gas – from which profile data, gas lift hydraulic analysis, and vertical flow performance tables can be created. Components, such as compressors, pumps and choke valves, can be modelled. In addition, well or flow lines capacities can be analysed using multiple boundaries and can quantify the effect on production potential.

Transient analysis is used for the time-dependent simulation of well and flow line behaviour. Typical applications where the transient module in the Roxar METTE software can be deployed include cool-down times for different pipe wall insulation configurations, the calculation of the necessary hydrate inhibitor amounts during cold start-ups, and the evaluation of requested times for flow line depressurisation.

Virtual metering provides a cost-effective solution for finding well phase flows, requiring only the connection of a computer to a production database for the retrieval and measurement of field data. Operators can measure and interpret field sensor measurements and calculate flow based on virtual measurements coming from, for example, temperature and pressure probes.

## Bridging the Gap

The strong links with reservoir simulation and history-matching is where the production management software plays the most significant role in bridging the gap between production and reservoir engineering. This can be seen in the software's focus on network simulation. This module is an advanced engineering tool for single and multiphase flow systems. It relies on a very fast and robust algorithm with demonstrated capabilities that have been in extensive use on the Ormen Lange field development offshore Norway and for planning on the Shtokman field in the Russian part of the Barents Sea.

By directly connecting to reservoir simulators, the software provides concept-dependent production profiles, with reservoir out-takes reflecting production targets and constraints in the downstream production network.

This coupled capability from the subsurface allows for the seamless simulation of hydrocarbon flow through the reservoir production system to a processing facility. This provides life-of-field (LOF) variations in mass and energy balances and optimised power and gas lift use as well as hydrate inhibitor usage. It determines well routing, the effect of pigging and scheduling for infill wells or third party tie-backs, the quantification of the effect of pressure boosting equipment and timing, and the quantification of the effect of subsea separation.

Well inlet boundary conditions in the network are generated by the reservoir simulator, providing phase ratios and flowing bottom hole pressures in the form of IPR tables.

A large number of additional network production targets and constraints can also be specified, the implementation of which are executed during run time and dictated by user-specified conditions. The constrained problem is also solved through employing active components, such as chokes, gas lift, pumps, compressors and heat exchangers. With no or limited active components, solutions will be dictated by well flow potentials.

The software's calculation speed is high and scales linearly. Depending on field complexity, LOF simulation times are typically measured in minutes. Using tank type models (decline curves), multi-case production profiles can be made very quickly, providing a useful tool for quantifying system parameter changes.

When coupled to a reservoir simulator, the software feeds back guide rates to the reservoir for the next time step, reflecting current production system capacity. The production network can be interfaced to service networks for lift gas and/or continuous hydrate inhibitor distribution, with all networks being solved in each time step. Constraints in the service network(s) will be reflected in the production network.

The different available options for production optimisation make this a powerful tool for investigating different productions strategies to see the effect of recovery.

The software currently supports interfacing to many reservoir simulators but will become more closely aligned with Emerson's Tempest MORE as a result of the acquisition.

### Other Reservoir Engineering Links

There are other ways in which the new software links in with reservoir engineering tools. Virtual metering results, for example, can be used with reservoir model history-matching as well as for daily or historical production allocation. The combined virtual metering and forecasting capabilities add up to a powerful production management tool, in particular when combined with PID control functionality.

With the close integration of the software with Emerson's reservoir engineering solutions – its simulation tool Tempest MORE and history-matching and sensitivity tool Tempest ENABLE – an effective system is available for production forecasting and optimisation. With Tempest ENABLE's ability to intelligently drive the simulator through hundreds of realisations and conduct 'what if' scenarios on a wide range of reservoir scenarios, the same will be the case when combined with new software, where the tools can work together to provide a wide range of values and look at a large number of scenarios.

### Two North Sea Fields

Examples of integrated production management can be found in two North Sea fields.

In the first case, the software is being used as a flow assurance tool on a medium size oilfield in the North Sea with three different reservoirs requiring artificial lift in the form of gas lift. A large number of development alternatives were screened in the early phase to create concept-dependent production profiles.

To provide consistent LOF data, the software was used to perform coupled simulations, interfacing the three separate reservoir simulation models with gas lift optimisation. The production network model was simultaneously interfaced with a gas lift supply network to determine its variation in mass and energy balances. Using decline curves that originated from these simulations, the effects parameter variations, such as flow line and tubing sizes, were investigated to find optimum sizes based on reservoir model predictions over field life. Lifetime mass and energy balances for the production system were generated for different development concepts including the use of multiphase pumping. Using the transient module, cooldown and heat-up simulations were performed to address insulation requirements. Blowdown simulations were also performed to address both time and liquid drain volume requirements.

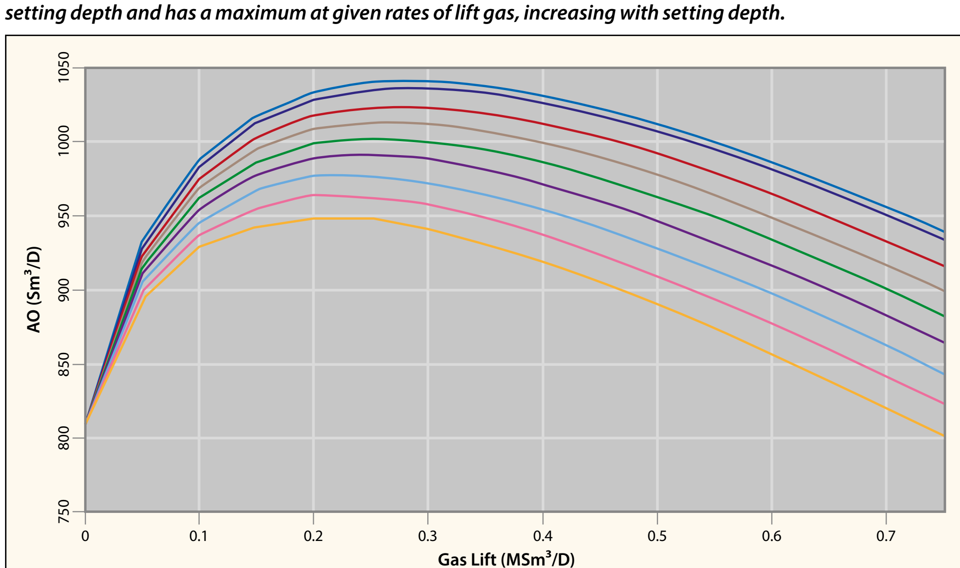
The second application is in a marginal North Sea oilfield with a heavy non-Newtonian fluid that required artificial lifting. In this case, the software provided functionality for the use of shear-dependent viscosity data during both steady state and transient simulations.

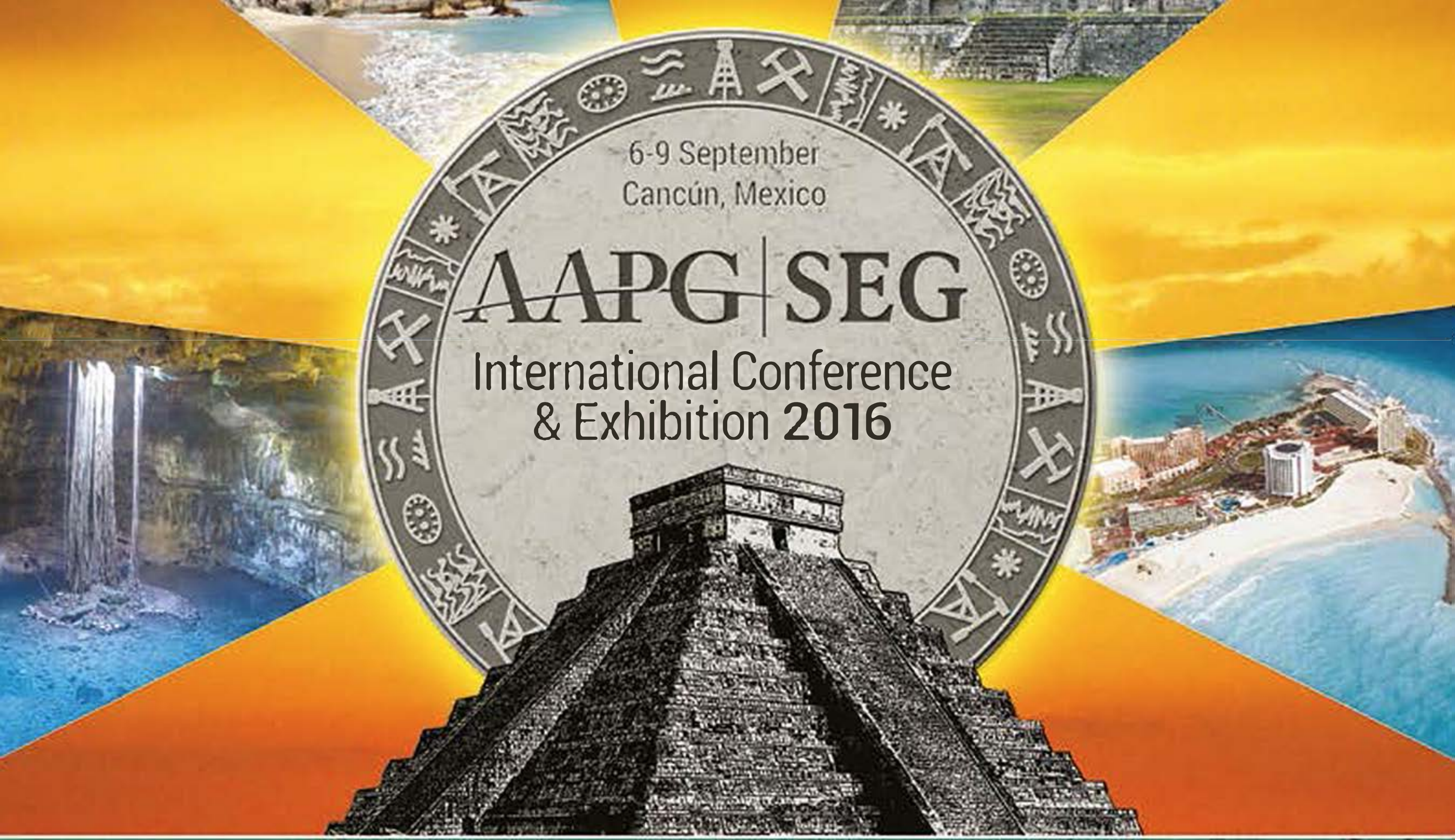
Decline curve data from the reservoir simulation model was used as input to a production network model. The network model was then used to predict artificial lift times, together with system lifetime mass and energy balances. These used two alternative lift methods in the form of electrical submersible pumps and gas lift. The strong gelling tendencies of the production fluid also required the implementation of experimental yield stress data to perform realistic transient start-up simulations of the wells and flow lines. The development concept also included SWAG (Simultaneously Water Alternating Gas) for gas reinjection into the reservoir, simulated by the use of the software.

### A New Era

Operators today are looking for a workflow that integrates production and reservoir engineering and is part of a truly digitally enabled oilfield. Combining data from predictive reservoir models, production modelling and field instrumentation will enable operators to monitor production continuously and use information from the field when forecasting future reservoir performance and making operational decisions. ■

*Effect of gas lift on oil production potential for different mandrel setting depths. Oil potential increases with setting depth and has a maximum at given rates of lift gas, increasing with setting depth.*

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# Supercomputers for Beginners PART III
## GPU-Accelerated Computing

**LASSE AMUNDSEN**, Statoil
**MARTIN LANDRØ** and **BØRGE ARNTSEN**, NTNU Trondheim

*I changed my password everywhere to 'incorrect'. That way when I forget it, it always reminds me, 'Your password is incorrect.'*

***Anonymous***

**Many TOP500 supercomputers today use both CPUs and GPUs to give the best of both worlds: GPU processing to perform mathematically intensive computations on very large data sets, and CPUs to run the operating system and perform traditional serial tasks. CPU-GPU collaboration is necessary to achieve high-performance computing.**

To greatly simplify, a computer consists of a central processing unit (CPU) attached to memory. The CPU executes instructions read from this memory. One category of instructions loads values from memory into registers and stores values from registers to memory. The other category of instructions operates on values stored in registers – adding, subtracting, multiplying or dividing the values in two registers, performing operations like 'or', 'and', or performing other mathematical operations (square root, sin, cos, tan, etc).

Until 12 to 15 years ago, CPUs improved in speed mainly by increasing the frequency of their clocks, from MHz speeds to 1 GHz and on to 3–4 GHz. At this point speed stopped advancing, since if the frequency gets too high, the chip can actually melt from the excessive power/heat, unless cooled down. To improve speed, CPU manufacturers added more CPU cores onto the same CPU chip. Each core could work on different tasks so that the user experiences a faster computer. This is where parallel computing first entered the compute scene in a big way. But the CPUs again hit a physical barrier since the size of the chip grew with the number of cores, and the power and heat started to rise again.

For geophysicists and other scientists running big simulations, CPUs were no longer fast enough to get the computing work done. The answer to the challenge was to put GPUs (graphics processing units) on the video card as a companion to the CPU in computational tasks.

GPU developments were primarily driven by the demand for more awesome video games. In order to support the need of physical simulations, GPUs have now advanced significantly enough to do mathematical computations. They can crunch more numbers per minute than CPUs as they have thousands of cores for number calculations. GPUs in addition use less energy per computation than CPUs. Every computer, smartphone and tablet has GPUs in it.

### GPU-Accelerated Computing

GPU-accelerated computing is the use of a GPU together with a CPU to accelerate applications, offering increased performance by offloading compute-intensive portions of the application to the GPU, while the remainder of the code still runs on the CPU. From the perspective of the user, the application simply runs significantly faster.

CPU-GPU collaboration is necessary

CSCS – Swiss National Supercomputing Centre

*The Piz Daint supercomputer is the flagship for the Swiss National Supercomputing Centre. Piz Daint is the most powerful system in Europe, having computing power of 7.8 PFlops, or 7.8 quadrillion mathematical operations per second. The supercomputer has a total of 5,272 compute nodes, each equipped with an 8-core 64-bit CPU, a 2,496-core GPU with 6 GB memory, and 32 GB of host memory. Compared to a CPU, the GPU has reduced functionalities that are optimised for numerical calculations, which enables the GPU to compute much faster, while saving energy. Piz Daint is also the most energy efficient system in the TOP500 list, consuming a total of 2.33 MW and delivering 2.7 Gflops/W. Following tradition, CSCS named the supercomputer after a Swiss mountain, 'Piz Daint', in the Alps.*

to achieve high-performance computing. Known as heterogeneous computing (HC), which intelligently combines the best features of both CPU and GPU to achieve high computational gains, it aims to match the requirements of each application to the strengths of CPU/GPU architectures and also achieve load-balancing by avoiding idle time for both the processing units. Novel optimisation techniques are required to fully realise the potential of HC and to move towards the goals of exascale performance.

A simple way to understand the difference between a CPU and GPU is to compare how they process tasks. A CPU consists of a few cores optimised for sequential serial processing, while a GPU has a massively parallel architecture consisting of thousands of smaller, more efficient cores designed for handling multiple tasks simultaneously.

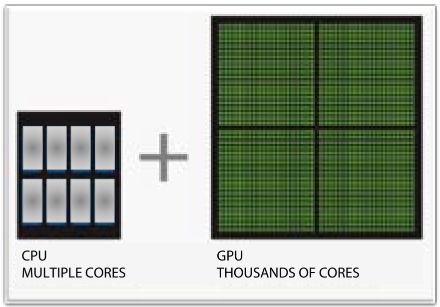
Solving a computational problem on a GPU is in principle similar to solving a problem using many CPUs. The task at hand must be split into small tasks where each task is performed by a single GPU core. Communication between the GPU cores is handled by internal registers and memory on the GPU chip. Instead of programming using message passing, special programming languages like CUDA or OpenCL provide mechanisms for data exchange between the host CPU and synchronising the GPU cores.

A modern supercomputer system may then in practice consist of a large number of nodes, each holding between 2 and 32 conventional CPUs as well as 1–4 GPUs. There will usually also be a high-speed network and a system for data storage. The software for this system can be written using a combination of conventional programming languages, like C or C++, combined with a message passing system for parallelisation of the CPUs and in addition CUDA or OpenCL for the GPUs. All of these components must be tuned and optimised for best possible performance of the total system.

The fastest GPU-enabled supercomputer on the TOP500 list, where it is number two, is the Titan Supercomputer at Oak Ridge National Lab (see *GEO ExPro* Vol. 12, No. 6). Fitted with 299,088 CPU cores and 18,688 Nvidia 2880-core Tesla K20 GPU accelerators, it achieved 17.59 PFlop/s on the Linpack benchmark. Titan is the first major supercomputing system to utilise a hybrid architecture. The second fastest, Piz Daint, number seven on the list, is installed at the Swiss National Supercomputing Centre (CSCS) in Lugano, Switzerland.

### Seismic Imaging: RTM

Reverse time migration (RTM) is an industry standard algorithm used to generate accurate images of the subsurface in complex geology. Although RTM has been in use since the 1990s, its applications have steadily widened




***When multiple processors are integrated into a single physical processor, the individual processors are referred to as cores. A multi-core processor is a single computing component with two or more cores. Terms like 'dual core', 'quad-core' and 'octo-core' give the number of cores on the processor. Whereas the CPU consists of a few (8–32) cores optimised for serial processing, the GPU can have thousands of cores to process parallel workloads efficiently. The GPU market is dominated by Nvidia and AMD. As an example, the Nvidia GeForce Titan-X GPU has 3,072 compute cores clocked at 1GHz.***

with increased access to computational power. Because of RTM's computational intensity, each important step in its development was linked to a significant increase in computational power. Examples include moving from 2D to 3D RTM, from acoustic isotropic to acoustic anisotropic, and from low to higher resolution. In the future, we expect to see quantification of uncertainty in combination with RTM imaging.

Over the last few years, we have seen a shift towards the use of GPUs in seismic data processing and imaging – in particular, RTM. The bulk of the computational cost stems from simulating the propagation of waves inside the earth.


***The amount of data collected by seismic vessels continually increases – all needing processing by supercomputers.***

The simulation process involves solving differential equations that describe the wave propagation under a set of initial, final and boundary conditions and a velocity model of the subsurface.

In RTM, two wavefields, one from the seismic source and one from the receiver array, are simulated in 3D in the computer. By using a finite-difference approximation of the wave equation, the source wavefield is modelled forward in time whereas the wavefield measured at the receivers is modelled backwards in time. The image is calculated by summing the time correlation of these two wavefields. The wave equation currently used is acoustic with some kind of anisotropy thrown into the model. The space-derivatives of the wave equation can be calculated in the space domain by using various difference approximations, or more accurately, in the wavenumber domain using so-called pseudo-spectral methods. The space-domain method currently dominates due to the high cost of the wavenumber domain method, which requires 3D Fourier Transforms. However, efforts are being made to develop and implement faster wavenumber domain approaches to RTM. RTM is applied to every shot in a seismic survey. Much effort is paid to keeping data movement to a minimum or to localise it as best as possible – whether it is I/O or message passing.

## Increasing Volumes of Data

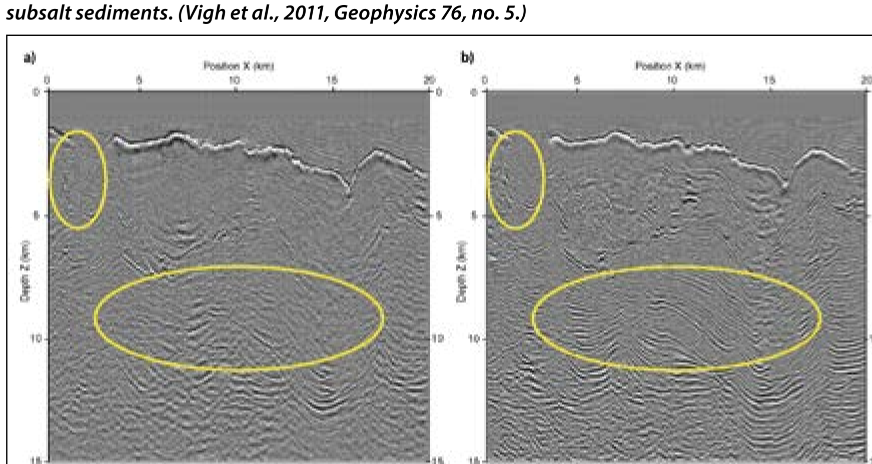
Two trends will affect how RTM is applied in the future: firstly an increase in algorithmic complexity, and secondly an increase in the volume of acquired seismic data to be imaged.

Elastic migration, based on the elastic, anisotropic wave equation, with attenuation, provides a more accurate physics model and ultimately will lead to more accurate subsurface images. However, this would dramatically increase the cost of an already expensive computation. The RTM solution then will require larger grids, and will increase both data parallelism and FLOP requirements. More advanced forms of anisotropy will increase the model space, and lower the operations per memory read. Further, to handle attenuation will require additional memory. The immediate consequence of elastic migration is that the compute power required for such algorithms increases, irrespective of the data size.

Until 2015, the trend in seismic data acquisition was to collect more and more data using larger vessels with more streamers, with the objective of further improving imaging and inversion. In particular, the number of sources and receivers in seismic surveying seems to have increased approximately by a factor of 10 every 10 years. Although oil prices took a nose dive from the second half of 2014, leading to difficult market conditions for the international seismic acquisition business, other parts of the seismic market are less affected by the spending downturn, especially data reprocessing and imaging services and specialised technologies (e.g., reservoir monitoring and ocean bottom seismic). Over longer time periods, the trend that we have seen – an increase in the volume of acquired seismic data – is expected to continue. Geophysicists will acquire more and more data – more azimuths, more density, more channels, more frequencies, with longer recording times and at increased resolution – with ever-greater efficiency. Our desire to process data at the resolution they are acquired is forcing huge increases in processing, storage and networking requirements.

These trends impact geophysicists. To come up with innovative, useful solutions to the seismic imaging challenge, at one end we need to master wave equations and their numerical solutions, and at the other end to understand heterogeneous computing. As we make imaging more sophisticated we need to make algorithms run even faster. And, as we increase the sophistication of the numerical imaging method, the complexity of the software implementation and optimisation also rapidly increases. These challenges will keep geophysicists, computer architects, programmers and researchers busy for many years to come. ■

***In the past 10 years seismic acquisition and imaging technology have gone through major changes to provide more reliable depth imaging for oil and gas exploration and development. This figure compares images from seismic acquisition and imaging in (a) 2005 and (b) 2010. In 2005, data were narrow-azimuth and processed with 2D surface related multiple elimination (SRME) and wave-equation migration; in 2010, data were wide-azimuth and processed with 3D SRME and RTM. RTM combined with wide-azimuth data results in better imaging at the salt flank, base of salt, and subsalt sediments. (Vigh et al., 2011, Geophysics 76, no. 5.)***

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# New Opportunities Offshore West Egypt

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**ØYSTEIN LIE**, PGS;
**AYMAN ALMORSHEDY**, EGAS

**Hydrocarbon exploration success offshore Egypt to date is mainly associated with the prolific Pliocene sequence in the Nile Delta Basin, but as the recent Zohr discovery shows, there are other potential plays to follow. Here, we look at the relatively unexplored area of offshore West Egypt.**

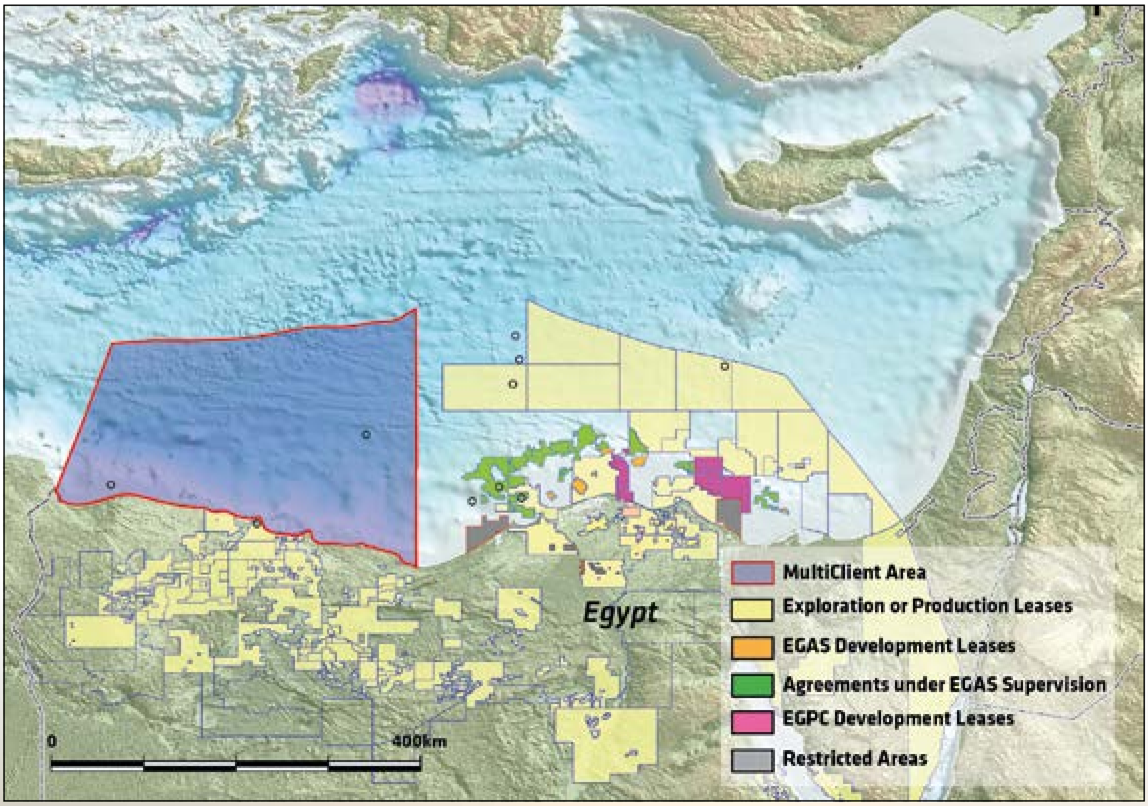
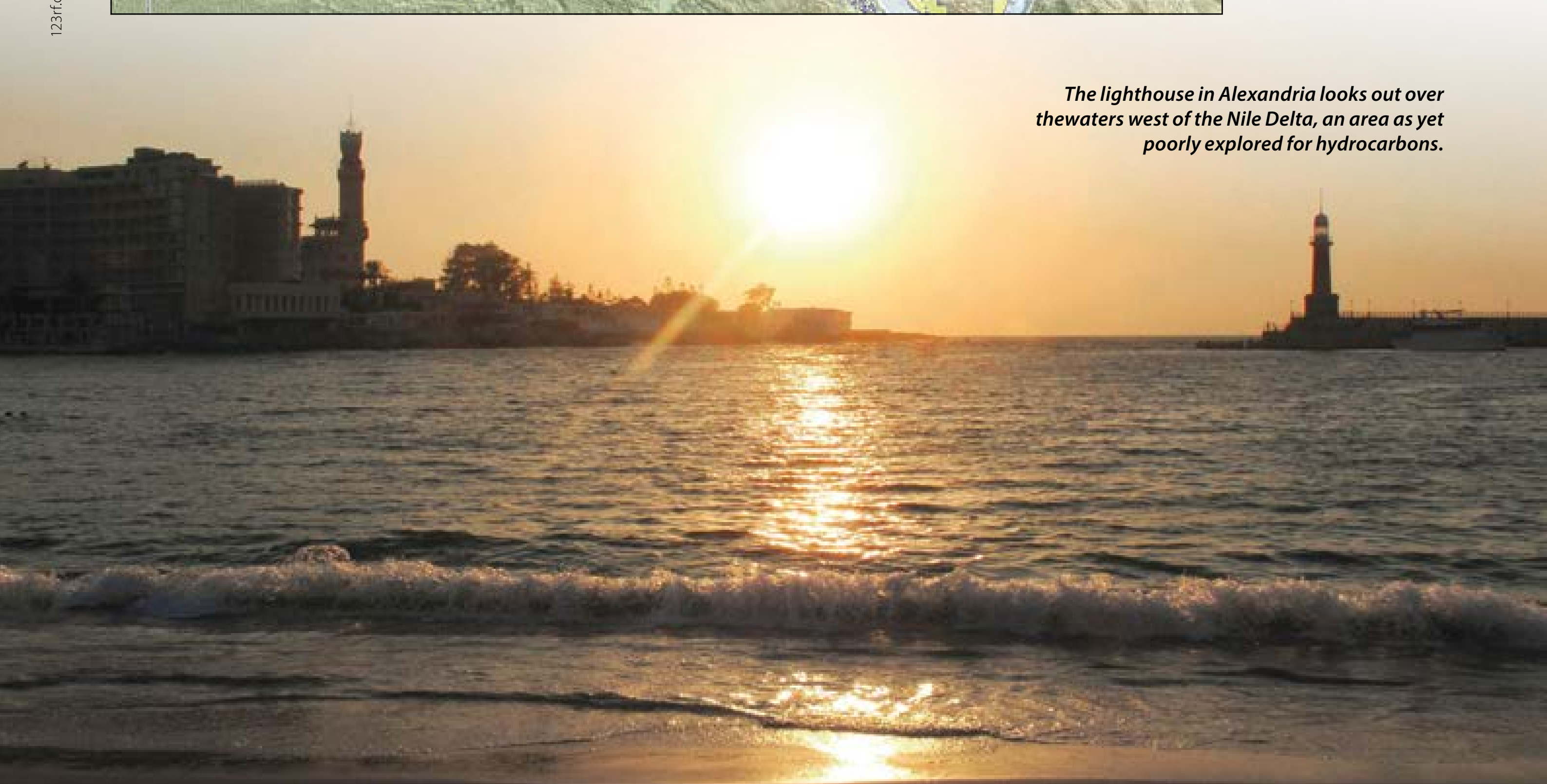



*Figure 1: Location map of Egypt's Mediterranean Sea area showing licensed acreage together with the 80,000 km² frontier area west of the Nile Delta.*





*The lighthouse in Alexandria looks out over thewaters west of the Nile Delta, an area as yet poorly explored for hydrocarbons.*

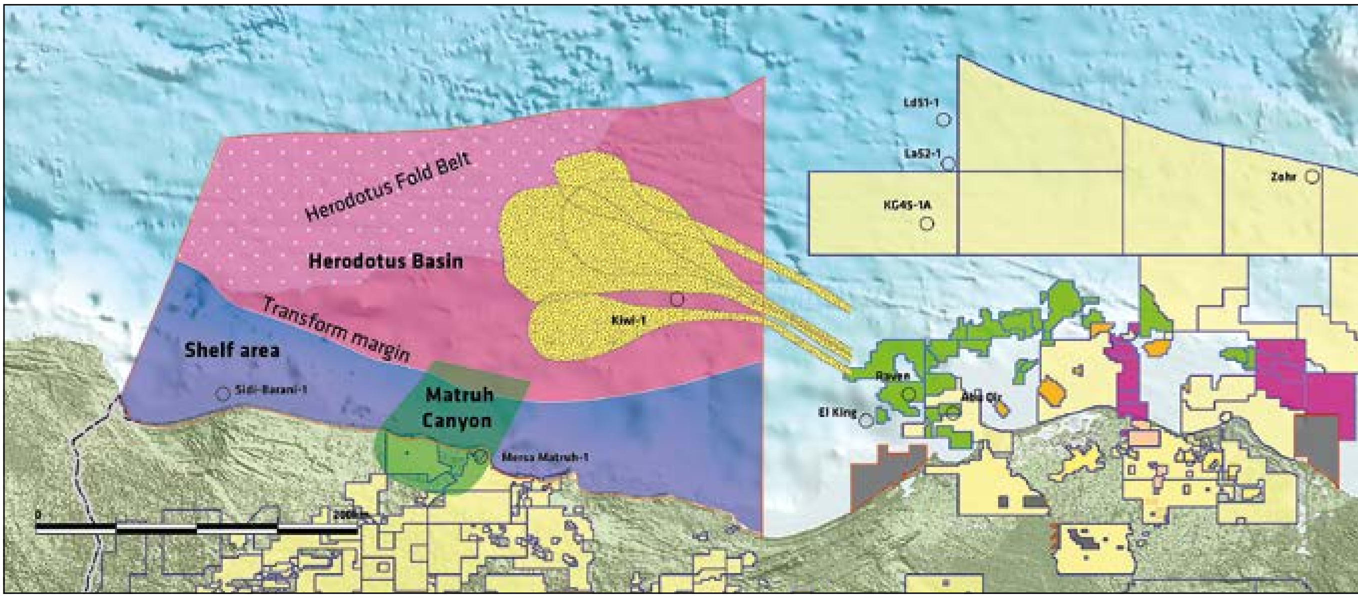



*Figure 2: The study area, outlined in red, includes several different geological domains based on interpretation of existing data: the Shelf area, the Matruh Canyon, the Herodotus Basin and the Herodotus Fold Belt. The relevant exploration wells within the survey area and in the vicinity are marked on the map. The yellow stippled areas are potential basin floor fans from the Nile Delta.*

The frontier exploration area offshore West Egypt (Figure 1) consists of several structural domains (Figure 2) including, from south to north, a comparatively narrow shelf zone; a west-south-west to east-north-east trending transform margin; parts of the Herodotus Basin; and the Herodotus Fold Belt to the north-west. The onshore extension of this area contains a proven petroleum system for both oil and gas, as evidenced by the Matruh and Emerald fields.

To date, exploration in this large area has been limited, and consequently the petroleum systems are currently not well understood. Only two exploration wells, Kiwi-1 (2010) and Sidi Barani-1, (1976) have been drilled, and both were dry, although Kiwi-1 did prove very good sandstone reservoir properties of Rupelian age (Figure 5). New seismic 2D data acquisition is currently being planned to enable a full assessment of the petroleum system in this area. These data will form the basis for a future licensing round tentatively planned for 2017.

### Petroleum Systems

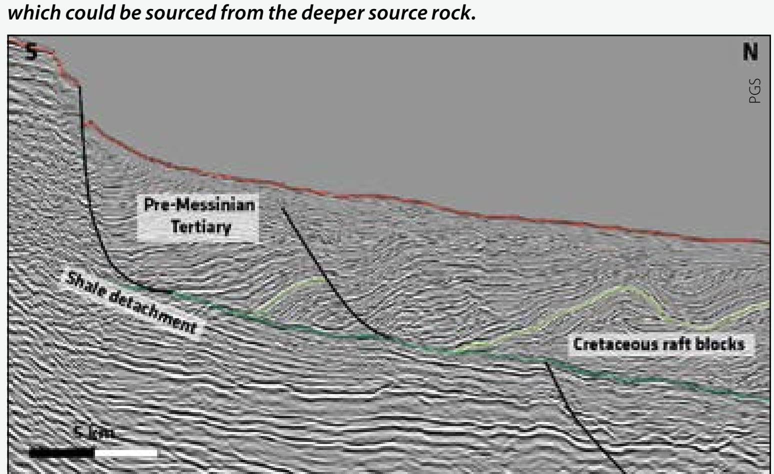
Different potential play types have been identified utilising seismic data, well information and existing discoveries from analogous geological settings such as onshore discoveries in Western Egypt, the recent Zohr gas discovery (Figure 2) or other giant discoveries in the Levant Basin. Play types can be identified in four different geological domains, which are described below and illustrated on legacy lines in time.

## Matruh Canyon

The Matruh Canyon is a north-north-east trending Jurassic to Early Cretaceous rift basin, inverted in the Late Cretaceous – Early Tertiary, with a major Early Cretaceous depocentre. Cretaceous raft blocks from the Matruh Canyon can be defined as a structural analogue to the producing post-rift Cretaceous raft blocks from the Lower Congo Basin. The Cretaceous blocks in the Matruh Canyon are rafts on a shale decollement, as seen on the data example in Figure 3, and could potentially be sourced by a deeper source rock from the Khatatba Formation, which is a proven hydrocarbon source for the onshore discoveries. Based on its burial depth, the Khatatba Formation could be interpreted to be partially or entirely in the gas-generation window within this area.

The Matruh Canyon extends offshore down dip from the onshore discovery trend where the Mersa Matruh-1 well, with significant oil and gas shows, is located just onshore (Figure 2). Further seismic evidence for an active deepwater hydrocarbon charge is given by gas chimneys and active mud volcanoes.

*Figure 3: Legacy seismic data example from the Matruh Canyon showing the Cretaceous shale decollement (green) and Cretaceous raft structures (light green) which could be sourced from the deeper source rock.*



## Shelf Area

The comparatively narrow shelf can potentially be linked to the onshore discovery trend, where most reservoirs are found within the Lower Cretaceous Alam El Bueib Formation and in the Jurassic Khatatba Formation. Potential traps can be observed in both formations within the Shelf area. Figure 4 shows a potential lead along a north-west – south-east trending fault that represents the general structural trend in the Shelf area. This trend is perpendicular to the stratigraphic dip, and thus provides potential fault-bounded traps for hydrocarbons migrating up-dip or acts as a vertical conduit for hydrocarbon migration into shallower traps.

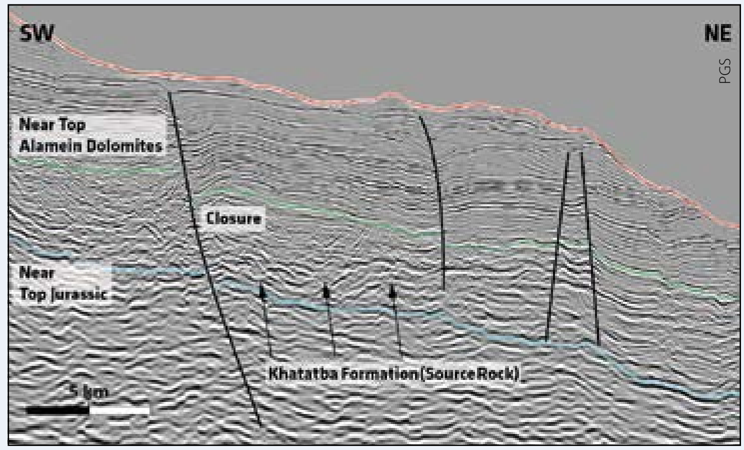



*Figure 4: Legacy seismic data example from the Shelf area, an extension of the onshore Western Desert Basin with a proven petroleum system.*

## Herodotus Basin

The Herodotus Basin is a Tertiary sag basin resulting from the opening of the Neo-Tethys during Mid-Jurassic to Early Cretaceous times and is characterised by the presence of Messinian Salt over nearly the entire area.

The biogenic gas window in the Herodotus Basin is deep due to the low geothermal gradient as a result of the thick Messinian Salt and the old passive margin (20–25°C/km). These conditions allow biogenic gas to be generated and trapped deeper than in other basins, meaning that the reservoirs can contain larger volumes of gas, thus improving the overall economics. These conditions are exceptional but apply to all major gas discoveries offshore the Eastern Mediterranean Sea. Pre-salt structures are observed in the Herodotus Basin, all of which are located within the biogenic gas window. These could be analogous to the giant biogenic gas discoveries seen in the Eastern Mediterranean area such as the recent Zohr discovery, found in pre-salt carbonates. In addition, the cooler conditions also allow a thermogenic system that could generate hydrocarbon liquids and gas at greater depths than might be normally expected in such thick sedimentary piles.

The Zohr discovery appears to prove excellent porosities within parts of the carbonate reservoir and thus highlights the exploration potential in pre-salt carbonates. However, potential pre-salt sandstones could also have high porosities as a result of being subjected to fewer digenetic processes due to the low geothermal gradient. A Miocene sandstone fairway is proven on the western flank of the Nile Delta by wells from the Raven, Abu Qir and El King fields (Figure 2). A more distal down dip extension of this fairway is indicated by RMS attribute maps from a 3D seismic survey around the Kiwi-1 well in the Herodotus Basin. This well failed to find sandstones within the Miocene section, although it found good quality ones within the Oligocene.

Paleogene to Neogene pelagic sediments are considered to be the hydrocarbon source for the potential biogenic gas in the area. Seismic characteristics, such as continuous, layered reflectors, indicate that these pelagic sediments are likely to be well distributed in the Herodotus Basin, and unconformities may allow long distance lateral charge.

The thermal conductivity of the salt lowers the geothermal gradient in this area, which will deepen the generation window for both biogenic gas and thermogenic hydrocarbons. A potential thermogenic play can thus be found in deeper Jurassic carbonate and Early Cretaceous sandstone reservoirs sealed by interbedded shales (Figure 5) and within structural closures as a result of a Late Cretaceous to Early Paleogene inversion period.

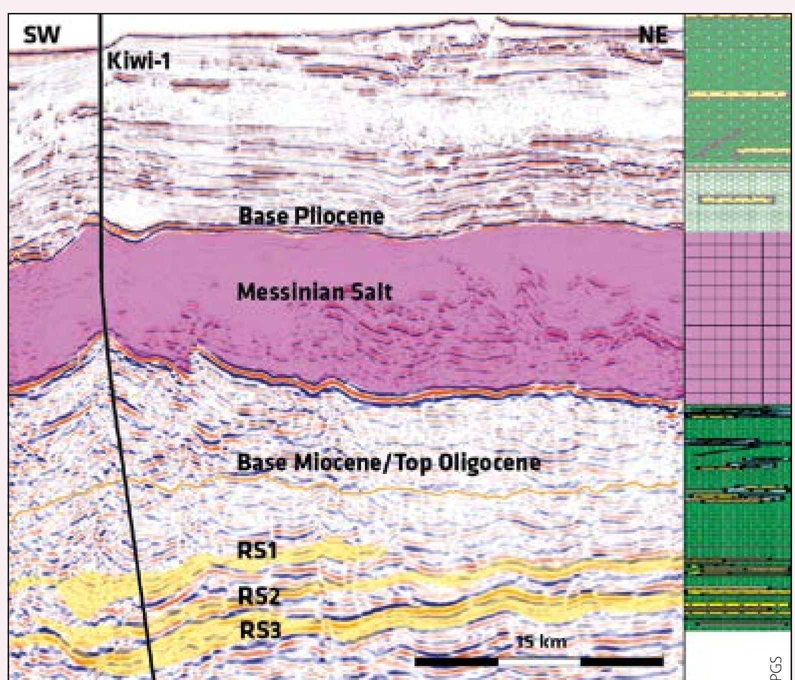



*Figure 5: Seismic data example and lithology column through the Kiwi-1 exploration well. Sub-salt sandstones in Rupelian (Oligocene) age (RS1-3) with high porosity values were proven.*

### Herodotus Fold Belt

The Herodotus Fold Belt is associated with the Mediterranean Ridge and is located in the north-west part of the Aegean Plate (Figure 2). The Messinian Salt is thick and folded in this area as a result of tectonic compression and gravity-driven deformation. Salt-related anticlinal structures can be found within the Pliocene sequence and could form structural traps. The overburden here is sufficient to place any potential reservoirs in the prolific biogenic gas window, so that any traps could potentially contain biogenic gas in economical quantities, whereas the Pliocene sequence in other parts of the Herodotus Basin is likely to be too thin for this to occur. In this area, the Pre-Messinian is not well understood due to a limited amount of data and the challenges related to 2D seismic imaging of strata beneath the thick folded salt sequence.

## New Geophysical Data Needed

The existing geophysical 2D and 3D data coverage is limited, and the 2D generally poorly images the subsurface in many areas where it has been acquired. Reprocessing of this legacy 2D data, which consists of three surveys from 1999, 2005 and 2007, is currently being undertaken using up-to-date broadband processing sequences, in which both receiver- and source-side deghosting will be applied. De-noise techniques including demultiple will be very important in addition to pre-stack depth migration to optimise the use of this vintage data.

A new 2D GeoStreamer® broadband data acquisition programme of approximately 5,000 line km has been planned. Combined with the reprocessed legacy data, it is hoped that this will improve the definition and understanding of the structural and lithological trends that have been interpreted using the old existing data. The new data will be positioned in areas where the legacy coverage is poor, such as the south-eastern part of the Shelf area and within the Herodotus Basin (Figure 2). Infill to the existing 2D coverage will also provide better control when identifying and quantifying potential leads. In this frontier area, tie lines to exploration wells outside the survey area will be highly important. Ties from the two exploration wells within the survey area to pre-salt gas discoveries (exploration wells Ld51-1, La52-1, KG45-1A) and an Upper Miocene – Lower Pliocene oil, gas and condensate discovery (exploration well El King) would be valuable (Figure 2). 2D gravity and magnetic data is included in the new acquisition programme planning to further enhance the geological understanding of the area.

## Stimulating Further Exploration

The re-processed upgrade of the legacy data, combined with the new broadband data coverage, are essential for defining new play types and are expected to reveal similar potential to that seen in analogous geological settings like the deep Nile Delta and west Cyprus. The seismic data will be the basis for defining new exploration blocks and for future licensing rounds. The objective is to provide both EGAS (Egyptian Natural Gas Holding Company) and the industry with optimum geophysical data, allowing a better understanding of the complex geology and helping stimulating further exploration in the area. ■

# The Atlantic Road
## A Metamorphic Journey

**The Atlantic Road, one of the National Tourist Roads of Norway, offers great scenery all year around.**

MORTEN SMELROR

"'I've never met a morph that I didn't like," I say, repeating a joke I heard a long time ago in an episode of the TV-series *Fame*. My wife has just asked me to explain what metamorphic rocks really are. I continue: "One of the students was asked to… Oh, never mind!" We are at the Norwegian coastal village of Bud – a paradise for those who love nature and fishing. We have parked in a former quarry and in front of us is a naturally-occurring exhibition of different rocks found in the region, mostly various metamorphic ones like gneiss and marble, but also granites and conglomerates.

### How to Mend a Broken Heart

To get to Bud from the city of Kristansund, one must drive along the Atlantic Road, often called the 'road in the ocean', which runs north-westwards from Vevang on the mainland across to Kårvåg on the island of Averøy. It is only 8 km long, yet passes across 17 islets and skerries, with over 10% of its length on bridges. In 2012 it was officially named one of Norway's 18 'National Tourist Roads'; it has received a number of other awards – and, according to Lonely Planet travel guide (2007), the Atlantic Road is the world's best place to mend a broken heart. No wonder it has become one of Norway's biggest tourist attractions!

Bud is certainly a good start for a road running through some of the most scenic landscapes in Norway. From the disused quarry you can walk up to the Ergan coastal fort, a war museum built around the WWII German coastal fort, as well as the natural and cultural exhibition in modern buildings next to it. The steep quarry wall holds a colony of breeding kittywakes. From the top of the hill the panoramic view is stunning: the wide North Atlantic lies in front of you, numerous islands and the strandflat open towards the south-west and the north-east, with the gentle mountains rising behind you.

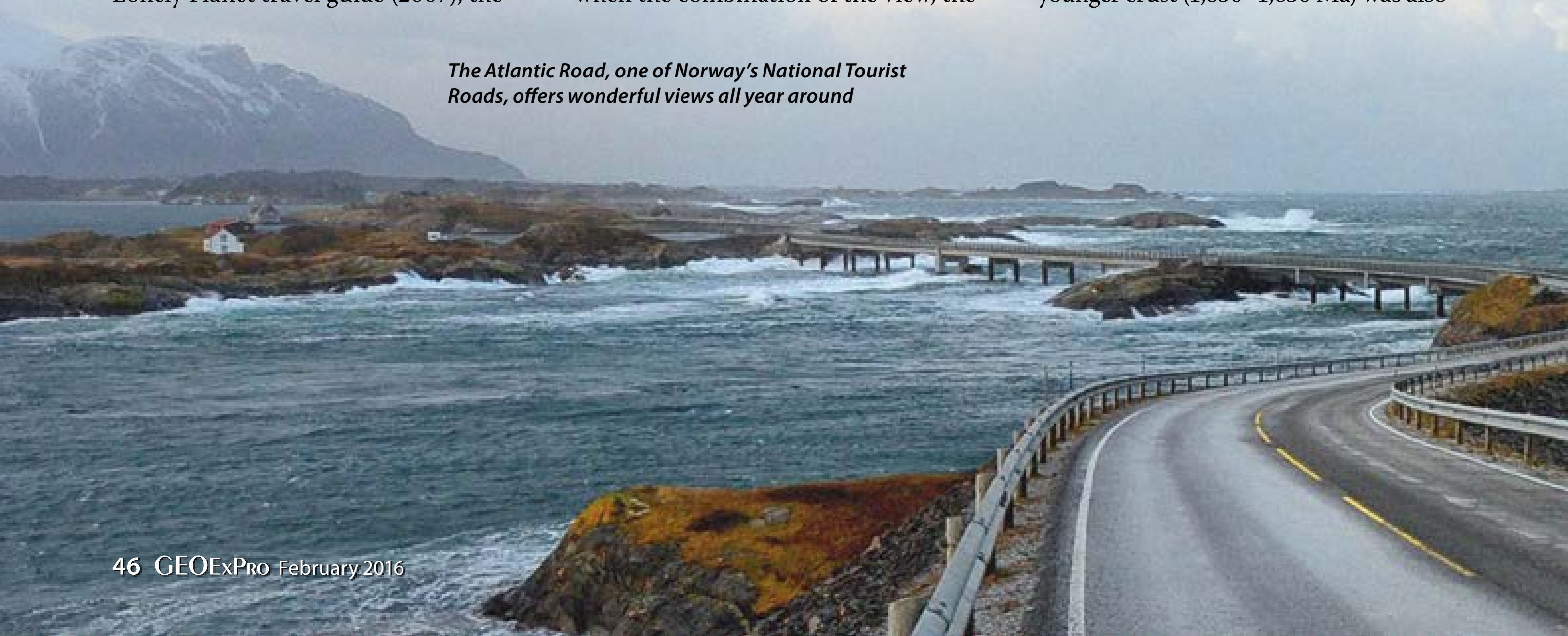
On our walk towards a local fish restaurant we meet a cute little fellow in the middle of the road – a young sea-otter – while in the harbour in front of us, we discover a majestic swan sipping rainwater dripping from an old quayside warehouse. Yes, we believe this place could mend a troubled heart, at any time. The Lonely Planet claims it is best to go there in the autumn, when the combination of the view, the wind, waves and the cries of the gulls are at their most intense. During the construction of the Atlantic Road the workers experienced 12 hurricanes before it was finally opened in 1989.

### On the Roots of Something Bigger

The Atlantic Road runs along the north-west corner of what is called the Western Gneiss Region on the geological maps of Norway. The Precambrian rocks of this region cover an area of more than 25,000 km² west of the Caledonian nappes from Sogn to Nord-Trøndelag. During the Caledonian plate collision around 400 million years ago, these rocks along the western margin of the Fennoscandian Shield were conveyed down to a great depth, heated, metamorphosed and deformed.

At the end of the collision the Caledonian mountains stretched from Scotland to Svalbard, as high as today's Himalaya, before being eroded down to their roots. Over the past 2.6 million years repeated glaciations and coastal erosion have sculptured the landscape along the Atlantic Road and left us with scenic exposures of metamorphic rocks, dominantly granitic gneisses and migmatites.

While most of the rocks in the Western Gneiss Region were formed between 1,700 and 1,500 Ma, some of the bedrock found in the region along the Atlantic Road is around 1,830–1,840 million years old, and thus a continuation of the Trans-Scandinavian Igneous Belt in Sweden. Gabbroid gneiss, granitic gneiss, migmatic gneiss and granite were formed from 1,686 to 1,653 Ma, and somewhat younger crust (1,650–1,630 Ma) was also



Roar Bech

*The Atlantic Road, one of Norway's National Tourist Roads, offers wonderful views all year around* formed in the southernmost part of the Western Gneiss Region.

We leave Bud and drive a few kilometres north to Hustadvika. Given that the open water to our west is one of the roughest and most feared ocean stretches along the Norwegian coast, the green fields around us and the long sandy beach in the bay appear surprisingly calm and pleasant.

Another surprise is the presence of plutonic rocks that almost entirely escaped the Caledonian orogeny. Near the lighthouse at Farstad the rocks of the Hustad Complex (1,654 Ma) consist of reddish granite surrounded by monzodiorite and some pyroxenite. Here, samples of the basement deep below the present surface have been brought up and laid before us as an intrusion breccia. These samples, or xenoliths, consist of dark rock types that seem to have been formed by early differentiation from the magma itself, together with light-coloured dioritic rocks.

## A Clearcut Bedrock Wall

The view is magnificent, and great bedrock exposures are numerous, as we continue northwards along the Atlantic Road. The wave-washed surfaces make it easy to see the various geological structures. If you get tired of studying the landscape and the geology, you can take side-tracks to the historic fishing villages, or you can enjoy fishing from one of the many islets and bridges along the way – not to mention the unique possibilities for scuba-diving in the shallow oceanic water just offshore. If you turn inland, great places for mountain hiking are easily found.

And if you want more geology, the road builders have made it easy for you by creating a great clear-cut bedrock exposure at Myrbærholmen. Here you can study the rocks in detail, and discover younger dykes intruding into the gneisses. Few places offers such good possibilities for 'polished plate' examinations of the geological structures.

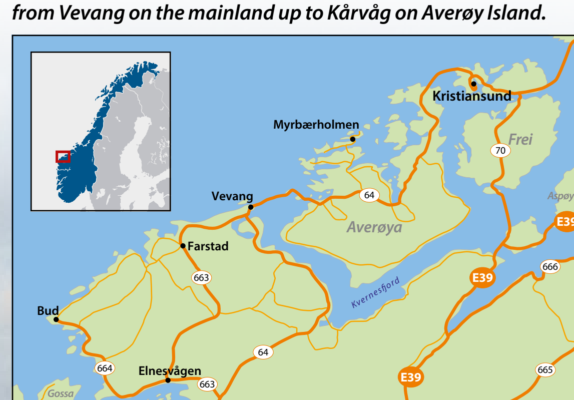
Speaking of which: continuing on the last few kilometres of our journey, I turn to my wife: "Did you know that the company Hustadmarmor, located at Elnesvågen just a short drive from here, is the world's biggest producer of pigments for the international paper industry? They use limestones to make filler and coating pigments, contributing major environmental benefits and improvement in the paper quality. The shining white and glossy appearance of the magazine you are holding is most likely due to pigments from the metamorphic limestones at Elnesvågen quarry. Surely a marvellous journey: starting with some tropical carbonate deposits in a Precambrian Ocean; being trapped in a collision between continents; becoming small components of a giant mountain chain; before being mined out to end up as tiny particles in a magazine." My wife looks at me: "Now, that is what you could call a metamorphic journey."

*Ice-transported, erractic block of augen gneiss exhibited at Bud.*

## Viewing the Strandflat

The landforms of present-day Norway were largely shaped by glaciers in the last 2.6 million years. Along the Atlantic Road you travel on the strandflat, a low brim to the mainland, headlands, islands and skerries. On Averøy, at the northern end of the Atlantic Road, a modern and somewhat architecturally

*The Atlantic Road on the north-western coast of Norway runs from Vevang on the mainland up to Kårvåg on Averøy Island.*





***Hustadvika, with the strandflat and the mountains behind.***

futuristic visitor and information centre was opened in June 2014, along with a trail and walkway around the small island, which offers a safe walk and a great panoramic view of the surrounding strandflat.

The formation of the strandflat has been the subject of much debate. Many researchers believe that the coast was free of ice for long intervals during glaciations, similar to conditions along the margins of Svalbard and Greenland today. Weathered bedrock was removed from the foreshore, first by waves and later by glaciers. As a result the coastal islands developed a low-lying bedrock topography, with a well-defined inner margin bounded by steep mountainsides. Since weathering was most intense close to the sea, the steep mountain margin was maintained during colder periods.

In a recent study, researchers from the Geological Survey of Norway suggest that during Mesozoic times there was deep weathering of the bedrock, laying down the foundation for the formation of the strandflat and fjords, which in a tropical climate lasting for millions of years made the bedrock porous, and the rocks became less resistant to later erosion by waves and ice. Some rock formations were more easily weathered than others, and while meta-sedimentary rocks and especially shales were eroded, more solid granites, gneisses and gabbros were left behind to form islands and skerries, as well as in some places small steep mountains extending up from the strandflat. Today, we can find occasional isolated zones and small pockets of loose, weathered bedrock, but generally the results of deep weathering are hidden to the naked eye.

***Folded Precambrian gneiss at Ramsøya.***


### Culinary Treats

On your way along the Atlantic Road you should find time to enjoy some of the local culinary treats. The cheese Kraftkar from Tingvoldost won the award for the best blue cheese at the International Cheese Awards in 2013, and fresh fish of various kinds from the Atlantic Ocean is of course a must. However, the best known speciality from the district is bacalao: dried, salted cod, known locally as 'klippfisk'.

The production of bacalao dates back to the 1600s and became very popular in the 1700s. Both in former times and today most of the production is exported to an international market. The town of Kristiansund is founded on bacalao production, and even today is known as the Bacalao Town. Naturally, it has its bacalao museum, a bacalao festival and a bacalao opera. After a geotouristic journey along the Atlantic Road and studies of the geology of the 'klippfisk' hills, nothing could be more natural than ending the day with a meal of bacalao.

"Did you know that I described a lithological unit of Early Cretaceous condensed carbonates on the Barents Shelf, which I formally named the Klippfisk Formation?" I ask my wife as we enter into Kristiansund. She looks at me. "Oh, never mind…"

*See GEO ExPro Vol. 9, No. 5 'Cycling the Norwegian Strandflat' for more on the Norwegian Atlantic seaboard.* ■

Third Announcement and Final Call for Papers

# Africa: What's Next?

## The 15th HGS-PESGB Conference on African E&P

### September 12-14, 2016

**The Westin Houston, Memorial City, Houston Texas**

This annual conference, alternating between Houston and London, has established itself as the primary technical E & P conference on Africa with attendances in recent years exceeding 600, including industry operators, consultants, governments, and academia. There will be a large poster program in addition to the oral program of about 25 high quality talks covering aspects of E & P in all regions of Africa.

**Theme 1: African Exploration in a Global Context**
Session Chair: Joan Flinch (Repsol)

**Theme 2: Knowledge Transfer: Emerging Exploration Concepts, Conjugate Margins and Analogues**
Session Chair: Bill Dickson (DIGS)

**Theme 3: Hydrocarbon Generation Through Time and Space**
Session Chair: Carol Law (Soaring Eagle Energy)

**Theme 4: Storage and Containment: New Insights into Reservoirs, Seals and Traps**
Session Chair: Katrina Coterill (BHP)

**Interactive Seismic Showcase and Geology Workshop**
Session Chair: John Moran (Anadarko)
*Ongoing throughout the conference – see website for announcement of details.*

**Abstracts** Abstracts (up to 2 pages long and can include diagrams) should be sent as soon as possible and no later than **March 1, 2016** to Africa2016@hgs.org. Extended abstracts are normally written once your paper is accepted and are issued on a conference CD.

**Invited Keynote and Other Speakers** A number of respected industry leaders have accepted invitations to deliver keynote presentations: Presenters include: opening keynote address by Bob Fryklund (Chief Upstream Strategist-IHS Energy) on *Africa Exploration – Dealing with the New Reality?*, plus Peter Elliott (PVE Consulting Ltd) on *Exploration Strategy and Performance in Sub Saharan Africa*, GlobalData on *Commercial Aspects of Exploration in Africa*, Cynthia Ebinger (Univ. of Rochester) on *Fluid Flow in East African Rift Systems* and Anadarko on *Reservoirs and Seals of the Deep Ivorian Basin*. Further announcements to be revealed in due course; please consult the HGS website.

**Short Courses** 2 short courses will be held in conjunction with the conference
Duncan Macgregor – *Petroleum Basins and Recent Discoveries in North and East Africa*
Ian Davison – *South Atlantic Margins: Geology and Hydrocarbon Potential*

**Conference Opening Evening Lecture** Prof. Andy Nyblade (Penn State University) will present the Conference Opening lecture on *Imaging First-Order Structure of Large Karoo and Younger Basins in Central, Eastern and Southern Africa Using Passive Source Seismic Data*. The lecture will be held on the evening of Monday September 12th. Details to be announced shortly.

Details of sponsorship opportunities and exhibition booths are available at office@hgs.org or on the HGS website.

Registration will open in April, 2016.

Early bird rates will be available: check the HGS website for details.

**Abstract submission: Africa2016@hgs.org • Information: office@hgs.org**

# Iran After Sanctions: Opportunities and Risks

**MAHDI KAZEMZADEH**, Afraz Advisers;
**BABAK SAMI VAND**, Petroxin Ltd

**Iran provides a significant opportunity to access low cost production for the right companies. In response to the removal of sanctions, we take a look at the opportunities and challenges, both technical and commercial, of working in the country.**

Iran has the largest deposits of hydrocarbon resources in the world, with the world's biggest proven gas reserves (34 Tcm or 1,200 Tcf) and the fourth largest proven crude oil reserves (157.8 Bbo). Due to the imposition of sanctions, over the last few years Iran has not been able to invest adequately in its upstream sector – the official figures suggest an average of $3 billion/year over the last three years. However, since a comprehensive deal on sanctions was finalised on 14 July 2015 and the prospect of foreign investment has become a reality, there has been significant interest from foreign E&P operators and service companies.

### What's on Offer?

Iran is offering 70% of its untapped oil and liquid reserves from a range of green and brownfield projects. The National Iranian Oil Company (NIOC) presented 51 upstream E&P projects for foreign participation during the Tehran Summit on 28 November 2015. In total it is estimated that these fields could add over 1.28 MMbopd – probably a conservative estimate – and 8 Bcfgpd to Iran's production.

*The Sheikh Lotfollah Mosque, a 17th-century architectural masterpiece, on the eastern side of Naghsh-e Jahan Square, Isfahan. An increase in tourist numbers is also expected in the wake of the lifting of sanctions.*

Bruce Winslade


*Iran nuclear deal: agreement in Vienna. From left to right: The foreign ministers/secretaries of state for China, France, Germany, the EU, Iran, the UK and the USA agreed to lift sanctions on Iran in Vienna in July 2015.*

To facilitate this, in 2013 the Iranian government embarked on an unprecedented overhaul of the contractual regime. The new Iranian Petroleum Contracts will offer significant incentives to IOCs over the previous buy-back contracts, including:

- Longer contract horizon (20–25 years);
- Appointment of the IOC as 'Operating Manager';
- Development fee per barrel linked to the market price of oil;
- Alignment of interests for all parties to encourage long-term collaboration.

Through the new contracts NIOC is seeking to encourage participation from IOCs to address gaps in the local Iranian market. They hope they will bring in advanced technologies, including those used for IOR and EOR in order to improve or maintain recovery in existing fields and reduce gas injection in oil fields, a commodity Iran is looking to export. The NIOC also expects participating companies to introduce the latest technologies in use in heavy oil fields, deep reservoirs and sour gas fields, and innovative methods for reservoir management and optimisation as well as surface asset integrity management.

A number of the smaller fields on offer, with production in the range of 3–5 Mbopd, will require lower CAPEX investment, which should encourage smaller and medium sized IOCs to enter the Iranian market.

Based on analogous costs in the neighbouring Kurdistan region of Iraq, the break-even costs of Iranian onshore oil fields could be $20–35/bo, with a lifting cost of $4.5/bo. Assuming sanctions are lifted in the expected time frame, a conservative estimate of $30 billion can be made for the upstream investment into development projects out to 2020.

### Why So Much Oil?

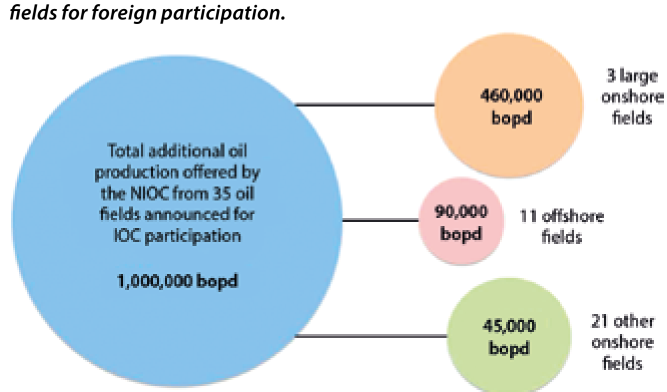
Iran can be divided into several tectono-sedimentary zones, all of which have been investigated for hydrocarbon potential by regional geological studies and through drilling exploration wells.

The first oil discovery in Iran was in the Zagros Basin in the Masjed-Soleyman area in 1908 and until 1956 it remained the sole petroleum region in the country. Oil was discovered in the Alborz anticline in Central Iran in 1956, and the first hydrocarbon discoveries in the north, though deemed to be uneconomic due to low permeability, were in the 1960s, when large gas fields were also discovered in the Kopet-Dagh Basin in north-west Iran. However, most of Iran's reserves are located in the Zagros, which remains the most prolific basin in the country. (For more on the history of oil exploration in Iran, see www.geoexpro.com)

Tethyan Ocean evolution shaped Iranian geology and its tectonic style, resulting in the generation of prolific petroleum systems.

Iran was on the northern margin of Gondwana until Devonian times, when extension resulted in rifting and the creation of the Palaeo-Tethys Ocean and the separation of northern Iran from Gondwana (Boulin, 1988). During Carboniferous to Permian times another extension phase in northern Gondwana resulted in the creation of the Neo-Tethys Ocean. By the late Triassic this had reached its maximum extension and the Palaeo-Tethys Ocean had closed. The

*NIOC aims to increase production by offering 24 onshore and 11 offshore fields for foreign participation.*



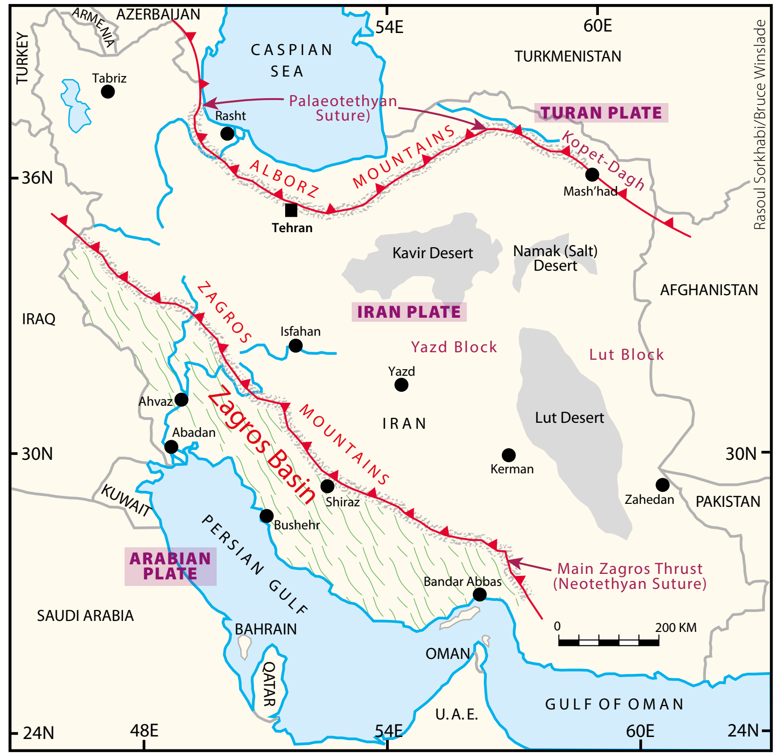
majority of Iranian oil and gas reservoirs in the Zagros Basin were deposited in the margins of this new ocean.

From the Jurassic to early Tertiary, the Neo-Tethys Ocean underwent subduction as the Arabian plate collided with Eurasia, creating major structural traps in the Zagros area, including many large, hydrocarbon-filled anticlines in the foothills of the Zagros Mountains, primarily trending north-west to south-east. A few structures exhibit a north-south trend due to movement of the basement faults (Steineke et al., 1958).

At various times passive margins with extensive carbonate platforms developed along the Tethys Ocean, creating high quality reservoir rocks in the Zagros Basin. In addition, intrashelf basins formed during vertical movements of rift blocks, and important source (Garau Formation) and evaporate cap rocks (Hith Formation) were deposited (Pratt and Smewing, 1993).

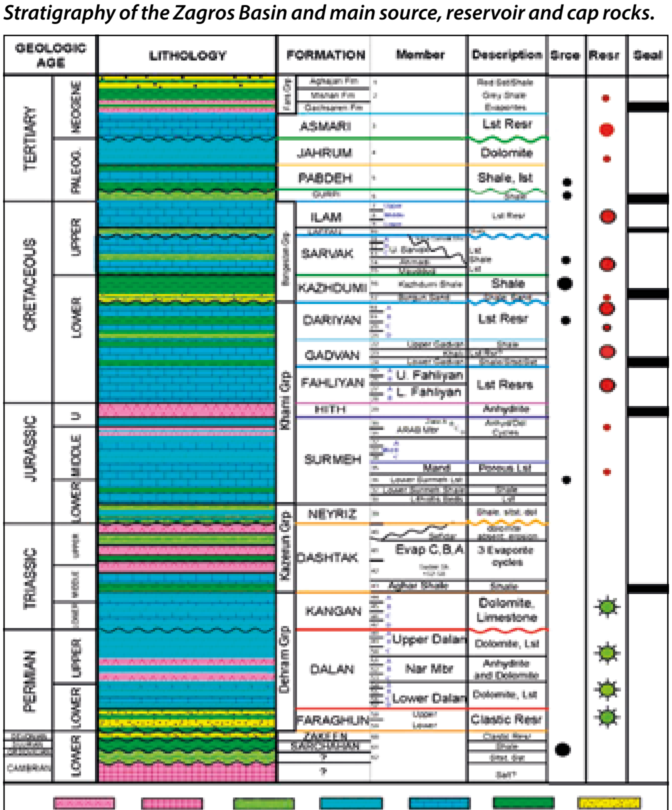
Relative sea level change caused by tectonic movements and climate change resulted in the depositional cycles which are responsible for the creation of the prolific petroleum systems found in the Zagros Basin. Organic rich shales were deposited during sea level rise, followed by prograding carbonate deposition during highstand times. Cap rocks were created either by continental deposition during lowstand or as marine deposits of the next cycle. There are multiple petroleum systems in the Zagros Basin as a result of this cyclical deposition. (Note that nomenclature and correlation of strata vary in each area of the basin.)

The most important source rocks are the Sergelu, Garau, Kazhdumi and Pabdeh Formations. The significance of each varies from area to area within the Zagros – and sometimes source rocks change laterally into reservoir rocks.




*Structural zones of Iran.*

*Stratigraphy of the Zagros Basin and main source, reservoir and cap rocks.*




## Summary of Main Reservoirs

Over 90% of the hydrocarbons in the Zagros Basin are found in carbonate reservoirs, with oil accumulating in Mesozoic and Tertiary rocks, while most gas is in Permian and Triassic reservoirs. In the majority of discoveries, hydrocarbons are trapped in the anticlines; no stratigraphic traps have yet been discovered.

Almost 85% of Iran's crude oil is produced from the Oligo-Miocene Asmari Formation, with 59 Asmari reservoirs (51 oil and 8 gas) having been found in the Zagros Basin. The main producing section is 330–500m thick, although in some fields – for example, Gachsaran – the vertical difference between spill point and the crest can be nearly 2,000m. The evaporates of the Gachsaran Formation provide a thick and efficient seal to the Asmari reservoirs.

The Asmari Formation is not all carbonate. The Ahwaz Sandstone, for example, is an important and extensive member of the formation, up to 249m thick. Asmari lithology can be a mixture of dolomite, limestone, anhydrite and shales interbedded with the Ahwaz Sandstones.

For the newcomer to Iran, it is interesting to note that Asmari reservoirs typically have moderate to high porosity (12–24%), particularly high in the Ahwaz Sandstone Member, and extensive fracturing systems, with high reservoir pressure and moderate to high aquifer water drive. They contain good quality crude oil with low $H_2S$ content and light gravity oil (API >30°), often in giant geological structures, and their shallow depth of burial means low-cost drilling.

Giant fields producing from the Asmari Formation include Maroun, Gachsaran, Aghajari, Karanj, Mansouri, Koupal,

## Challenges and Risks

The two key commercial challenges facing potential foreign partners are compliance and contractual risks.

IOCs are required to find local partners and deliver significant local content. This requires in-depth knowledge of the Iranian market and significant on-the-ground business development, together with due diligence effort to establish the right companies to work with. Although the majority of sanctions against Iran have been lifted, the US primary sanctions will remain in place and companies will need to pay attention to the restrictions introduced by these laws when doing business in Iran.

In addition, the revised contracts, like anything new, come with implementation risks and there are still questions about various aspects of them that need to be worked out. Fortunately, the Iranian team in charge of drafting the new contract has been willing to listen to the industry and collect feedback.

Bibihakimeh and Masjed Soleyman.

The second largest reservoirs are the Middle Cretaceous Bangestan Group, producing from Ilam, Sarvak and Kazhdumi Formations. They are capped by the thick Pabdeh/Gurpi marls in most areas of the basin. Bangestan reservoirs are deeper than Asmari oness, making them harder to drill and produce. As the reservoir rocks are generally dense with low to medium porosity and permeability, the primary recovery factor is low, and they have a weaker water drive than Asmari reservoirs. IOR and EOR methods have therefore been proposed, including hydraulic fracturing and massive acid treatments.

The common characteristics of Bangestan reservoirs are huge geological structures bearing high oil volumes in dense limestone and dolomite reservoir rocks with low to medium porosity. Asphaltene is found in some reservoirs.

Bangestan Group Formations are the main oil reservoirs in the Azadegan, Abteymour, Yadavaran, Jofeyr, West Paydar and Binak fields, and secondary producer in many fields, including Ahwaz, Gachsaran, Bibihakimeh, Mansouri, Rag Sefid, Koupal and Soroush.

The Middle Jurassic – Middle Createaceous Khami Group, which includes the Dariyan, Gadvan, Fahliyan and Surmeh Formations, usually contains oil or gas condensate fluids, sealed mainly by the Gadvan Formation. There are a limited number of these reservoirs, which are located at low depths up to and beyond 4,500m subsea, so they require advanced drilling and completion practices. Khami reservoirs have high initial reservoir pressure and contain some $H_2S$ gas. The main Khami reservoirs are located in the Gachsaran, Khaviz, Arash, Darquain and Garangan fields.

The Dehram Group includes gas reservoirs in the Early Triassic Kangan and Permian Dalan Formations, making the latter the oldest reservoirs in the Zagros Basin. They are composed of dark limestones and dolomites and capped by Dashtak and Nar evaporates. The dolomitised oolitic carbonates of the Kangan Formation exhibit enhanced porosity due to diagnetic process.Despite having a major unconformity between the two formations, they are hydraulically connected and thus make one reservoir unit. The best example of this reservoir is the South Pars gas field in the Persian Gulf.

### Time for Iran?

The presence of thick depositional sequences with good quality source, reservoir and cap rocks and suitable structures have made the Zagros Basin one of the most prolific petroleum basins in the world.

Iran, and in particular the Zagros, has multiple petroleum systems and a long production history, suggesting therefore, that it has a very high geological chance of success. Coupled with the improved contracts and a large number of expert Iranian companies looking to partner with outside companies, maybe it is time to take another look?

*References available online.* ■

# An Electrical Rock Physics Framework For CSEM Interpretation

**A low-resolution rock physics framework relating CSEM-derived Rn measurements to reservoir properties can provide precise property estimates even in high-uncertainty settings.**

**DANIEL BALTAR and NEVILLE BARKER, EMGS; MATTHEW CARR and CHRISTOPHER SCHMIDT, QI Petrophysics**

In the November 2015 issue of the *AAPG Explorer*, Zweidler at al. reviewed the value potential from embedding 3D Controlled-Source Electromagnetic (CSEM) information into a seismically-driven exploration portfolio. The interpretation method followed is broadly applicable and non-disruptive to standard exploration processes. An understanding of the rock physics of CSEM-measured resistivity is implicitly needed in order to draw appropriate conclusions from the data, although a detailed reservoir rock physics model is not. This makes the CSEM information particularly valuable in high-uncertainty exploration settings. Here we describe the relationship between the CSEM measurement and reservoir rock properties, and provide a framework for interpretation, applicable from frontier exploration through to appraisal.

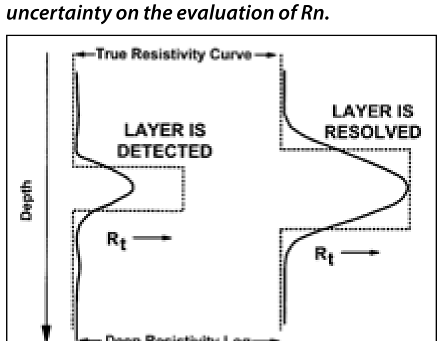
## Measuring Sub-surface Resistivity

CSEM allows for a low-resolution reconstruction of sub-surface resistivity, both parallel (Rp) and normal (Rn) to the bedding, in contrast to conventional resistivity-logging tools, which are mostly sensitive to Rp resistivity. Such tools provide a harmonically averaged reconstruction of the resistivity structure, thereby biasing the measurement to the lowest-resistivity layers present below the tool's resolution. This is the source of many instances of 'low resistivity pay': pay that would be evaluated as high water saturation from the measured resistivity but that can show high hydrocarbon productivity with very low water saturation in production tests (Worthington, 2000). This has also been a strong motivator for the development of multi-component resistivity logging tools.

Rn is a better indicator of accumulation quality (its horizontal permeability) than Rp. It scales linearly with hydrocarbon pore column height, so thinly-bedded but high-quality charged reservoirs therefore continue to exhibit high Rn long after they are below detection in Rp. This strength remains true even at the lower vertical resolution of the CSEM measurement.

Classic rock physics models, such as Archie and its dispersed-shale variants, focus on translating Rp log measurements into hydrocarbon saturation estimates (Passey et al., 2006). As accurate Rn log measurements are less widely available, Rn rock physics is correspondingly less widely understood. We are therefore faced with a missing link in the interpretation of low-resolution CSEM-derived Rn. Since Rp is typically lower than Rn, Rp can only provide a lower limit to the true value of Rn when high resistivity layers are involved (see figure below). This implies potentially large uncertainty in reservoir Rn (with the exception of extremely homogeneous and thick reservoirs, where Rn and Rp will tend to be more similar). Application of Rp models and measurements to CSEM can lead to an underestimation of CSEM value during survey planning, and a failure to realise its full potential during interpretation (for example, failing to understand the full implications of a low-resistivity reservoir interval, as measured by CSEM).

*Taken from Worthington 2000, the peak Rp (continuous black curve) just provides a lower limit to the true resistivity, producing a large uncertainty on the evaluation of Rn.*




## A Rock Physics Framework for CSEM

A rock physics framework for exploration CSEM needs to account for characteristics of the Rn measurement and the tool's low vertical resolution, and also handle exploration-level uncertainties. High-resolution deterministic frameworks may be accurate, but will typically provide imprecise, or even wrong, predictions in such a setting. Instead, we have found low-resolution probabilistic approaches, which aim to constrain the average properties of an interval, to be more suited to the task. Such approaches are well documented for addressing the hydrocarbon pore column uncertainty from log Rp measurements (Passey et al., 2006).

In order to characterise average Rn over the reservoir interval, and its uncertainty, we propose a low-resolution Monte Carlo method, analogous to that described by Passey et al., 2006, but augmented with additional parameters which have a negligible effect on hydrocarbon pore column calculations, but a major effect on average Rn. These are the hydrocarbon saturation variability between laminations within the reservoir interval (e.g., due to grain size variability); and the maximum possible hydrocarbon saturation in any layer (or minimum irreducible water saturation).

The algorithm creates a number of sub-imaging resolution reservoir layers, along with laminar shales. Each reservoir layer is fluid-substituted (using Archie, or derivatives as appropriate), according to the fine-scale saturation distribution provided. For the models resulting from each iteration, the average Rp and Rn are then calculated. Once a few tens of thousands of models have been generated, stable probability distributions of Rn and Rp can be produced. Such results should include all existing Rn uncertainty (high-precision, even if low accuracy in a typical exploration setting).

## Main Drivers of Difference Between Rp and Rn

To illustrate the different characteristics of the CSEM-derived Rn compared to the better understood Rp, a simulation has been generated with wide input-parameter distributions (the results of this exercise should not therefore be taken as representative of any specific real-life reservoir).

From the figure (right), it can be seen that large differences between Rp and Rn tend to arise when the volume of shale is moderate to high, the average hydrocarbon saturation is >60%, and the maximum hydrocarbon saturation is >85%. This maximum hydrocarbon saturation will be a function of the maximum reservoir permeability; if the permeability of some layers is high (due to coarse-grained sediment), the saturation of these layers will also be high. This is consistent with the aforementioned low-resistivity pay zones, characterised by low Rp (suppressed by the shales or low permeability/fine-grained water-filled sands), but high hydrocarbon productivity (coming from the coarse-grained parts of the reservoir, which are high permeability, high saturation, and drive-up the vertical resistivities).

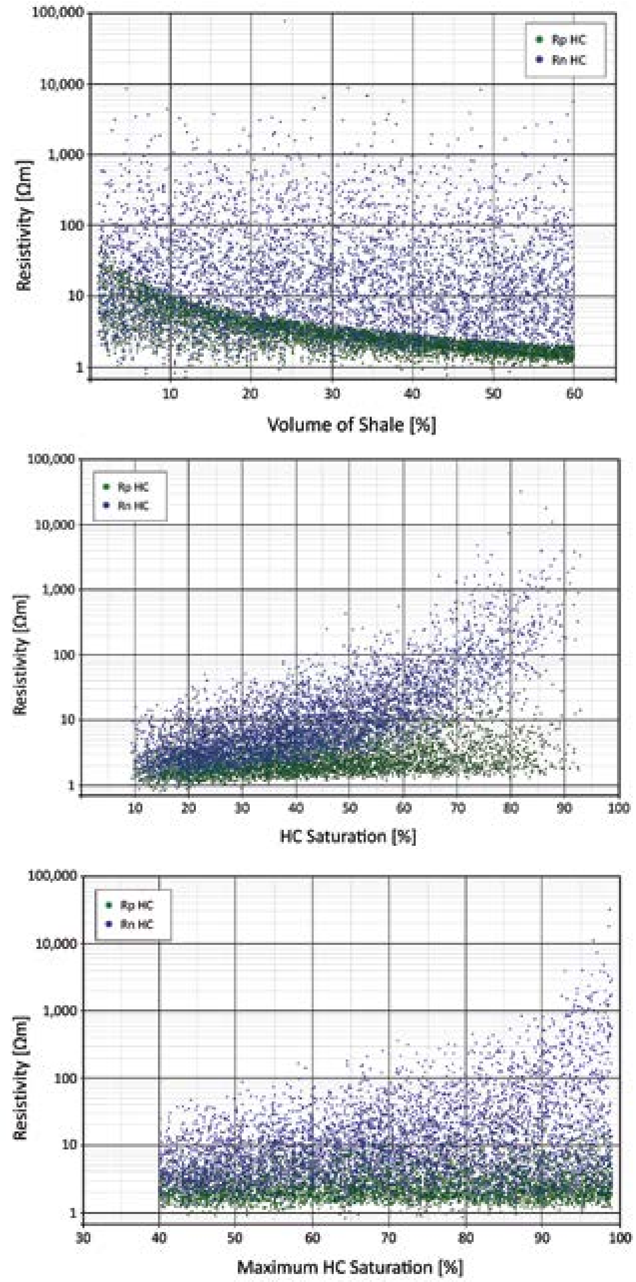
The figure below shows results from a model with more realistic exploration-level parameter uncertainties: anisotropy ratios (Rn/Rp) of around 10 would be the norm in this case.

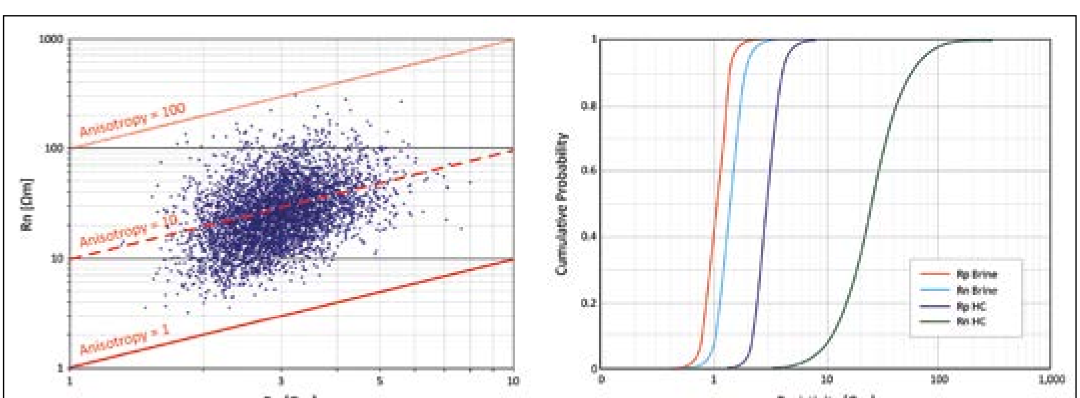
## Aiding Interpretation

As can be seen, we have demonstrated here a low-resolution rock physics framework for relating CSEM-derived Rn measurements to reservoir properties, which can provide precise property estimates even in high-uncertainty settings. When additional calibration information is available, the same framework can be used to produce correspondingly more accurate constraints.

The synthetic simulation illustrates the power of the CSEM measurement for reservoi quality assessment in exploration: in contrast to the more widely used Rp log measurements, Rn remains high for a larger proportion of quality reservoir scenarios. For this reason, when faced with a low vertical resistivity from CSEM data, an interpreter is typically able to conclude that an exploration target has either an increased risk of thin reservoir, low saturation, or low horizontal permeability. ■

*Primary drivers of reservoir-scale electrical anisotropy (differences between Rp and Rn), illustrated through a Monte Carlo reservoir simulation with broad input parameter ranges: (top) laminar shale volume, (middle) average HC saturation, (bottom) the maximum HC saturation present in any sand layer.*




*A realistic low-resistivity pay zone simulation. Far left: Rn and Rp for each realisation of the Monte Carlo simulation; left: the cumulative probability distribution for Rn and Rp with different fluids.*

# Australia on the Map

HEATHER SAUCIER

**Through researching the carbonate deposits in her country's back yard, a geotechnical engineer is pioneering industry advances on the seafloor.**

In the early stages of her career, geotechnical engineer Susan Gourvenec, 44, began work in the pre-dawn hours – before London's underground train system began operating – to study the stability of its oldest tunnels, which date back to the 1860s.

The expertise she developed while deriving the geotechnical properties of the soil supporting the tunnels eventually transported her below the equator to the University of Western Australia's (UWA) Centre for Offshore Foundation Systems (COFS) in Perth, which maintains the world's highest concentration of geotechnical researchers. There, Gourvenec turned her focus toward the diverse and precarious nature of carbonate seabeds in an effort to help move the oil and gas industry forward.

## Quirky Carbonates

The transition from the underground transit field to the offshore petroleum industry was not as far-fetched as one might think. "Soil is soil, and in principle the same fundamental mechanics govern the geotechnical response beneath the foundation of a high-rise building or a bridge pier as beneath an offshore oil platform or subsea structure," Gourvenec explains. "However, this is not to say that all soil is equal, and carbonate deposits in particular can be notoriously fickle in their strength and behaviour."

To better understand the quirky nature of carbonates, Gourvenec is working in an ideal place, as carbonate deposits are highly prevalent off Australia's north-west coast. At COFS, which is jointly funded by industry and government, Gourvenec works as a professor, researcher and author in offshore geotechnical engineering, focusing on foundation and pipeline solutions for offshore oil and gas developments. Australia's seabeds have given her a foundation on which to thrive, as they present continual challenges and opportunities, which Gourvenec continually seizes and solves.

She has become a rising star in the areas of education, research, industry engagement, scholarship and service. She is the co-author of the world-renowned book, *Offshore Geotechnical Engineering*, a developer of smart engineering solutions relevant to industry needs, and the creator and organiser of the popular International Symposia on Frontiers in Offshore Geotechnics (ISFOG) conference. Add to that list a fervent champion of programmes that encourage women to become scientists, and Gourvenec's contributions to the industry seem near limitless.

While some credit her success to exceptional intelligence and organisational skills, Gourvenec cannot stress enough the importance of always maintaining a steep learning curve: "My experiences have taught me that if you throw yourself into something, you probably can achieve it."

## Outside the Comfort Zone

Gourvenec's all-girls high school near London offered few opportunities for advanced mathematics classes, forcing her to study the subject at a local college before she could apply to the University of London to study civil engineering. "The academic who interviewed me for university entrance told me that it would require a lot of work to get through the first year of the engineering course," she said. "I must have put up a convincing argument because they gave me a chance." Gourvenec subsequently graduated top of her cohort.

Recognising her potential, a professor convinced Gourvenec to pursue a PhD in geotechnics, a specialisation of civil engineering, at Southampton University. Gourvenec dived into the unfamiliar research territory without

*Susan Gourvenec is a professor at the Centre for Offshore Foundation Systems, University of Western Australia.*

hesitation and emerged successful.

In the midst of her graduate studies, she was thrown another learning curve when she joined a team of environmental engineers mapping water flow and quality in a tributary to the Aral Sea in Kazakhstan. This temporary foray into hydraulics posed no problem for Gourvenec, who returned to Southampton to complete her doctoral degree on time.

As a post-doctoral research fellow at Cambridge University between 1998 and 2000, Gourvenec was busy researching tunnels when she learned of the cutting-edge research taking place at COFS, which was founded in 1997 by geotechnical engineer, Professor Mark Randolph. Despite the fact that Gourvenec had never met Randolph, she sent him an e-mail enquiring about possible research opportunities.

"She had worked with close colleagues of mine in the UK, so I was able to tap my network for their views of her," Randolph says. "All positive!" So when a position became available in 2001, Gourvenec left for Perth with only a backpack.

The offshore oil and gas industry intrigued her unlike any other, and it offered another scintillating learning curve. "Offshore engineering is super-sized engineering and that is exciting," Gourvenec says. "The complexity of intuitively simple processes – such as identifying the strength of the seabed – is mind-blowing. It is an engineering achievement just to carry out a reliable test to discern these relatively low strengths, in situ, from a mobile vessel with possibly a thousand or more metres of water between it and the seafloor."

## Diving Into Carbonates

Perhaps even more mind-blowing was the boom that hit COFS around 2005. A number of emerging megaprojects around Australia prompted the need to better understand carbonate soils, particularly in previously untouched regions of the shelf and in deeper water on the continental slope, to develop smart engineering solutions.

Carbonate deposits cover roughly 35% of the ocean's seabeds, so the expertise developed in Australia can be applied to other regions with carbonate seabeds including Brazil, India and the frontiers of East Africa and the South China Sea.

Carbonate seabed deposits are essentially the skeletal remains of marine plant and animal life, which contain calcium carbonate. The fragility of the calcium carbonate coupled with the deposits' highly variable grain shapes and sizes can lead to high but easily degraded frictional strength and high compressibility, as Gourvenec explains. These characteristics can adversely affect driven pile capacity or the shaft capacity of dynamically embedded anchors, as well as lead to large degrees of settlement under mat foundations.

"High lateral and vertical variability of the nature and strength of carbonate deposits is a key challenge in offshore geotechnical engineering," she says. "Site conditions can vary significantly with depth, and two locations a kilometre apart may have completely different sediment properties."

An expanding knowledge of carbonate seabeds and the development of engineering tools for the design of safe infrastructure are allowing Gourvenec and her colleagues to assist the industry in unprecedented ways. Their research has contributed to the development of complex ROV systems that can take soil samples in deep water. They have established new sensors, tools, and engineering design methods that advance site investigation and seabed surveys, as well as improved assessment of geohazards, such as seabed slides. They also have developed more detailed measurements of soil response to varying loads, using seabed penetrometers developed by Randolph and his colleagues; devised new methodologies to efficiently optimise the design of shallow 'mat' foundations; and researched innovative anchoring systems to better secure fixed platforms and FPSO vessels while simultaneously reducing production costs.

***Susan Gourvenec and daughter at the 2010 ISFOG symposium.***

"Susie has led the work on analysis and design of shallow foundations – now ubiquitous within the industry for the various applications associated with subsea systems," Randolph says. "She has developed design approaches of increasing sophistication and value. Central to this has been the use of failure envelopes to quantify the interaction between different modes of loading. Failure envelopes represent a significant advance in industry design guidelines, as they provide a more accurate method of sizing foundations to accommodate the many complex loading events they may see during their operating life," Randolph explains.

"Susie's work has been eagerly adopted by an industry keen to unlock the cost and reliability benefits, and it now features extensively in design guidelines and codes of practice as an alternative approach to older methods," he adds.

Gourvenec has always supported COFS' mission to create smart engineering solutions, as identified by the industry, to develop challenging fields and unlock stranded oil and gas. She is now broadening her scope as COFS pursues end-of-life engineering solutions for aging infrastructure and launches a new Research Hub on Offshore Floating Facilities in carbonate environments this year. She is project leader for the new research hub, and says of this latest learning curve: "We have identified several design benefits that our work can unlock, and we're focused on rolling out this technology with our industry partners. I am looking forward to getting started."

### One Woman, Many Hats

While most achievements are not made alone, Gourvenec's individual contributions to her field have not gone unnoticed.

As a professor to undergraduates, post-graduates and industry personnel, her careful attention to each student earns her pages of praise, including the following unfiltered enthusiasm from a student: "She truly gives a damn…! and will take time to explain problems – she is there for the students and is interested in their feedback to ensure that the unit maintains a cycle of continuous improvement. She rocks!!"

As a research leader, Gourvenec supervises, trains and mentors a team of early career researchers, PhD students, honours students and visiting scholars. "In the Australian vernacular, I try to 'give everyone a fair go' because sometimes you cannot tell what people are capable of or what they will bring to a team. Not everything that matters can be measured with a KPI [key performance indicator]," she explains.

Also charged with duties of industry engagement, Gourvenec promotes and leads joint industry projects, and serves as an elected member for committees of the global International Organisation for Standardisation and the American Petroleum Institute. Not only is her research applied widely in the industry and referenced in international guidelines, she is a regular commentator on platforms such as the popular news website, The Conversation.

Gourvenec has published more than 80 peer-reviewed technical journal and conference papers, two edited proceedings of international symposia, and one state-of-the-art textbook with Randolph as the co-author. *Offshore Geotechnical Engineering*, published in 2011, has received positive feedback from academicians and industry personnel from around the world. "I often spot it on desks and bookshelves when I go to meetings locally and internationally. It will shortly be republished in Chinese due to demand," Gourvenec adds.

She has earned awards from the International Society of Soil Mechanics and Geotechnical Engineering, the Australian and New Zealand Geomechanics Society, the Institution of Civil Engineers in the UK, the American Society of Civil Engineers, the Canadian Geotechnical Society, and within UWA through the Vice Chancellor's Research Excellence Awards.

### The Gender Gap

Of all of Gourvenec's accomplishments, she seems most proud to have secured a respected place in the oil and gas industry – period.

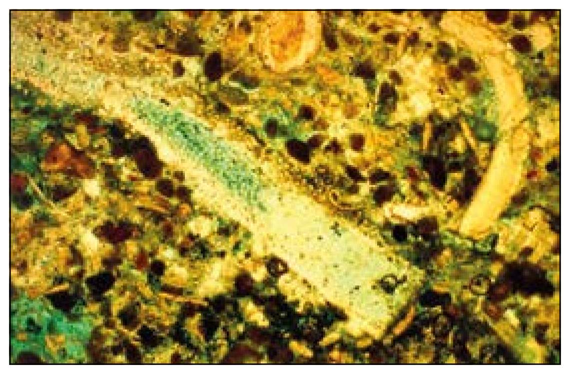
"Many girls never have engineering on their radar as a career opportunity, and once in the industry many women cannot successfully navigate children and a career because the environment is bound by norms that are only normal for the people that created them – not to the broader population."

Recently promoted to full professor at UWA, Gourvenec is now one of four female full professors of nearly 40 in her faculty – an imbalance that prompted her to oversee the UWA's Girls in Engineering Programme and to lead the establishment of the Equity and Diversity Committee in her faculty, which she now chairs, to help UWA, and more broadly the industry, become more inclusive. "Industry is ahead of academia in some respects by making changes in policy to stimulate a cultural shift to develop a more diverse workforce, and as a result an overall more effective working environment for all," Gourvenec says. "I greatly value my part in it."

That part sweetly made its way into one of the ISFOG symposia in Perth. Chaired by Gourvenec, the inaugural event in 2005 welcomed 182 academicians and industry practitioners representing 22 countries. The second event, held in 2010, saw a growth in participants with 306 delegates from 24 countries – plus one very special guest, Gourvenec's five-week-old daughter and perhaps budding scientist, Helen.

"The business case for diversity is unequivocal," Gourvenec says, "and it is surprising that academia – an evidence-based sector – is sometimes slow to recognise that the best environment and highest level of collective performance cannot be achieved when the workforce is selected from only half the population." ■

***Microphotos of cemented carbonate deposits from the North West Shelf of Australia; (A) calcarenite, (B & C) cement fringes around carbonate sand particles.***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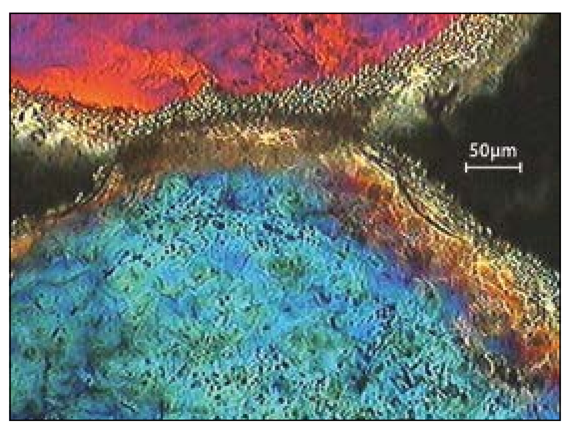

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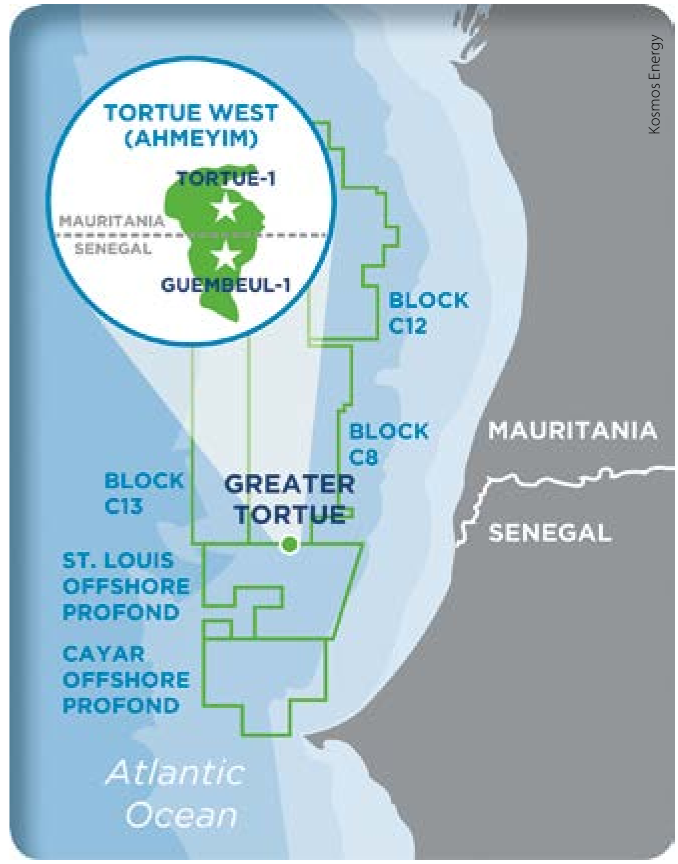
# Senegal and Mauritania: Two More Discoveries

The waters of the West African Atlantic Margin are one of the 'hottest' oil spots on the planet. Two recent discoveries confirmed this.

In November last year, **Kosmos Energy** announced that its **Marsouin-1** exploration well, located about 60 km north of the basin-opening **Tortue** gas discovery in **Mauritania**, had encountered at least 70m of net gas pay in Upper and Lower Cenomanian sands. Both Tortue (now renamed **Ahmeyim**) and Marsouin lie in the 11,900 km$^2$ Block 8 in water depths of over 2,400m, which Kosmos operates with a 60% stake.

The company believes that it has discovered an important, overlooked petroleum system based on an Upper Cretaceous structural-stratigraphic play concept, possibly unique to this region, in which sands bypassed the shelf and were deposited in deeper water. This concept was recently reinforced by the **Guembeul-1** exploration well in the northern part of the St. Louis Offshore Profond licence area in **Senegal**, which was spudded in December last year, the first in a series of wells designed to delineate the Greater Tortue area. In late January 2016, Kosmos announced that Guembeul had encountered 101m net gas pay in two excellent quality reservoirs, including 56m in the Lower Cenomanian and 45m in the underlying Albian. Importantly, the well appears to have reservoir continuity and static pressure communication in the Lower Cenomanian with Tortue-1, which lies 5 km to the north. This suggests they could represent a single, large gas accumulation, while also de-risking the prospectivity of adjacent reservoirs like the Albian. The next well in the area will delineate the down-dip limits of the field, with the appraisal programme being completed in the first half of 2016.

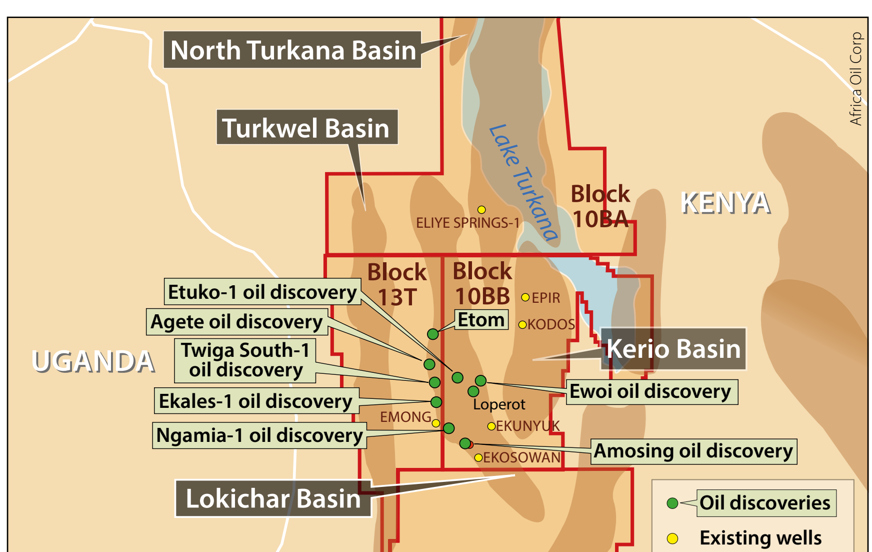



According to Kosmos, the Pmean gross reserve estimate for the Greater Tortue Complex now lies at **17 Tcfg**, making this potentially a world class resource. The company recently signed an MOU with the national oil companies of Senegal and Mauritania, to further the cross-border development of the field.

# Kenya: Excellent Lokichar Basin Reservoir

At the very end of 2015 **Tullow Oil** announced that its latest well in northern **Kenya's South Lokichar Basin** had encountered the best quality reservoir yet for the area. **Etom-2**, in Block 13T, was spudded in late November in order to explore the north flank of an untested fault block identified on recent 3D seismic. The well, drilled to a TD of 1,655m, found 102m of net pay in two columns. It was particularly significant as it is the most northerly well Tullow have drilled in this basin, located close to the axis of the basin and away from the basin-bounding fault. It opens up the northern part of the Lokichar Basin, where the seismic has identified a number of other promising projects which will be part of the future exploration drilling programme.

The Etom well is the most recent in a string of discoveries in Block 13 and the adjoining Block 10BB, where a recent extended well test on the Ngamia field about 60 km south of Etom-2 produced about 38,000 bo at a cumulative rate of 2,400 bopd. Tullow, which operates Block 13T and shares the licence equally with partner **Africa Oil**, estimates it has discovered over **600 MMbo** in the South Lokichar Basin. ■



# The Next Generation of Petroleum Geoscientists

**Royal Holloway, University of London (RHUL) recently celebrated 30 years of their M.Sc course in Petroleum Geoscience. In light of this milestone, we asked RHUL's Dr Jürgen Adam, Professor Pete Burgess, Professor Bernie Vining and Dr Nicola Scarselli to look back over the past 30 years and forward to what the future may hold.**

***What key elements give a successful teaching programme global appeal?***
We believe that three key elements define a successful petroleum-related teaching programme. Firstly, expose students to rocks. You cannot provide world-class geology training without field trips to excellent outcrops where elementary concepts of petroleum geology can be directly observed and understood. The second element is a strong link between teaching and research, where research is the main driving factor that inspires the lectures. The third key element is to position our students at the forefront of technology in hydrocarbon exploration.

These elements are at the core of our RHUL master programme, which is globally renowned for regional basin analysis. Students enjoy multiple field trips during their curriculum, including to the Pyrenees where spectacular outcrops demonstrate tectonic and sedimentary processes at a basinal scale, and also Dorset, where they work in teams to generate a prospect, investigating the play elements and geological timing, performing volumetric estimates, uncertainty and risk analyses and addressing the commercial considerations.

As for research, our highly acclaimed research consortia like the Fault Dynamics Research Group and the Compass and SE Asia Research Group have for over 20 years produced high quality studies on regional tectonic, structural geology and basin analysis.

***What part does the petroleum industry play in your training programmes?***
We have an Industry Advisory Board of 24 companies from across the spectrum, including super-majors, independents, service companies and consultancies, which gives guidance as to what the industry is looking for both in teaching and research. To ensure our students learn industry-standard practices and skills, industry experts contribute with lectures and short courses on a range of subjects, including subsurface evaluation, basin modelling, petroleum systems and economics.

***During this downturn, what advice would you give students contemplating a career in petroleum geoscience?***
Keep optimistic! Remember, downturns are followed by upturns; it's all in the timing. Meanwhile, we advise our students to look at ways in which they can distinguish themselves from others. For example, in addition to their excellent academic record, in what other interests have they excelled? Demonstrate the key talents and qualities the industry looks for: leadership, initiative, motivation, team-working, integrity, professionalism, enthusiasm.

***How do you see petroleum geoscience training changing in the next 30 years?***
That's a question we continually ask ourselves. To quote Winston Churchill: "The farther backward you can look, the farther forward you are likely to see"! As part of our 30-year celebrations we held a symposium, with presentations from alumni and staff from over the decades. It was really interesting to find that many of the founding principles of the course are still very important today, including the annual symposium where students make presentations, reinforcing the need for good communication skills; the brand of regional basin analysis; group projects using industry datasets; even visiting the same field areas!

This is a constantly evolving industry, and the teaching programme needs to maintain flexibility, recognising that change takes time and that a strong link to our research programmes is essential. We want to equip future geoscientists with a broad and yet fundamental set of core skills such as structural geology, sedimentology and geophysical analysis, which will always be relevant as the industry develops.

***What future trends are in your crystal ball?***
Keeping a finger on the pulse of future industry trends is very important, so we rely on the insights and advice of the Industry Advisory Board. There are two certainties: firstly, petroleum geoscience will continue to have huge societal impact over the next 30 years as petroleum products will remain important facets of everyday life. Secondly, change will be continuous and frequent; the challenge is to successfully manage it.

What other trends do we see? The need for capability-building in many parts of the world is on the increase. Distance learning will play an important role. A strong tie to research, embracing an integrated, multi-disciplinary approach, in a global context, will continue to underpin teaching. In the end, though, it's a people thing: students and teachers, with passion and enthusiasm, producing high quality science in an environment that nurtures creativity – as evidenced last year, when RHUL won the AAPG Imperial Barrel Award! ■

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# Planet Oil

## The BBC continues its mission of energy education with good results.

The public needs to understand energy, where it comes from and where it goes. That is becoming increasingly obvious – and critical. But how to do it? Over recent months, the BBC has risen to the challenge (see *GEO ExPro* Vol. 12 No. 6), and the corporation got it just right with its three-part series 'Planet Oil', a particularly clear and up-to-the-minute overview of oil. Condensed, but not rushed, into one hour episodes, it presented the broad facts for the uninitiated, and a few shafts of light for those who thought they knew it all. It should become a benchmark for broadcasters around the world.

If anyone doubts that we need such public education, the scene of the young and dashing presenter, Prof Iain Stewart, accosting passers-by in the City of London should be proof enough. The professor's question, to young and old alike, was whether they recognised the term 'OPEC'. Undoubtedly there was some editing but for any oil 'insiders', it was both jaw-dropping and embarrassing as person after person either shook their head in ignorance or made a semi-confident stab at it. "It's part of the EU, isn't it?" says one professional woman. Even the artfully gelled, super-cool professor seems close to exasperation.

### A Rocky Ride

The thrust of the programmes is to remind us first, just how quickly we've become dependent on oil, and secondly, just how total that dependence is, from morning to night, in plastics, power, food, transport, manufacturing. It's a powerful message for anyone who takes the modern world for granted, and it is delivered with energy and verve.

The third theme is that oil has created and connected strange worlds. Camels wander along a tarmac road in the Arabian desert; the glass and steel sky-scrapers of Dubai stand like cliffs against a featureless dry sea. And behind the physical incongruities lie the murky politics: how ex-UK diplomat Jack Philby stitched up his home nation and handed Saudi Arabia to the Americans; Churchill's crass attempts to woo Ibn Saud with cigars and alcohol; the UK's resort to manipulation and violence in Iran and Egypt as the country faced a

BBC

no-oil chaos and coal-induced smog; the first open use of guns in US cities as car owners stood watch over their gasoline tanks in 1973's oil shut down.

The series goes no further in charting where oil dependency has taken the world's foreign policies, but the point is well made. There's no subterfuge, double-crossing or military campaign that dependent countries won't consider if they think their supplies are in danger. Running out of energy is every OECD government's nightmare.

Perhaps the underlying theme of the whole series is just what a rocky ride this love affair has been, even for the industry. Our dependency on kerosene was first threatened by coal-fired electricity, but saved in the nick of time by Karl Benz's motor car; ever after, the industry has been plagued with supply gluts and supply threats as companies have competed to diversify their sources and push the engineering boundaries. For the public, it's been a political roller-coaster as the search for oil has fuelled imperialism and war. Perhaps the biggest 'What if?' is the near-miss of Hitler reaching Baku. It's a chilling thought. Twentieth-century history could have been so very different.

### Current Challenges

And now the current challenges. As Prof Stewart explains, in just the last ten years the industry has faced the rapid shrinking of conventional supplies, and now the full-on uncompromising facts of climate change. Somewhat randomly, Stewart turns his attention to thorium experiments in Norway, the solar city of Masdar, and potential carbon capture and storage in the North Sea. None seems to offer an answer to the perplexing question of how the world, including those outside the Global North, can use – and waste – energy thoughtlessly without killing our planet. Perhaps the only real weakness of the series is that it does not address the question of pricing our energy so that all costs are covered.

If the world is serious about engaging the public in this debate, 'Planet Oil' is a good starting point. A documentary on energy was always going to be – well, energetic. This was a real success in terms of public education, and entertaining delivery.

**Nikki Jones**

*'Planet Oil' can be purchased from the BBC at www.store.bbc.com/planet-oil-the-treasure-that-conquered-the-world*


When the stakes are this high, and the times this tough, you sure better have the best image.
From marine acquisition to processing to multi-client licensing, nodal seismic technology gives you undeniable advantages. And we pioneered it. No one else brings you the experience, expertise or ongoing nodal innovation that we share with our clients every day, nor the long-term results.
Right image. Right economics. Right team.

# How Much is 'A Tiny Fraction' 20 Years From Now?

**The world's use of energy will increase in years to come. There is plenty of oil to cover demand. However, the big question is if, and possibly at what rate, renewables will substitute fossil fuels.**

It's green all over. *NOT!* Contrary to a growing perception by the public, it's almost all black. Coal, oil and gas still predominate as energy carriers.

Let's look at some numbers to authenticate this statement.

In 2015 the world's total energy consumption was 13,200 MMtoe. Out of this fossil fuels (coal, oil and gas) made up 11,300 MMtoe; that amounts to **86%**. Renewables (wind, solar, biomass, but not including hydroelectricity) produced 350 MMtoe, a tenfold increase in 20 years, but still a mere **2.6%** of the total consumption (the gap is filled by nuclear energy and hydroelectricity.)

As the oil price depends partly on total energy consumption, and also on how much of the demand can be met by energy carriers other than fossil fuels at a competitive price, it is interesting to look at how much of the energy demand can be covered by renewables. According to the *BP Energy Outlook 2015*, 20 years from now renewables may have increased their share of the consumption budget to **6.7%**. During the same time, fossil fuels will have reduced their share to **81%**, meaning that renewables are increasing at the expense of fossil fuels – but they are not.

The truth is that, with this scenario, the actual increase in the use of fossil fuels amounts to **25%**. This means that, if we believe in the BP numbers, **fossil fuels have not peaked at all**; instead, their use will continue to grow.

BP may, of course, be wrong. Perhaps their experts are not taking into account a potential exponential increase in the technological development of renewables. In fact, from 2010 to 2015 the use of renewables did have an exponential increase (an average of 15% every year). What if this 15% growth continues for the next 20 years? The mathematicians give us the answer: renewables will then produce 5,600 MMtoe – as opposed to the BP prediction of 1,180 MMtoe.

Given that this scenario does not change the total energy consumption, in 2035 renewables will have a share of **32%**. Would this be at the expense of fossil fuels?

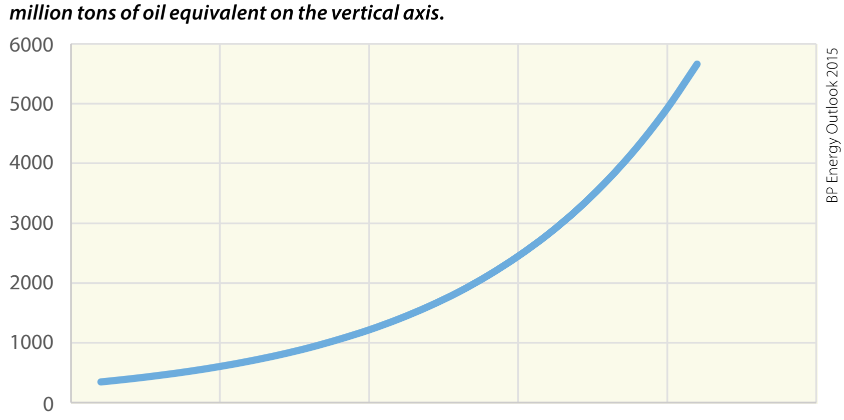
If we assume that the use of hydroelectricity and nuclear energy continue to grow according to the BP prediction, this also means that our consumption of fossil fuels in 2035 will be about 10,000 MMtoe (73,333 MMboe): a reduction of **25%** compared to 2015.

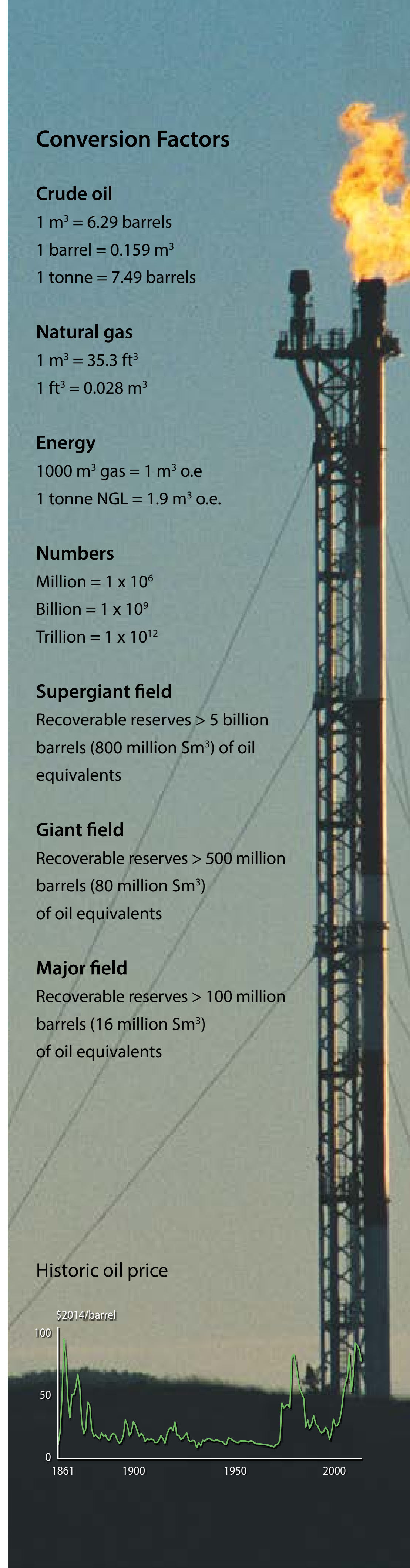
And yes, a 15% annual growth *is* substantial….

As ever, technology is key. ■

**Halfdan Carstens**

***Given an exponential increase in the use of renewables, the use of fossil fuels can shrink by 25 per cent in 20 years' time. Renewables in million tons of oil equivalent on the vertical axis.***



## Conversion Factors

### Crude oil
1 m$^3$ = 6.29 barrels
1 barrel = 0.159 m$^3$
1 tonne = 7.49 barrels

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

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

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

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

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

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

Historic oil price