VOL. 16, NO. 1 – 2019

GEOExPro

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GEOEDUCATION
Creating Excitement in the Geosciences

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Myanmar: The Golden Land

GEOTOURISM
Australia's Big Outdoor Museum

TECHNOLOGY
The Pre-Drill Prediction Toolbox

HISTORY OF OIL
Mr Five Per Cent

GEO ExPro

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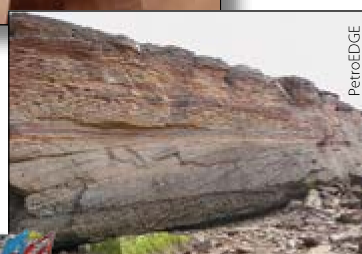

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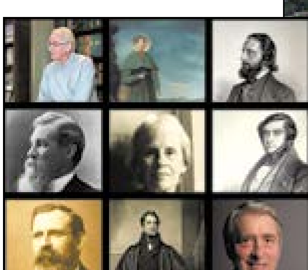

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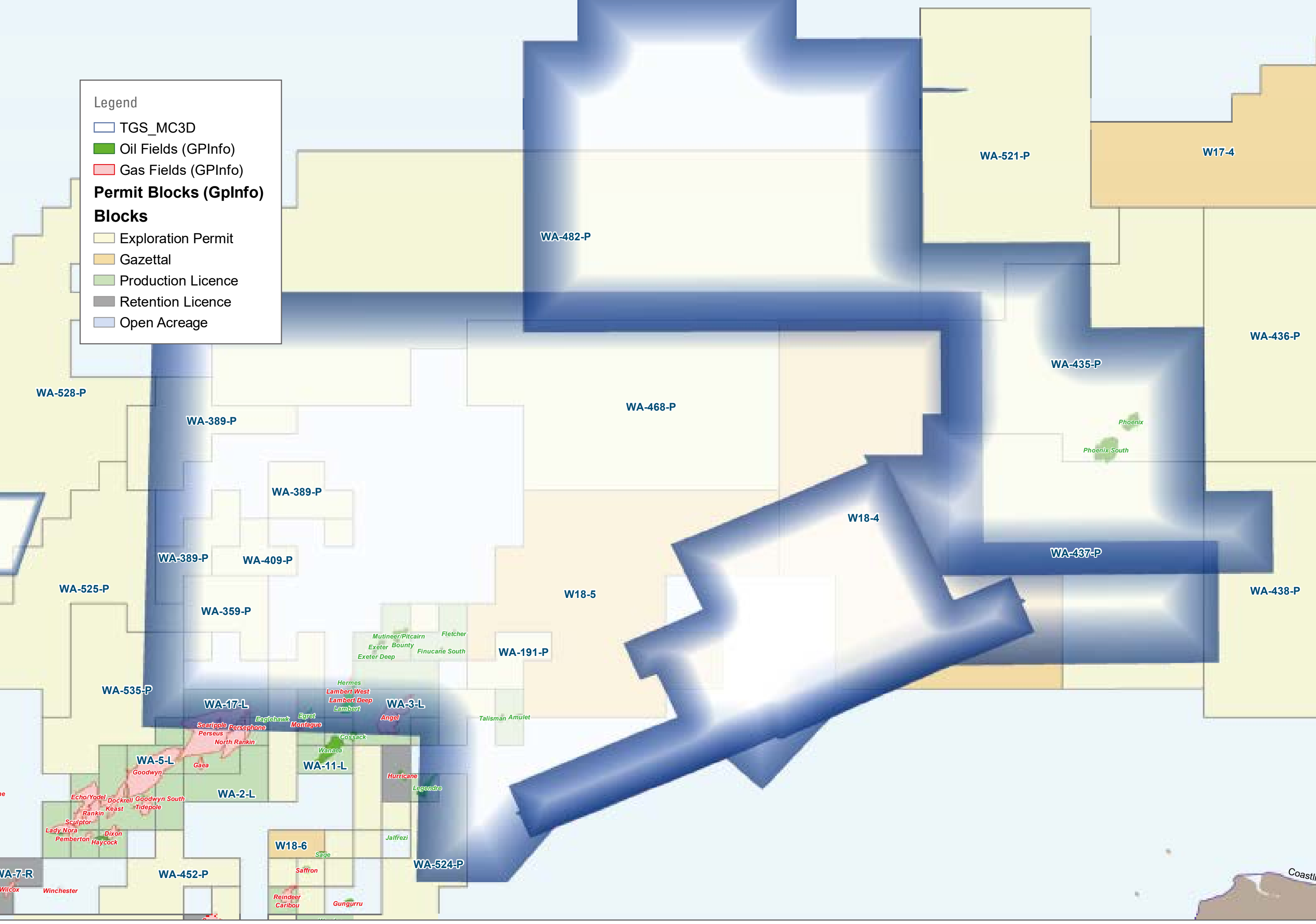

We have the Australian Bedout and Beagle Sub-basins Covered

The Bedout Sub-basin, offshore Western Australia contains the largest oil discovery of the North West Shelf in the last 30 years. Blocks are available within the data coverage.

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- New Polly 3D, Repro PSDM
- New Beagle 2D^{cubed}
- Capreolus 3D PSDM
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Increasing Demand in South East Asia

Producing oil with hand-dug wells in Myanmar.

South East Asia holds only a relatively small percentage of the world's oil and gas (about 2% of total proved oil reserves and 5% of total gas), but has nonetheless played an important role in the development of the industry. Oil produced using hand-dug wells in Sarawak was mentioned in official Chinese documents in the 11th century and the process is thought to have been used in Myanmar as long ago as 900 BC. The first commercial well in South East Asia was drilled in 1885 in East Sumatra by Aeilko Jans Zijklert, a 25-year-old Dutch tobacco planter-turned-oil-explorer who, five years later, founded the Royal Dutch Company. Sadly, he died shortly afterwards, and was not able to see either the success of his discoveries or how his fledgling company eventually morphed into the supermajor we know as Shell.

As elsewhere, investment in exploration in the region reduced dramatically after the oil price collapse in 2014. Demand, however, has not – in fact, in the ten countries which make up the Association of South East Asian Nations (ASEAN), energy demand grew by 60% in the years between 2000 and 2017. Many of these countries have experienced significant economic growth, and the population of the ASEAN countries increased by an average of 23% during this time, so there is an urgent need for new resources to feed this economic development and reduce the strong dependence on coal and imported oil.

There have been signs of a rally in the market since the middle of 2018, albeit at a lower rate than in other parts of the world. In Vietnam, for example, PetroVietnam is developing a large gas field known as Block B, while in Indonesia significant investment is planned for the second phase of the giant Senoro gas field. In fact, it has been reported that as many as 50 oil and gas fields, with a collective resource of 4 Bboe, will be approved for development between 2018 and 2020. While some of this investment will focus on developing existing fields, a number of large new fields, such as the Pegara discovery offshore Sarawak, are in development, hoping to start production within the next couple of years.

Over three-quarters of the planned development is for gas fields. For many years, South East Asia had limited attraction to explorers as it was viewed as too gas-prone, but with economic development has come an increased demand for gas for both domestic and industrial uses throughout the region. The appetite for exploration in South East Asia should continue to grow.

Jane Whaley
Editor in Chief

MYANMAR: THE GOLDEN LAND

The famous Golden Rock of Myanmar is precariously balanced on the 1,100m high summit of Mount Kyaiktiyo, a granite boulder covered in gold leaf. This is a testament to the multitude of minerals and gems found in the country, as well as a very productive petroleum industry that has been active for nearly 3,000 years.

Inset: Teachers learning about geology at G-Camp, a diverse and eye-opening field experience.

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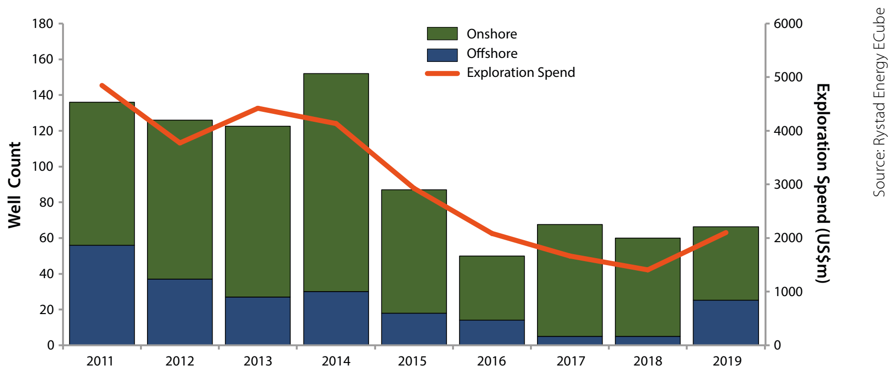
Australian Exploration

RYSTAD ENERGY

The year that was, and what will [may] be.

Australia experienced both exciting discoveries and disappointing dry holes in 2018, drilling 60 exploration wells over the year. Buoyed by strong demand, policy change and recovering oil prices, Rystad expects to see this figure rise to 65 in 2019, with offshore exploration increasing to the highest level seen since 2014.



Australian exploration well count and expenditure.

Several Successes

About 360 MMboe were discovered in Australia in 2018, at an exploration expense of close to US$1.4bn (US$850m offshore and US$550m onshore). Chief among 2018's successes was Quadrant's Dorado-1 well in the Bedout Basin (North West Shelf), which discovered 171 MMbo, 16 MMbc and 552 Bcfg (2C), making it 2018's 12th largest discovery globally. Quadrant has now turned to the Apus prospect, where it hopes to unlock over 750 MMboe, although drilling is not expected until 2021.

In contrast, ExxonMobil and BHP's much-hyped 2–3 Tcf Dory prospect in Victoria's Bass Straight came up dry, with both wells, Baldfish-1 and Hartail-1, plugged and abandoned as uncommercial. However, the joint venture plan to continue exploration within Dory's permit area (VIC/P70), where further gas potential remains in the Angler (140 Bcf) and Archer-Anemone (175 Bcf) prospects.

High Expectations

Strong market fundamentals and favourable policy change should see exploration expenditure in Australia more than double from 2018 levels in the next five years, reaching an annual spend of US$3.6bn by 2023.

Offshore, 2019–20 should see Equinor drill its long-awaited Stromlo-1 well in South Australia's Ceduna Basin: the first well in the Great Australian Bight since Woodside's Gnarlyknots 1A in 2003. However, there is strong community opposition to the project and NOPSEMA is yet to approve the well. Success here would be the first step to unlocking the Bight's potential multi-billion boe resource.

2019 could prove transformational for Australia's fledgling shale industry. The repeal of a fracking moratorium, in place in the Northern Territory since 2016, should result in at least four shale wells in the highly prospective McArthur Basin this year. Before the moratorium, Origin Energy conducted one of the largest fracture jobs ever undertaken in Australia on their Amungee NW-1H well in the MacArthur Basin, successfully flowing over 1 MMcfpd on test. This enabled Origin to book 6.6 Tcf of contingent resources in the play, and also acted as a proof-of-concept for the basin, representing the first extended commercial-level gas flow from shale in the state. Origin now plan to drill and frack two horizontal wells in 2019.

Following the success of its Northern Territory Tanumbirini-1 well in 2014, where the company reported gas over a 500m (gross) interval, Santos is expected to drill two horizontal appraisal wells in the McArthur Basin. Success here has the potential to kick-start a rapid development of the region.

Daniel Levy, Senior E&P Analyst, Rystad Energy

ABBREVIATIONS

Numbers
(US and scientific community)

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

Liquids

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

Gas

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

Ma: Million years ago

LNG

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

NGL

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

Reserves and resources

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

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

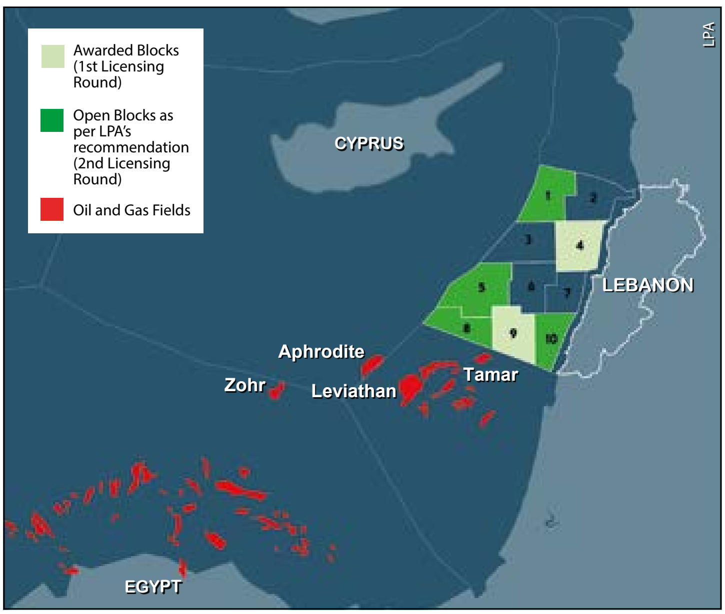
P3 reserves:
Quantity of hydrocarbons believed recoverable with a 10% probability

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

Ready? Set? Go!

Lebanon's Second Offshore Licensing Round is set to open.

The Northern Levant Basin offshore Lebanon was the last place to be explored in the Eastern Mediterranean. Following up on the country's first successful offshore licensing round in 2017, acreage in the prospective basin is once again available. Surrounded as it is by proven hydrocarbon discoveries to the west and south, including the offshore fields Tamar, Leviathan, Aphrodite, Zohr and Calypso, and with prolific hydrocarbon indicators already identified, this undrilled acreage should make Lebanon an exploration hotspot.

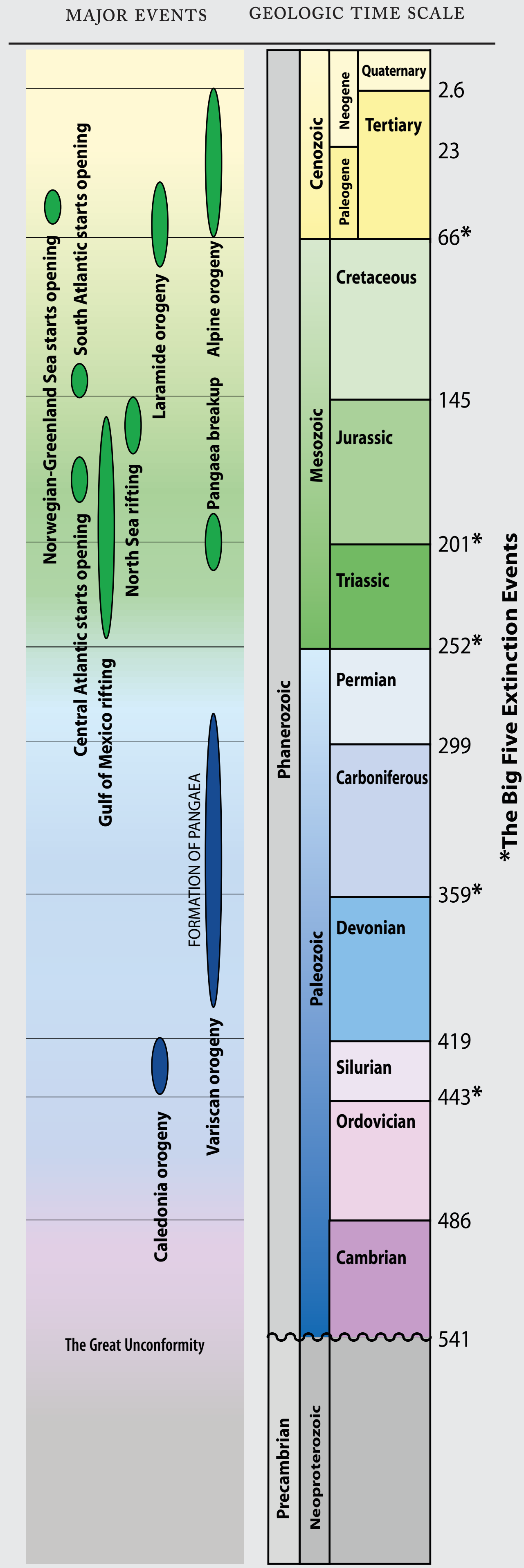


Prospects mapped in Lebanon are on trend with major discoveries in the Eastern Mediterranean.

Various prospective targets have been identified offshore Lebanon in siliciclastic, calciclastic and bioclastic lithologies. These prospects are found in structural traps including symmetrical anticlinal structures, simple 3-way dip-faulted anticlines and 1-way fault-closed structures. There is also evidence of stratigraphic traps such as pinch-outs with associated direct hydrocarbon indicators. Basin modelling shows potential for a mixed biogenic and thermogenic system offshore Lebanon and there is evidence for both gas- and oil-prone source rocks from the Triassic to the Neogene.

The first exploration well offshore Lebanon will be drilled in 2019 by Total, which operates in Blocks 4 and 9 in a consortium with ENI and Novatek. It is expected that more wells will follow in 2020.

The official launch of the bid round is scheduled to take place in the first quarter of 2019. Companies interested in participating in the tendering process must be prequalified, with requirements covering legal, technical, commercial, quality, health, safety and environment aspects. Interested companies will submit their prequalification applications, followed by a bid submission which will be evaluated, and subsequent award of the blocks will be towards the end of 2019. *For further details, see article online.* ■



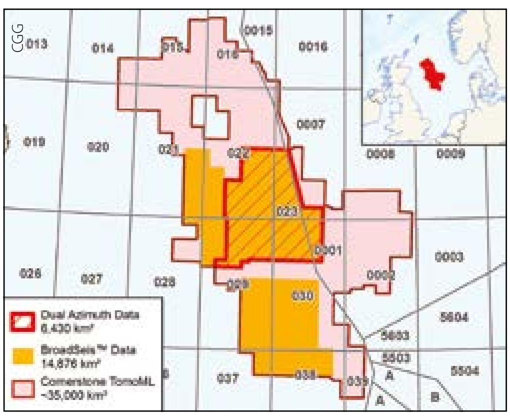
Your Upstream Connections into Africa

The **Africa E&P Summit** will be held on **22–23 May 2019** at The IET, Savoy Place, **London**, with a full two-day programme that aims to bring you the best of Africa's oil and gas in the heart of London. Serving as a platform for your upstream connections into Africa, attend this event to connect with and get the edge on Africa's oil and gas exploration horizon.

The summit brings together Africa's upstream industry at a world-class venue in London for a unique event shaped for companies active in Africa's oil and gas game and provides unrivalled insight into the continent's fast-changing exploration horizon. Hear directly from key players and decision-makers, from corporate players active in Africa through to fast-moving independents, finance, legal and service and supply companies and African governments and NOCs seeking investors. Hear from over 50 world-class speakers and uncover the leading edge on Africa's E&P hot spots.

You are also invited to join us on the concluding day for the **Africa E&P Summit Gala Dinner** 2019, on Thursday 23 May. This will be the finale to the summit and is a celebration of all things African – and all things African oil and gas – with a fabulous guest speaker. ■

Evolution of Imaging in CNS



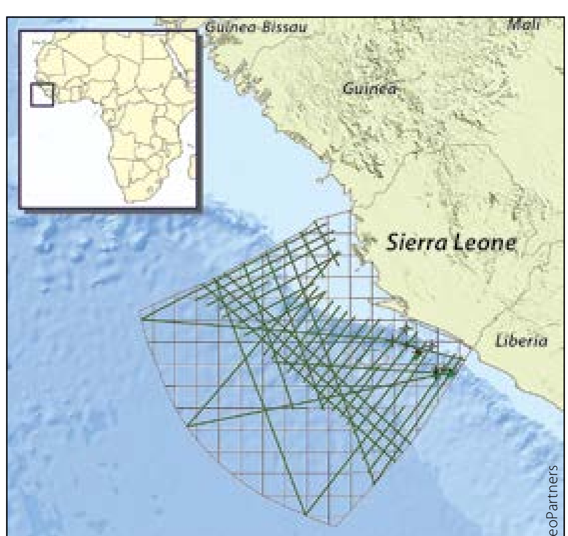
Location of the Cornerstone Evolution project in the Central North Sea.

Results from priority areas of **CGG's Evolution** reprocessing of its **Cornerstone Central North Sea** (CNS) data sets straddling the **UK-Norway** border are now available. The entire 35,000+ km^2 Cornerstone survey is being reprocessed from field tapes using the latest cutting-edge imaging technology, in order to merge conventional long-offset, BroadSeis™, BroadSeis-BroadSource™ and dual-azimuth data and thus create a single contiguous broadband PSDM data set.

The processing is tailored to address the geological complexities, with model building benefitting from Q-Tomo, Q-FWI, and Q-RTM. Final PSDM data sets will include least-squares Q-Kirchhoff and wave-equation migrations. Early-out data will be available in Q3 2019, and impressive new high-resolution images of the Forties channels and the HPHT (high pressure – high temperature) dual-azimuth area have already been achieved. ■

New 2D Offshore Sierra Leone

International geophysical consultancy **GeoPartners** has announced a new **2D seismic** survey offshore **Sierra Leone**. The survey, consisting of over 9,000 line-km, is to be acquired in partnership with the Petroleum Directorate, and will support the **4th Offshore Petroleum Licensing Round** planned for later this year. This is the first new 2D survey off Sierra Leone for seven years and will provide geophysical data covering the entire offshore area from shallow to ultra-deepwater, providing ties to all existing wells and allowing a complete evaluation of the available acreage.



Four out of five exploration wells drilled in the southern deepwater basin encountered light oil, condensate or gas in the Upper Cretaceous. Reservoirs include stacked, high net:gross channelised turbidite sands, with good porosity, located in slope apron fan systems of the Cenomanian and Turonian. Interbedded marine shales are organic-rich, oil-prone and mature. Equivalent source/reservoir facies are prospective on the French Guiana conjugate margin where Zaedyus-1 found 72m net oil pay in high quality Cenomanian and Turonian fan sands.

Acquisition is planned to commence after completion of the necessary regulatory approvals and a subset of the data will be available for companies participating in the Licence Round. ■

GeoConvention 2019: Advancing Geoscience

The oil and gas industry has been completely reshaped over the past four years and a more stable footing for the industry is on the horizon for 2019. International markets are picking up, as are the opportunities within **Canada** and, despite market fluctuations, geoscientists will continue to find and develop the resources necessary to power our economy.

GeoConvention offers some of the best local and international insights to efficient energy exploration and production, critical to the success of the industry. The 2019 technical content will build upon the success seen in 2018, hosting topical sessions within impactful themes, covering topics like technical fundamentals and applications, novel technological tools and advancements, unconventional plays and the management of associated risks, as well as analyses and case studies that address both challenges and opportunities in the industry.

GeoConvention 2019 is an opportunity for delegates, exhibitors and supporters from around the world to benefit from and give back to the oil and gas community through their technical contributions, technology showcases and industry partnerships. GeoConvention 2019 is held in beautiful **Calgary, Alberta, Canada**, on **13–17 May**. ■

Two Days About Technology

Imagine a world-class petroleum province with several billion barrels of discoveries. Imagine that oil has been found in carbonates intruded with volcanic sills, and that the reservoir is located beneath a thick layer of salt. Then you would also imagine that you have a problem with imaging of the reservoir. At the forthcoming conference **NCS Exploration – Recent Advances in Exploration Technology** in **Fornebu, Oslo** on **21–22 May**, Peter Szatmari, Senior Geologist with Petrobras, will give a keynote about how his company has attacked this challenge.

Imagine that oil is trapped in thin, vertical sandstone reservoirs with excellent properties. Imagine that they have been overlooked for tens of years, but that it is now possible to image them using either broadband or ocean-bottom seismic. What will be the best technology to use? At the conference several companies will relate their experience of imaging injectites that have turned out to be extremely productive reservoirs.

De-risking petroleum systems using up-to-date technology is the main topic for this third NCS exploration technology conference. It targets users of technology, rather than tech nerds, and will thus concentrate on how explorationists can benefit from recent advances in petroleum exploration technology. The NCS website has further details. ■

Devex: Learn and Be Inspired


Rory Raitt, c/o Devex conference

DEVEX 2019, a conference jointly organised by the **Society of Petroleum Engineers** Aberdeen Section, **Aberdeen Formation Evaluation Society** and the **Petroleum Exploration Society of Great Britain**, has recently closed the abstract submissions process. The organising committee has been encouraged not only by the high number of abstracts received, but also by their quality, which continues to create a strong technical programme.

The DEVEX programme comprises technical presentations, expert masterclasses and core displays as well as special events such as the Young Professional session and a field trip to view the Old Red Sandstone near Stonehaven and Glen Esk.

Conference Chair, Henk Kombrink (pictured), a petroleum geologist at Lloyd's Register, commented: "At DEVEX 2019, around 400 engineers and geoscientists have the opportunity to share industry best practice on how to achieve maximum economic recovery in the UKCS. Our technical programme is central to this and provides delegates with all areas of expertise and skill levels the opportunity to learn more and be inspired. This shared learning is so important in ensuring that we continue to collaborate and innovate in the energy industry."

DEVEX 2019 takes place **7–8** May at the **Aberdeen Exhibition and Conference Centre**, with the field trip on 9 May. ■

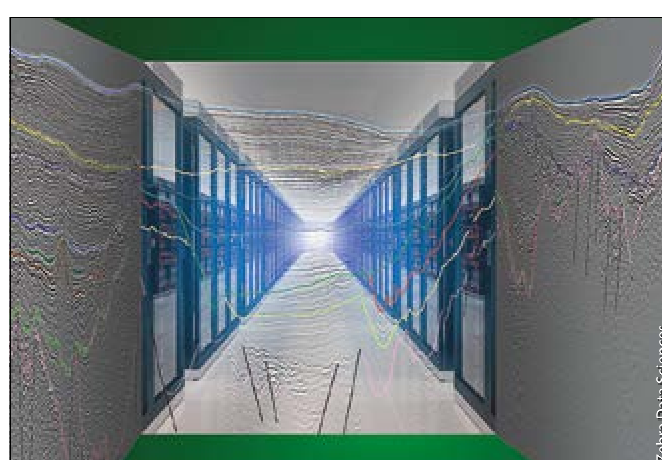
ACE Returns to San Antonio

The **American Association of Petroleum Geologists**, along with the **Society for Sedimentary Geology**, the **Austin Geological Society**, and the **South Texas Geological Society** are proud to host the AAPG 2019 Annual Convention and Exhibition (ACE) at the Henry B. Gonzalez Convention Center in San Antonio, Texas, on 19–22 May 2019.

Heading back to San Antonio for the first time in a decade, ACE 2019 looks to attract a global audience of some **7,500 professionals** from more than **72 countries**. ACE continues to be one of the most prestigious events for the geoscience community, with a tradition of delivering an exceptionally strong, juried technical programme, state-of-the-art technology displays and networking activities that create a dependable, fun and valuable business forum. ACE will feature more than 900 technical presentations, over 200 exhibiting companies, 15 short courses, 13 field trips, eight networking events, seven forums and special sessions, and four luncheons, as well as U-Pitch presentations, student and young professional activities, and much more.

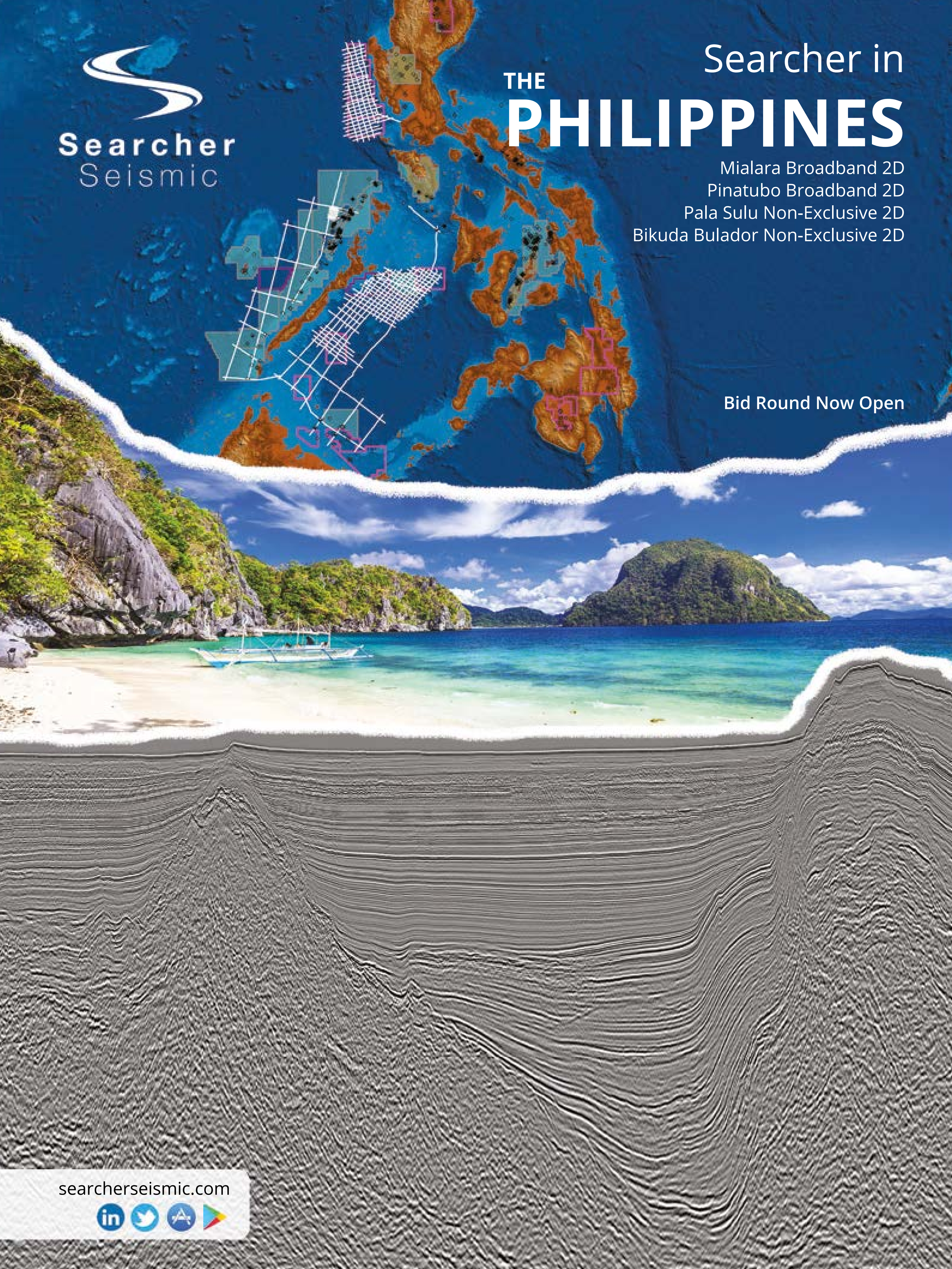
Make plans to attend ACE 2019 and register today. Don't miss the chance to join a community of geoscientists and petroleum industry professionals in San Antonio. Exhibition and sponsorship opportunities, as well as the full technical programme, are available now on the AAPG ACE website. ■

Guided Reality


Zebra Data Sciences

GeoReality is **Zebra Data Sciences**' revolutionary new web-based **3D Visualisation tool** and makes 'Showcasing as a Service' possible by taking geoscience data and creating a 3D model which can be viewed on a PC, smart device or VR headset. It does not require the end user to have specialist hardware or software, just a browser and an internet connection. Not only that, but the end user (wherever they may be) can be taken through a guided tour of the model in real time, selecting the best viewpoints and combinations of data to showcase it in the best possible way. This really saves time when compared with the traditional way of providing access to a data room where potential investors wade through all the information in a linear fashion.

GeoReality is a great way of promoting an asset, project or data set to both technical and non-technical people and allows collaboration between all parties. So, whether you are trying to get investors interested in your area, or trying to sell a new study, GeoReality provides a simple way to tell your story in a dynamic, compelling fashion. ■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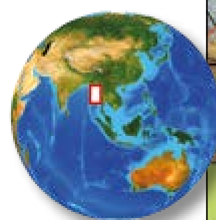
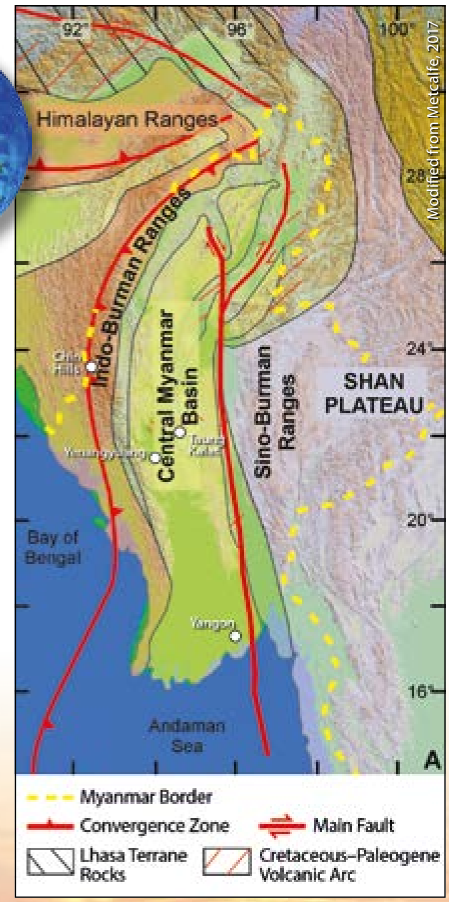
The Golden Land

Reserves and Resources of Myanmar

Despite having a long history in petroleum production – and being the place where the anticlinal trap was first recognised – there is much left to learn about the geology of Myanmar and its remaining potential.

AMY GOUGH, South East Asia Research Group, Royal Holloway, University of London





Modified from Metcalfe, 2017

A Rich History

On a clear day a landscape littered with buildings covered in glittering gold facades greets you when flying into Yangon, the old capital city of Myanmar. This pays homage to the original Mon name of Suvannabhumi, which directly translates into the tag line of the country – 'The Golden Land.' The gilded temples are covered in real gold and often numerous jewels. For example, the largest temple in Yangon, the Shwedagon Pagoda, is covered in 27 tons of gold, 5,000 diamonds and 2,000 rubies, mostly sourced from precious gem mines in the country itself. These gems have long been mined in Myanmar, most specifically from marble gravels in the Mogok Region, often referred to as the 'Valley of Rubies,' in the central north-east of the country. They are considered some of the finest in the world. The country is also famed for its gold reserves, cretaceous amber, and the rare tropical wood (e.g., teak and rosewood) that grows there. In addition, its vast hydrocarbon reserves lead to a great future exploration potential.

A Country Uplifted

Myanmar sits to the east of the India–Asia collision zone, where the Indian Plate is obliquely subducting beneath the West Myanmar Block. The country is subdivided into three north–south trending belts: the accretionary prism of the Indo Myanmar Ranges in the west; the central depression of the Central Myanmar Basin, where most of the known onshore petroleum reserves are located; and the

The volcanic plug Taung Kalat rises sharply to a height of 657m and is topped by a Buddist monastery.

Conor McMillan

Sino Myanmar Ranges, which include the precious gem-rich Mogok Region. Another notable feature is the partially buried Wuntho–Popa magmatic arc that dissects the centre of the Central Myanmar Basin in a north–south orientation. A large pagoda has been built on the flat top of Taung Kalat, a volcanic plug related to the extinct Mount Popa.

The timing of the uplift of the Indo Myanmar Ranges is still an area of dispute, with some people arguing for an early Cenozoic age and others proposing that it is as young as 5 Ma. This affects the sediment routing through the Central Myanmar Basin in the Cenozoic, and the timing of any deflection or distribution of the sediments that were deposited in the actively producing offshore oilfields in the west. This is important, as the Cenozoic sediments in the Salin Sub-basin of the Central Myanmar Basin are extensive and exceed thicknesses of 18 km (Hall and Morley, 2004), suggesting a high sediment yield was sustained for a long period of time. Abundant load and flame structures are common throughout the Cenozoic deposits and can be related to a high sediment supply and concurrent rapid deposition. Sediment provenance studies onshore in the Central Myanmar Basin can help to answer some of these questions.

A 3 cm- wide load structure found in Cenozoic deposits indicates high sediment supply with concurrent rapid deposition.

Long Production History

From the construction of the walls of Babylon to salt production in ancient China, humans have been utilising petroleum reserves for over 4,000 years. Myanmar is no exception, with hand-dug wells dating back to 900 BC (Thornton, 2015). Exploration and production carries on into the current day. Currently, Myanmar has 51 onshore blocks in operation, 18 of which are offshore, mostly producing natural gas (MoEE, 2018). The Ministry of Electricity and Energy (MoEE) reports proven reserves of 16.6 Tcfg (CEIC, 2018) but this leaves room for many more substantial finds. In addition, Myanmar derives energy from a range of renewable sources, with solar panels and hydroelectric plants being a common sight across the country.

The city of Yenangyuang, Central Myanmar, has been built on the petroleum industry: in fact, the very name is directly translated as 'stream of oil'. The modern-day landscape is littered with thousands of pyramidoidal bamboo frames marking the location of hand-drilled oil wells. The luckiest villagers will strike oil close to surface, but some of the wells can reach more than 460m in depth. They are mostly drilled by using metal-tipped bamboo rods attached to car engine-sized generators, and the oil extracted by lowering long plastic pipes down the well and winching the reserves back up to surface. There are also smaller operations, where one person uses a hand-winch and plastic bottles cut to act as a receptacle to extract the petroleum.

Still forming a prominent industry for the people of Myanmar, these operations have been ongoing in the Yenangyaung area since at least the 1750s (although the field was only officially 'discovered' in 1889). George Baker, a British captain, recorded the location of similar hand-dug wells in the area, and it has remained an area of interest for exploration into the modern day (Longmuir, 2008; Racey & Ridd, 2015). Interestingly, the Yenangyaung field is considered to be the first place that the anticlinal theory of petroleum accumulation was identified, in 1855 by Anglo-Irish geologist Thomas Oldham when he was working for the Indian Geological Survey – a fact that the geologists who work on the field for the national oil company, MOGE, are incredibly proud of. Oldham recognised that the local villagers were only digging for oil on the crest of the highest part of the anticline and made the connection between this and structural traps.

A typical outcrop of marine Oligocene sediments.

After the official 'discovery' of the field in 1889, 'Well One' was drilled. It was completely dry, mainly because it was too shallow. Further efforts of exploration have, however, proven to be highly successful, with a derrick actively producing directly next to this initial 'Well One'. The field is now officially owned and run by MOGE, but many villagers still hand-drill and produce oil in the area. Many other fields have the potential to be as productive as the Yenangyuang field, but further research and exploration efforts are required.

New Geological Understanding

Despite this long history of reserves and exploration, fieldwork-based studies are relatively limited in Myanmar. The South East Asia Research Group (SEARG) have been on the ground in the country since 2013. A combination of geological mapping, sedimentological logging, sampling, and subsequent analysis through petrology, XRD, heavy mineral analysis, and U-Pb dating of zircons has allowed us to make some interesting discoveries about this unique and dynamic country. For example, analysis from the Chin Hills area suggests that the West Myanmar Block was tectonically already part of Asia from the Mesozoic (Sevastjanova et al., 2016).

SEARG have more recently found that the sediment routing pathways in the Central Myanmar Basin are a lot more complex than previously thought, with sediment sources in the Indo-Myanmar Ranges to the west and from the magmatic arc to the east (McNeil et al., in prep). This has enabled us to revise the Cenozoic sedimentology in the hydrocarbon-bearing areas (Gough & Hall, in prep). For example, a spatially dense logging campaign allowed for facies associations and architectural elements to be studied through the Oligocene, and it was found that the fluvio-marine environments show that marine incursions transgressed further into the basin than previously thought. Further studies into the sediments of the Central Myanmar Basin will help us to better understand the geological history of the area and the numerous hydrocarbon plays found throughout the country.

A Yenangyuang oil well dug by hand using metal-tipped bamboo rods attached to a small generator.

Importance to South East Asia

The growth of energy use in South East Asia is generally considered to currently be unsustainable. Consumption in Indonesia, for example, has started to out-pace production, relying more and more on imports to keep up with demand (PWC, 2018). Areas like Myanmar, with plentiful potential reserves, could help this potential energy crisis with ongoing efforts in exploration.

References available online. ■

Hand drilled oil wells dug by villagers in the Mann Field, Central Myanmar.

Amy Gough

Great Expectations

A number of interesting, but not very adventurous, drilling campaigns are planned for 2019.

PETER ELLIOTT, NVentures

A summary of expected wildcat drilling campaigns around the world for 2019 suggests a continuing trend of fewer wells, mostly clustering in and near proven core basins, with few unproven frontier basins being tested.

The Usual Suspects

South America's Atlantic Margin deepwater trend will continue to catch the headlines in 2019 following ExxonMobil's world-beater Starbroek Block (CNOOC and Hess partners), with approximately 5 Bbo already discovered. Immediately south-west in 100m water, Repsol's Kaieteur-1 (Kanuku Block, Tullow and Total partners) will target a similar Upper Cretaceous fan system. With dry wells to the north and south, this is not a straight extension of the Liza play. It will be closely watched by Tullow and partners Total and Eco on the adjacent Orinduik Block as it is apparently on trend with their planned Amatuk-1 and Latuk-1. After two dry wells in Namibia, Tullow and Eco are shifting their subsurface allegiance to Guyana, but Total will stay with Namibia, possibly testing the huge Venus prospect in the ultra-deepwater Orange Basin later in 2019.

Suriname waits to claim its place in the hydrocarbon hall of fame, after a number of high-profile wells (Kosmos, Tullow) had light oil and condensate shows but were non-commercial. Tullow, with Israeli explorer Ratio, will try again, testing the 400 MMbo Block 47 Goliatberg prospect, while Kosmos, with new partners Chevron and Hess, will continue their efforts on Block 42 withApetina-1 and Aurora-1. In French Guiana Total plans to drill Nasua-1 in 2,000m water.

Elsewhere, the majors will test recent trends, with ExxonMobil in Cyprus, Eni and Sasol in South Africa, ExxonMobil and Eni in the Angoche Basin offshore Mozambique, and Murphy, BP, Premier and Petronas offshore Mexico, where the Sureste Basin (similar in style and scale to Lower Congo and Campos), in particular, holds great promise.

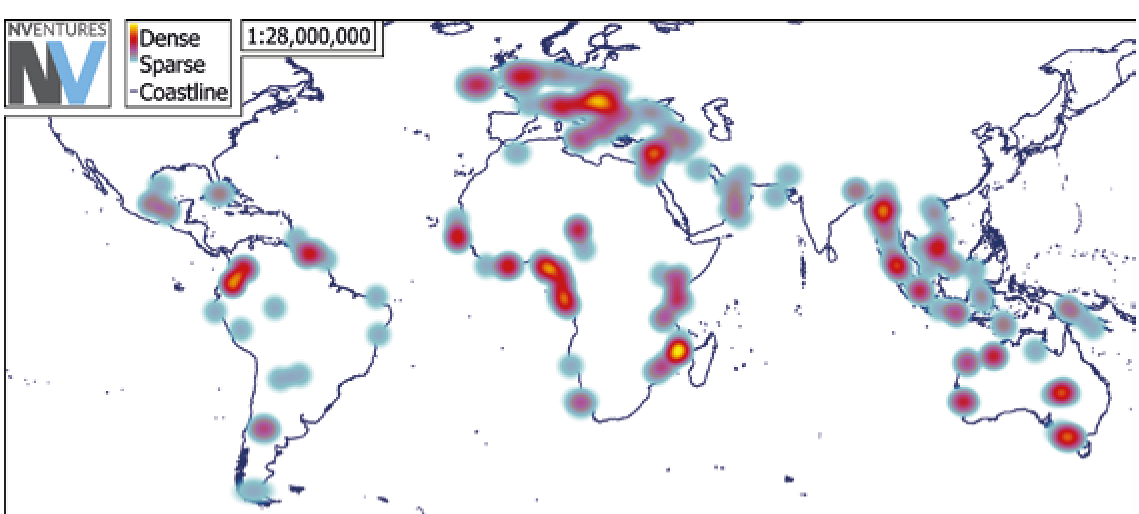
Testing New Plays

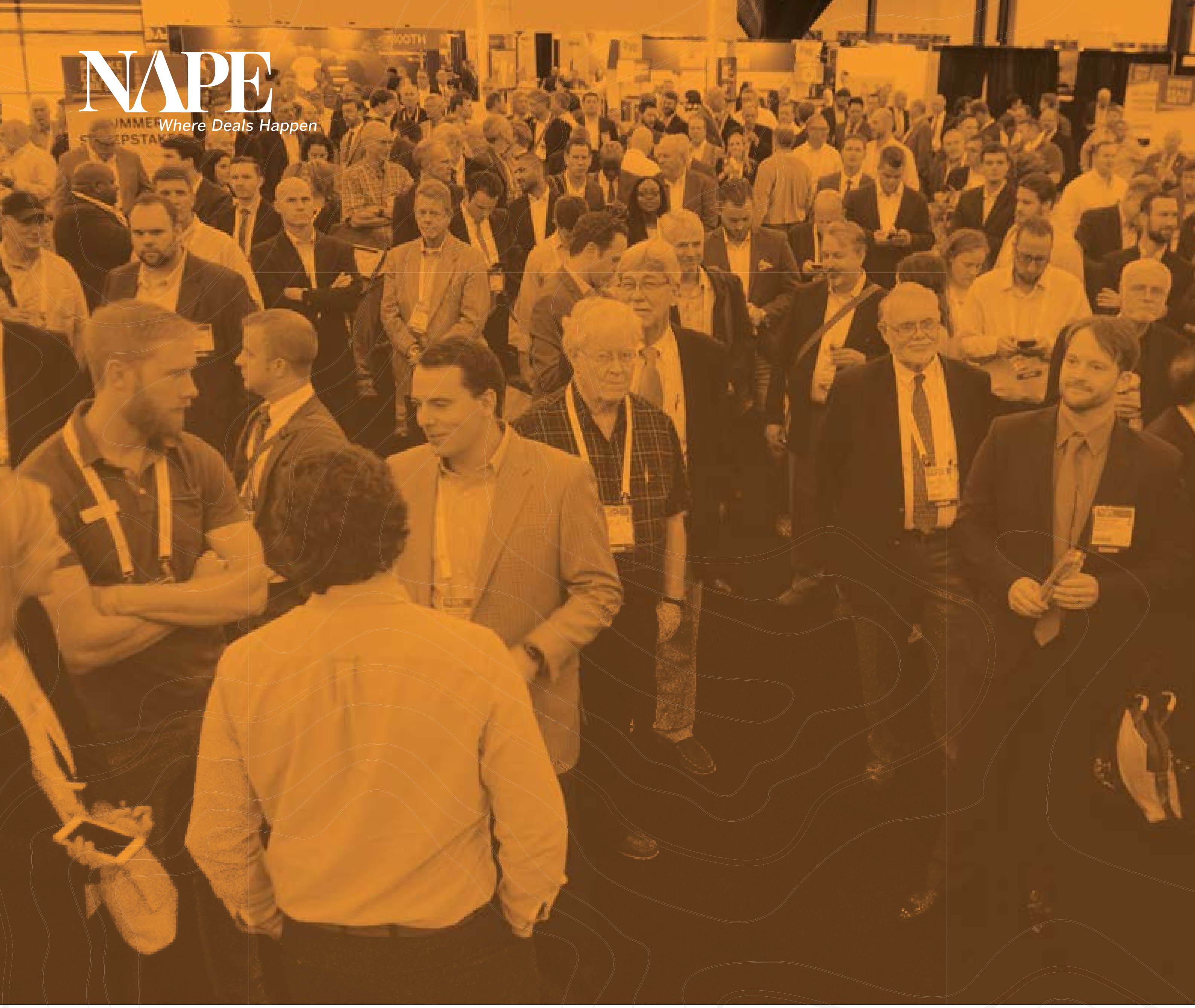
Away from the big names, smaller firms with regional focus plan to test new and challenging plays with the drill bit. Amerisur (and Oxy) will carry out a 3–6 well programme in Colombia's Putamayo Basin. Southern Australia's Otway Basin welcomes exploration drilling back in shallow waters, with Cooper Energy eyeing two wildcats, Annie and Elanora, which could deliver 200 Bcf in a high value, low-cost basin where gas is king in both demand and price. Octant Energy will drill up to five wells in southern Kenya and north Tanzania coastal basins. Guinea Bissau and AGC may see new drilling after a hiatus of over a decade, with Svenska pushing ahead with their SNE-style platform edge Atum and Anchovie targets. Impact Oil & Gas may get to taste drilling success with partners CNOOC in AGC this year, and with Total in the Orange Basin.

Atlantic Ireland will return to centre stage later in 2019, as CNOOC announced an all-Irish asset swap with ExxonMobil to fund the Iolar well in Block 3/18, targeting a pre- to syn-rift Jurassic structural play on the west flank of the Porcupine Basin. Total has taken the devil by the horns and joined Providence for the nearby Diablo prospect. Further Irish excitement could come if Providence find partners for the drill-ready Newgrange Prospect (Block 6/14), at Eni's Dunquin South (with Repsol, Providence and Sosina, FEL 3/04) and Europa's Corrib lookalike at Inishkea (subject to joint ventures concluding).

Drilling Clubs

One interesting development to watch for in 2019 is special purpose 'drilling clubs', partly driven by drilling companies sharing more risk. Seapulse and Maersk, for example, plan to expedite the JV process across a varied portfolio of high-graded prospects, targeting 12 wells in the next two years. This will be a welcome trend in an otherwise risk-adverse exploration industry. ■




NAPE
Where Deals Happen

Australia:

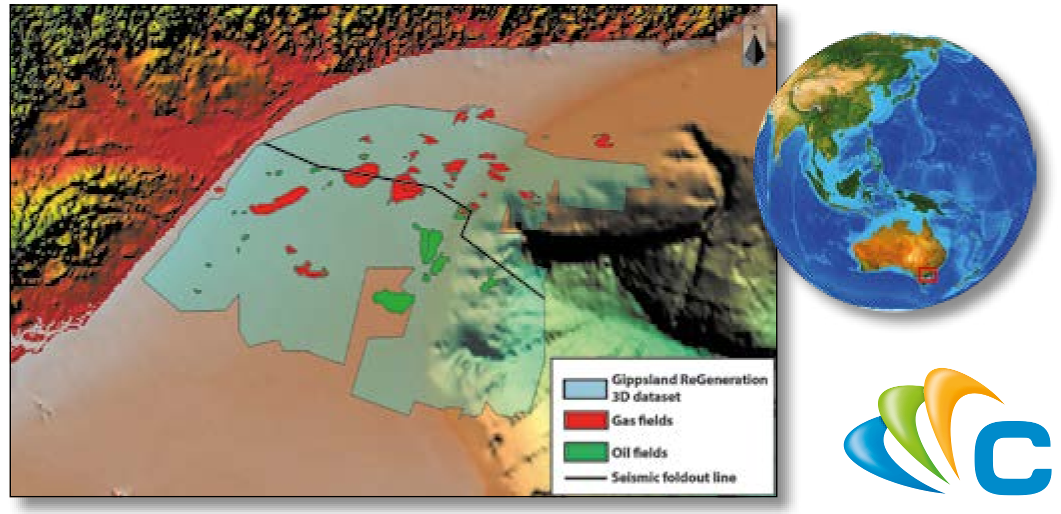
Depth Reprocessing Rejuvenates Gippsland Basin

For some years, the Gippsland Basin of south-east Australia has been the 'dowager queen' of the country's oil and gas industry – in decline but maintaining wealth and dignity.

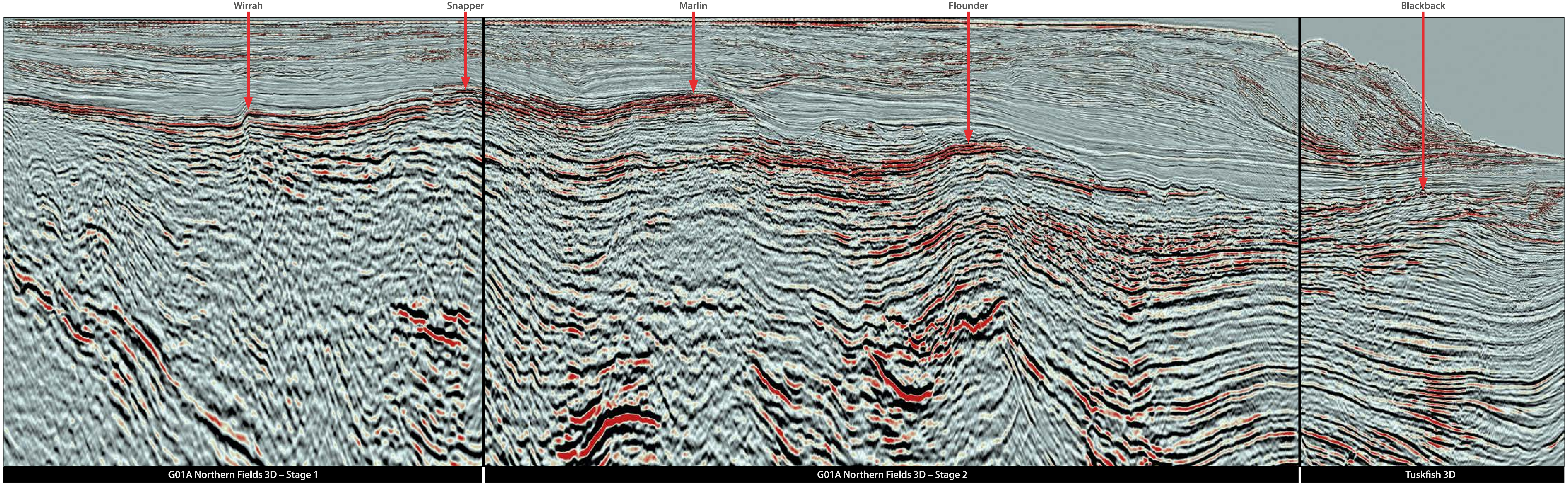
The world-class oil and gas fields of the Gippsland Basin, with original recoverable reserves of more than four billion barrels of oil and around ten trillion cubic feet of gas, were discovered following a 1962 2D seismic survey with a 19 x 27 km line spacing. Ten of the first eleven wildcat wells were successful and all the discoveries were related to a single play: porosity in top Latrobe Group clastic reservoirs below the regional seal.

Despite considerable exploration, it has long been known that unresolved seismic depth imaging issues have had a significant impact on data quality. As a consequence, the province probably has unrealised exploration potential, particularly in the deeper stratigraphic section. The basin-wide Gippsland ReGeneration reprocessing project by CGG has changed the paradigm and the basin is now seen as rejuvenated, with new exploration opportunities and significant upside potential.

The 'elixir of youth' was provided by new processing technologies, which have overcome the depth imaging issues that have plagued the basin since the beginning of offshore exploration in the 1960s.



CGG



Changing Perceptions

ReGeneration project overcomes the imaging challenges of the Gippsland Basin.

PETER BAILLIE, PAUL CARTER, JARRAD GRAHAME, JOE ZHOU and NIGEL MUDGE, CGG

Over the last ten years CGG has gained extensive experience in the processing and reprocessing of legacy datasets in the Gippsland Basin. Leveraging that experience, we recognised that further advances to our recent innovations in data processing could be critical in overcoming the imaging challenges of the basin.

There are two main challenges, driven by the geology and the seafloor character. The north-western area has water depths of less than 200m, and in general a hard seabed which leads to extensive multiple generation and data contamination. The impact on data quality in this area is exacerbated by the presence of high-velocity carbonate channels in the shallow section and highly absorbing and scattering coal reflectors in the deeper stratigraphy. The eastern area has a very rugose seabed at the shelf-break, and complex velocity variations associated with high-velocity carbonate-filled channels, adding to structural imaging challenges that lead to large well mis-ties.

By applying our latest improvements in velocity model-building and imaging algorithms, CGG reprocessed the vintage data, to the highest level of quality, to provide the highest-fidelity depth images available for improved prospect mapping. The outstanding success of the current multi-client reprocessing project with the latest data processing technology has led to a resurgence of interest in the Gippsland Basin.

Geological Development and Petroleum Systems

The Gippsland Basin formed as a result of Mesozoic rifting and the subsequent breakup of eastern Gondwana, and hosts at least 7.5 km of Early Cretaceous to recent sediments. The main recognised units include the volcaniclastic Strzelecki Group (130–95 Ma), deposited within a continental rift; the siliciclastic Latrobe Group, initially deposited within a continental rift with a major half graben near the north boundary fault; subsequent mixed marginal marine to lower coastal plain depositional deposits; and the calcareous Seaspray Group (32 Ma to Present), deposited on a prograding continental shelf.

In the early Eocene, a compressional period initiated, forming north-east to east-north-east-trending anticlines. The compression peaked in the middle Miocene, resulting in partial basin inversion. All of the major fold structures and associated hydrocarbon accumulations at the top of the Latrobe Group are related to this tectonic episode.

Throughout the Tertiary there were several periods of canyon formation and infill, including a major erosional phase in the mid-Eocene which enhanced the developing structures. Minor volcanics are sporadically present throughout the entire section. These depositional and erosional elements are known to have a significant impact on seismic velocities.

With regard to petroleum system elements, the primary source rock consists of Latrobe Group non-marine, coastal plain organic-rich shale and coal (kerogen Type II/III). The main reservoir unit is the Latrobe Group marine, nearshore barrier/shore-face sandstone, and fluvio-deltaic sandstone and sandy channel-fill. The regional seal is composed of fine-grained material of the Seaspray Group with intraformational and volcanics acting as local seals. Traps include anticlines, fault closures, erosional remnants, Top Latrobe sub-crops and buttress structural/stratigraphic plays in the late Cretaceous Golden Beach and Emperor sub-groups. These sub-groups are a secondary exploration target in the basin.

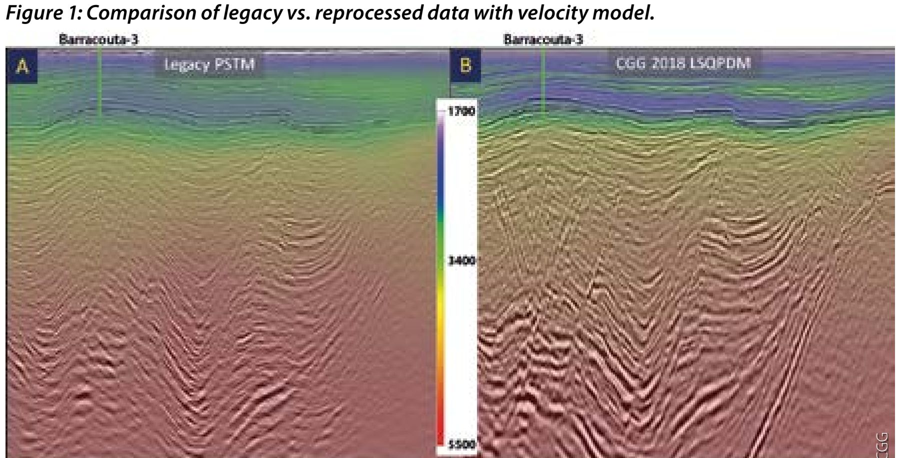
The main phase of hydrocarbon generation and expulsion occurred in the Neogene, with an earlier phase in the latest Cretaceous/Paleocene. Vertical migration, often in excess of two kilometres, is the primary charge mechanism. Trap definition represents the key exploration challenge in the basin.

Processing Technology

CGG's new processing flow includes three key technologies:

- 3D joint source and receiver deghosting was applied to suppress the ghost and extend the bandwidth for low and high frequencies, resulting in a step-change in resolution.
- Multi-passes of Full Waveform Inversion (FWI) were applied to generate a high-resolution and high-fidelity velocity model. To overcome the challenges such as poor signal-to-noise (S/N) ratio at low frequencies and limited

Figure 1: Comparison of legacy vs. reprocessed data with velocity model.



offset in the vintage narrow-azimuth data, a hybrid FWI and tomography velocity model-building flow was applied. The FWI processing focused on resolving the velocity contrast from the shallow, high-velocity channels. The resulting tomography update focused on the low-frequency background trend and updated the anisotropic parameters.
- Least-squares Q pre-stack depth migration was selected as the final imaging algorithm to compensate for illumination, improve S/N ratio and recover the bandwidth and amplitudes.

Figure 1, which is a comparison of vintage and reprocessed data, demonstrates the substantial imaging improvements, specifically:
- a high-resolution and geologically plausible velocity model, resulting in a greatly improved depth section and well tie;
- better suppression of multiples and coherent noise and significant improvement of S/N ratio from shallow to deep section;
- higher-resolution imaging, particularly at reservoir level;
- sharper fault delineation;
- reliable AVO inversion.

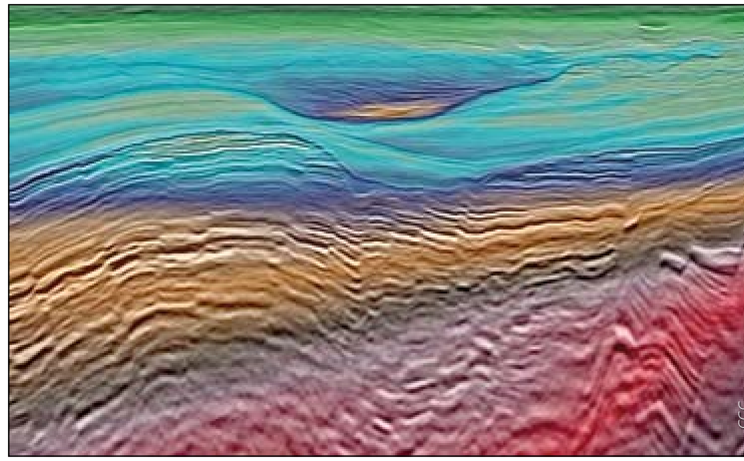


Figure 2: Marlin channel – new velocity model.

Key Insights and Opportunities

The newly reprocessed data provides greatly improved depth images, allowing for greater understanding of both the regional geology and the key exploration targets. The data provides improved definition below the thick coal seams despite the relatively short streamer length from previous acquisition.

Figures 2 and 3 illustrate improved imaging of canyons and their fill, made possible with the enhanced velocity model. Figure 2 is a vertical seismic section, colour-blended with the new velocity model, which intersects the Marlin Channel overlying the Marlin field. The channel system, which ranges from 5 to 30 km in width, 75 km in length and 700m in depth, developed during a period of tectonic uplift and associated sea-level fall in the mid-Eocene. The high-velocity zone, at the base of the channel succession, is likely due to the presence of lithified fine-grained micrite.

Figure 3 shows a vertical seismic section with a prominent canyon projected onto a time-slice from the velocity volume. The areal extent of the high-velocity zone at the base of the channel succession is clearly defined and highlights the complexity of the geology and associated depth imaging issues.

Another key exploration challenge is the effective imaging of fluid contacts, which has long been problematic within the Gippsland Basin. Preliminary analysis of the current dataset shows that imaging of fluid contacts over a number of fields is significantly enhanced, demonstrating the opportunity for future AVO and inversion studies.

Exploration opportunities identified from the reprocessing include the Top Latrobe, Intra-Latrobe, and Golden Beach and Emperor gas fields. There are very few shallow-water, Top Latrobe undrilled structures in the current dataset. However, large undrilled features in the deepwater have been identified beneath the continental slope, where depth imaging problems have been extreme in the past. The majority of untested opportunities are expected to be found at deeper horizons.

New Exploration Potential

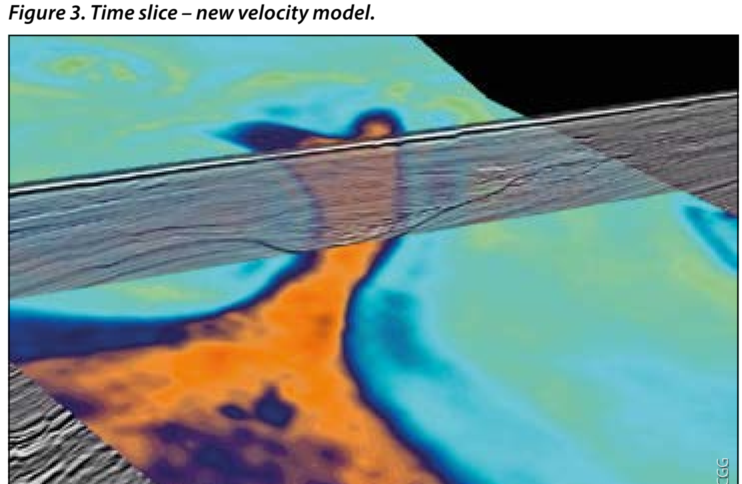
With offshore production reaching its golden anniversary this year, conventional logic would suggest that Gippsland is a 'mature' basin; however, because of the long-standing imaging problems, we believe that the basin still holds significant upside potential.

While the reprocessed dataset is a significant improvement, the imaging is inherently constrained by the original acquisition parameters, primarily cable length. New longer-offset data would allow even better imaging, particularly in the deeper section. CGG therefore plans to acquire a new basin-wide 3D survey with modern broadband to produce high-resolution reservoir imaging – and provide coverage of the deeper but highly-prospective eastern canyon area.

The success of the high-end reprocessing proves that even in basins that are considered mature, new ideas and processing technology can change long-held perceptions, and rejuvenate exploration activities.

Images courtesy of CGG Multi-Client & New Ventures.
References available online. ■

Figure 3. Time slice – new velocity model.



Creating Excitement in the Geosciences

At G-Camp teachers learn about geology through a very diverse and eye-opening field experience, returning to their classrooms eager to share their new-found knowledge and inspire their students.

THOMAS SMITH

While taking 36 teachers out in the field each year to study geology may seem inconsequential in the overall scheme of educating our young people in the sciences, it clearly demonstrates the need and demand for such programmes. Since its inception ten years ago, the founders of G-Camp now receive twenty times the applications that they can fill. Dr. Rick Giardino, professor in the Department of Geology and Geophysics at Texas A&M University at College Station, Texas, helped start G-Camp. It has become internationally recognised, with the future of this and similar programmes gaining strength to educate more teachers and students in STEM subjects: science, technology, engineering and mathematics (STEM).

In June 2018 I was lucky enough to be invited to spend several days at G-Camp, discovering what the students were learning and what they were taking back to their schools from the experience.

> *"My classes wouldn't be as rich or as interesting if I hadn't attended G-Camp."*
> ***Kayla Jubert, Colorado, 2018 G-Camp.***

Getting Students Excited About Science

The US government projects STEM jobs to greatly increase in the future, yet not enough students have access to quality STEM learning and too few of them see these disciplines as springboards for their careers. These factors have led to a great shortage of students pursuing STEM fields and this shortfall is being felt by companies that depend on people educated in the sciences. These facts caused President Obama and his administration to set a clear priority for STEM education, stating in March of 2015: "[Science] is more than a school subject, or the periodic table, or the properties of waves.

The teachers selected for the G-Camp field course experience spectacular geological locations, such as the Black Canyon of the Gunnison in Colorado, and learn from local experts like Supervisory Park Ranger, Paul Zaenger.

Thomas Smith

Rick has help along the way from local experts at specific locations and from the G-Camp staff. From left to right: Carolyn Schroeder, Nina Lawson, Fran Giardino, Rick Giardino, Kevin Gamache, Rita Gamache, and Merlin Lawson.

It is an approach to the world, a critical way to understand and explore and engage with the world, and then have the capacity to change that world…"

At a time when the Texas state government was trying different ways to attract more teachers into science programmes, Carlos Dengo of Exxon, one of Rick's Texas A&M graduates, was also noticing that many students lacked science backgrounds. Consequently, Mr. Dengo offered Rick a proposal for an Exxon sponsorship to create a geological field programme for teachers.

> *"What was exciting is that as the days unfolded, there was so much I knew that I could take back to my students. This was an experience I would be able to share that would encourage, motivate, and empower my students to delve into the science content."*
>
> ***Ms. Kimberly Renick, New Jersey, 2018 G-Camp.***

"I went right to work to put a geology field programme together that was designed for educators with little to no science background," says Rick. "I had a very short time to get something started before the summer field season in Colorado and New Mexico. I put a request for interested teachers, along with programme details, on the internet in late April, 2008. By the time I checked the website later that week we had over 300 applicants.

"The first eight years we took only Texas educators," he adds. "In 2016, we opened it up to ten people from outside the state and now it is open to the entire country; this year we had twenty from other states. The programme has been sustained by numerous industry sponsors, with Aramco the primary sponsor for the last two years.

Dr. Rick Giardino pointing out features in the western Colorado foothills of the Rocky Mountains. "Each year we tour locations in Texas, New Mexico, and Colorado," he explains. "The three-week trip can include Capulin Volcano, Great Sand Dunes, Black Canyon of the Gunnison, Carlsbad Caverns, various rivers, and the glacial valleys high in the Colorado Rockies. We keep the teachers busy with 12-hour days in an exhausting but exhilarating whirlwind of learning. They keep a daily field book and develop lesson plans each night. Post-trip, they present their knowledge and experiences to other teachers within their districts and at state and national meetings."

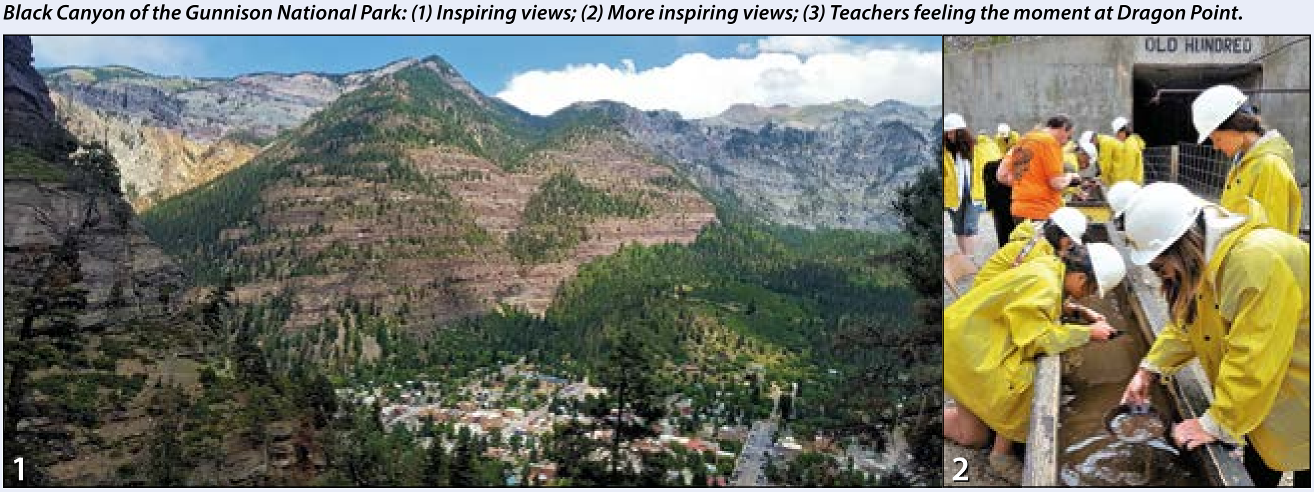
The Field Experience

Thomas Smith

Colorado National Monument: (1) View of Sentinel Spire and canyons; (2) Students are taught to observe; 3) Local Colorado teacher Kayla Jubert interviewed by Grand Junction TV.

Thomas Smith

Black Canyon of the Gunnison National Park: (1) Inspiring views; (2) More inspiring views; (3) Teachers feeling the moment at Dragon Point.



Thomas Smith

Colorado Rockies: (1) Home base in Colorado, the mining town of Ouray; (2) Teachers panning for precious metal at the Old 100 mine.

"The value of getting involved at the grassroots level and the positive impact our sponsorship brings to teachers and students is rewarding," says Jack Moore, Director, Washington, D.C. office, Aramco Services Company. "Through the years, we've supported hundreds of educators (teachers and career counsellors) and, in turn, made a difference to thousands of students' knowledge of geology and their potential career choices."

Moore says an experience like G-Camp gets educators out of the classroom and into the field to see, touch, and experience the subject matter first hand.

Why Fund Science Education?

Recent polls of US consumers show that a majority believe that the oil and gas industry is very important to our economy, but few want oil and gas companies in their communities. Fewer than 40% trust the industry to do the 'right thing' (EV polling, 2017). A majority of teens believe the industry is bad for society but would be "more likely to engage with oil and gas companies if they thought the industry was interested in their views" according to the EV polling.

"G-Camp doesn't just tell you stories; G-Camp gives you stories to tell. When education is all about personal relationships with students, having a personal connection to the content helps engage your learners."
David Downing, former student of G-Camp.

So where do programmes like G-Camp fit into the overall goals of oil and gas companies?

According to Alma Kombargi, Director, Strategic Relations, Aramco Services Company: "The energy industry benefits are many. A programme like this supports a new generation of talent excited and interested in pursuing a career in the energy industry. Students learn that there is a wide range of geoscience careers and applications – such as geologists, geophysicists, or petroleum engineers. It widens their horizons and they begin to consider the possibilities." She says G-Camp is an outgrowth of the company's broader commitment to STEM education.

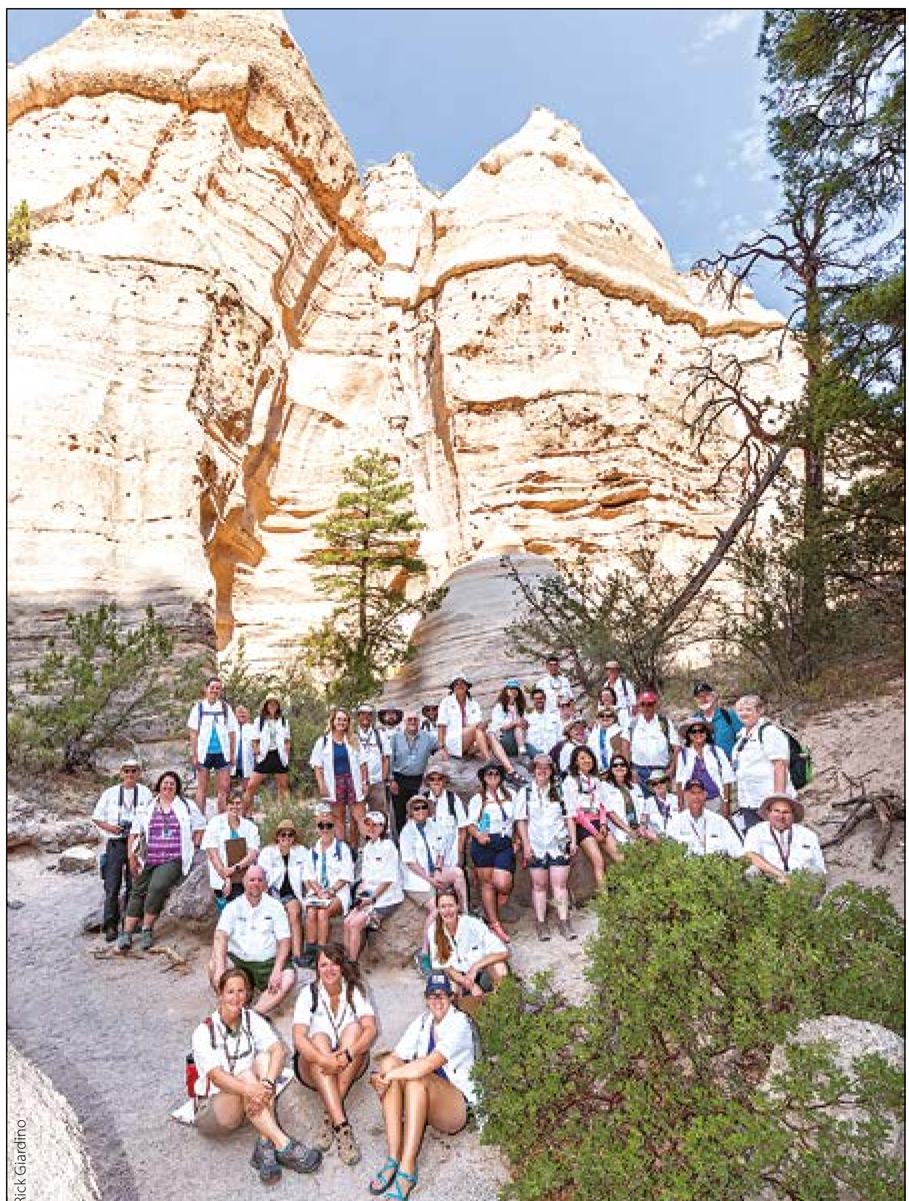
Timothy Diggs, Senior Geological Consultant, Upstream, Aramco Services Company, has an even more 'down to earth' perspective as to the importance of G-Camp. "I think it's instructive for people to understand the types of work geoscientists conduct in the field. How modern depositional environments like beaches or deltas inform our interpretation of ancient deposits, and how surface geology is related to subsurface structures, is of particular importance in the energy industry. The G-Camp field trip leaders provided an excellent series of locales that exposed the participants to a wide variety of geological settings, including those with direct connections as to how oil and gas reservoirs are formed."

While programmes like G-Camp may not change America's overall perspective of the oil and gas industry, the 2018 programme changed the lives of the 36 educators and how they view the earth. Having worked as a field and petroleum geologist, I know the importance that first-hand field observations play in becoming knowledgeable and proficient in this science. Dr. Giardino and his assistants' approach in teaching some of the many aspects of geology to a very diverse group was illuminating and gave me a great deal of respect for our educational system and the people that make it happen. It is these educators passing along their knowledge and enthusiasm for the sciences that will make a difference, one student at a time.

"Being in college and hearing lectures about this information taught me the basics, but getting a hands-on experience from G-Camp and our amazing teachers was the greatest learning experience."
Madalyn Culpepper, Louisiana, 2018 G-Camp.

Acknowledgements: Special thanks to Aramco Services Company and Rick and Fran Giardino for making my trip and this article possible. ■

G-Camp group photo at Tent Rocks in the Kasha-Katuwe Tent Rocks National Monument in north-central New Mexico. The tapering hoodoos were formed from a combination of pyroclastic flows, tuffs, and ash fall reworked by water.


Rick Giardino

Mr Five Per Cent
Calouste Gulbenkian

JONATHAN CONLIN

Intensely secretive, for more than half a century Gulbenkian personally controlled five per cent of Middle East oil production and shaped the firms we know as Shell and Total.

Calouste Gulbenkian in 1914.

Drawing the Line

Every map has its legend. The map attached to the Red Line Agreement of 31 July 1928 is no exception. This agreement saw the companies we know as BP, ExxonMobil, Total and Royal Dutch-Shell join forces in the Middle East. Instead of fighting each other for control of the region's oil, they would collaborate in a joint venture: the Turkish Petroleum Company (TPC).

TPC had been established by the Anglo-Armenian Calouste Gulbenkian back in 1912. Two years later the British Foreign Office and the Grand Vizier in Istanbul had given their blessing: rival powers were to cooperate not only in the oil-rich Ottoman provinces of Mosul and Baghdad, but in the entire 'Ottoman Empire in Asia'. For Gulbenkian, who held 5% of TPC, it was a promising start.

By 1928, however, the 'Ottoman Empire in Asia' was a distant memory. The Great War broke out just a few months after TPC secured its concession. Allied to Germany, in the wake of defeat the Ottoman Empire had collapsed, triggering a wave of genocidal violence which killed a million of Gulbenkian's fellow Armenians. A patchwork of mandates and protectorates was developing into the new nation-states we know today as Iraq, Jordan and Saudi Arabia. When it came to defining the 'Ottoman Empire in Asia' as it had been in 1914, therefore, the oilmen meeting in Ostend in Belgium that day in 1928 were in something of a fix.

According to Ralph Hewins's 1957 biography, all was confusion until Calouste Gulbenkian intervened:

'When the conference looked like foundering, he again produced one of his brainwaves. He called for a large map of the Middle East, took a thick red pencil and slowly drew a red line round the central area. "That was the Ottoman Empire which I knew in 1914," he said. "And I ought to know. I was born in it, lived in it and served it. If anybody knows better, carry on…"'

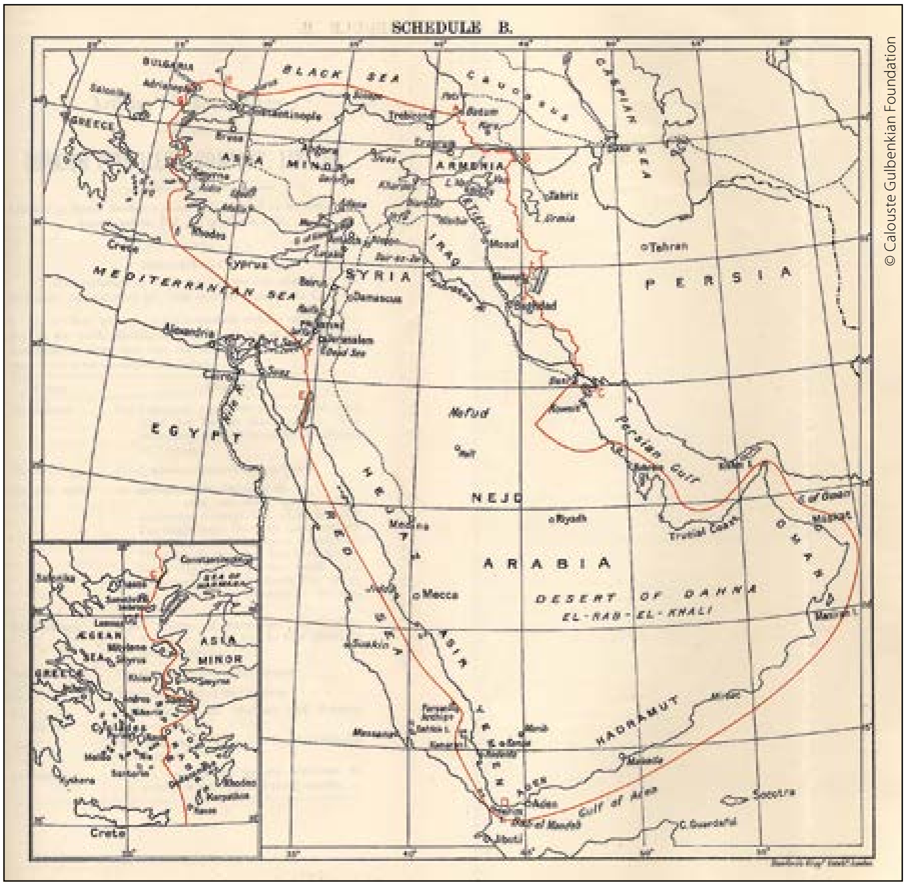
Gulbenkian's TPC partners inspected the map, and it was good. Hewins continues: 'Gulbenkian had built a framework for Middle East oil development which lasted until 1948: another fantastic one-man feat, unsurpassed in international big business.'

In his lifetime Gulbenkian studiously avoided the press, to the extent that today those who recognise the name often confuse the secretive Calouste with his publicity-seeking son Nubar. Londoners in particular fondly recall Nubar's chauffeur-driven taxicab. Many contemporaries and some historians have equated Gulbenkian's secretiveness with duplicity, rather than modesty. It is common to find Gulbenkian referred to as 'a shadowy Armenian manipulator', a 'detested' figure whose influence, we are told, derived 'from the liberal dispensation of bribes'.

A Great Buccaneer of Oil

Others have been kinder. In his Pulitzer-winning history of the oil industry Daniel Yergin places Gulbenkian on a par with Rockefeller, Getty and Mattei, as 'one of the great buccaneer-creators of oil'. But if Calouste Gulbenkian is known today, it is as the man who drew the red line. The 1928 Red Line Agreement embodied Gulbenkian's personal claim to 5% of TPC's oil, a claim which he later vested in a company, Partex, which continues to this day.

Yet on closer inspection the legend falls apart. Although the map was



The original Red Line Agreement map.

certainly left until the final phase of the negotiations that culminated at Ostend, Gulbenkian showed little interest in it. In fact, he was not even at Ostend on that fateful day. The others round this table were powerful empires and multinational companies, staffed by hundreds of employees, backed by armies of soldiers and sailors, as well as taxpayers and shareholders. They were hardly going to let Gulbenkian, an individual with no company or state behind him, scrawl red lines over their maps.

Gulbenkian had fought hard to get his quarrelsome British, French and American partners to agree to cohabitate in his 'house' (as he called TPC), and successfully defeated repeated attempts to defenestrate him. But he was not particularly bothered about the course of the red line itself. Nor was it his style to make pretty speeches. He worked as a back-room fixer, an intermediary between the worlds of business, diplomacy and high finance, a figure very different – and more interesting – than the Gulbenkian of legend. As Al Jazeera recently put it, Gulbenkian was 'the world's first oil fixer, broker and deal-maker'.

The spider at the centre of the emerging international oil and banking industry, Gulbenkian held empires and multinationals to ransom for more than fifty years. He would not have come to wield such power, however, had he not been an exceptionally skilled negotiator and financial architect. Oilmen from California to the Caucasus sought him out for his skill in raising capital on the stock markets of New York, London and Paris. He played an important, if previously unacknowledged, role helping both Royal Dutch-Shell and Total establish themselves as oil majors – notably as Svengali to Shell's Henri Deterding.

Gulbenkian's deals introduced American oil companies to the Middle East, and brought Royal Dutch-Shell to America – as well as to Mexico, Venezuela and Russia. The embryonic oil industry Gulbenkian found at the start of his career in 1900 was one dominated by a single oil producer and a single company: the United States and Standard Oil. At his death in 1955 the world oil industry was no longer an American monopoly, but an international cartel. Though the oil industry no longer resembles Antony Sampson's "Seven Sisters", the structure of multinational production, integration and partnerships remains the same. The web woven by Gulbenkian is with us still.

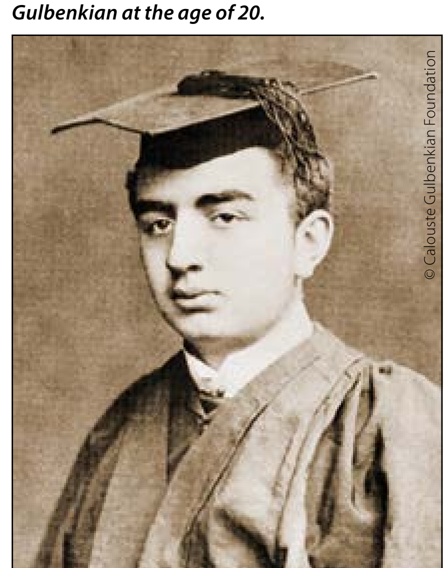
Crooks and Corners

In the 1920s the line which most exercised Gulbenkian was that separating Turkey from the new state of Iraq. Despite being 'Turkish', TPC's relations with the Turks were poor. The British-mandatory regime in Iraq was more likely to confirm the company's pre-war rights to Mosul's oil. For TPC, therefore, it was crucial that Mosul's oilfields ended up on the Iraqi side of any Turkish-Iraqi border. Unfortunately, the 1923 Lausanne Conference had failed to settle the border question, referring it to the League of Nations.

In June 1925 Gulbenkian proposed to get the League's maps drawn so that the Mosul oilfields were on the 'right' (Iraqi) side of the border. He happened to know the cartographer assigned to the survey party, a fellow Armenian named Zatik Khanzadian and, as he explained in a letter to his TPC partners:

'Khanzadian knows all the crooks [sic] and corners of the place, and as the other members [of the border commission] are not cartographers, it remains for him to make up the map according to certain instructions regarding topographical positions; I am

Gulbenkian at the age of 20.



Rembrandt's 'Pallas Athena' was sold to Gulbenkian by Stalin. It is now owned by the Gulbenkian Foundation.

The roof terrace of Gulbenkian's Paris palace.

given to understand that he can turn this as he likes, and so Khanzadian desires to get into personal and confidential touch with me, relying on my position and name to keep the whole thing [secret]. He is desirous of knowing which are the points that our company would like to remain on the side of Iraq.'

Why bother with conventions, protocols and treaties when international borders could be fixed your way, for just £2,000 (£100,000 in today's values)? Others might go to the starting line. Gulbenkian went straight to the finish.

Nowhere Man

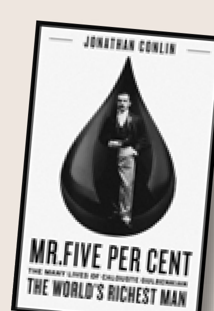
Born in Constantinople in 1869, Gulbenkian came of age in the Ottoman Empire, only to see this familiar world tear itself apart. He was not the only Ottoman Armenian to find refuge in the West, but he was the only one to make it big in this unfamiliar world. Far from holding him back, the destruction of his homeland and a loner personality became keys to his success: as a secretive man without loyalties to any one empire, state or company, Gulbenkian could present himself as the ultimate honest broker.

For 'westerners' he was a trusted source of intelligence on the Middle East. For 'easterners' he was someone to turn to in order to find out what the Great Powers and their mighty oil companies were up to. This was as true of Sultan Abdülhamid II in 1900 as it was of the Shah of Iran and Ibn Saud of Saudi Arabia four decades later. Gulbenkian was a diplomat in the service of both the Ottoman and Persian empires. Even Stalin sought Gulbenkian's advice, rewarding him with Rembrandts from the famous Hermitage Museum. No other business figure in the history of the oil industry wielded such influence, over such a scale, for so long.

Gulbenkian's story is timely. Whether we look back to the First World War and secret agreements like Sykes-Picot a century ago, or whether we consider the ongoing struggle for control of Iraq or current debates about capitalism, politics and identity, Gulbenkian is hiding in plain sight, challenging us to pin down the source of his fabulous wealth and influence. How did a man who knew nothing of geology and who never visited Iraq, Saudi Arabia or any of the Gulf states lay claim to 5% of Middle East oil production? Once he secured this stake, how did he manage to hold on to it, and so become the richest man on earth? How did a shy recluse bridge divides of East and West which seem insurmountable today?

Gulbenkian built a fabulous palace in Paris which he filled with treasures, not only paintings from the Hermitage, but Greek coins, Egyptian antiquities, Persian carpets, Iznik faience and Japanese netsuke. Today his collections are housed in Lisbon, next to the headquarters of the foundation which bears his name and which remains one of the wealthiest foundations in the world. Yet the great collector himself never slept in his palace. He lived in hotels. He held four different passports and intended his foundation to be equally international in ambition.

This freewheeling, cosmopolitan spirit reflected the pre-1914 world of unrestricted international exchange of capital, technology and people. Such globalisation subsequently went into retreat, until the 1980s. Now the tide is going out again: free enterprise and free movement are under assault from right and left. Trade disputes are trumped up. Sinister 'citizens of nowhere' are made up. And the cheers and the votes role in. Surely Gulbenkian, the ultimate 'citizen of nowhere', has something important to tell us at this moment in history. ■



If you want to learn more about Calouste Gulbenkian, Jonathan's new biography reveals the man behind the myths. Called *Mr. Five Per Cent: The Many Lives of Calouste Gulbenkian*, the book was published in January 2019 by Profile Books.

Field Trips in a Virtual World

Bringing world-class field locations into the classroom.

CAROL HOPKINS, PetroEDGE

'The best geologist is the one who has seen the most rocks' is a mantra often repeated to student geoscientists. Sadly, not everyone has the opportunity to undertake field trips, and are therefore not benefitting from the learning opportunities and skills development gained from conducting measurements and observations in the field environment.

The Rationale

PetroEDGE provides technical training to the oil and gas industry through taught courses, workshops and field trips, but recently there has been a significant decrease in the number of requests for field trips, primarily due to a reduction in training budgets. Since virtual reality (VR) modules focusing on facilities and equipment were already available, it was decided to extend this to VR geological field trips, presented in a style consistent with physical field trips.

The Hilbre Islands off the north-west coast of England were chosen as a pilot location. They are well visited by field groups, and of particular interest to oil and gas geoscientists as they comprise the Lower Triassic Ormskirk Sandstone Formation of the Sherwood Sandstone Group, which is producing oil and gas from fields 25 km away in the East Irish Sea Basin.

The VR field trips are intended to create an immersive and realistic environment designed to encourage exploration. Users are supplied with a virtual field guide, accessible at all times, and have access to various tools to make appropriate measurements. Guidance at the start of the field trip encourages the user to make the same observations they would in the field and to develop their fieldwork skills. Areas of particular interest have 'hotspots' providing more detail when selected, such as core or log images, photomicrographs, depositional models, illustrations of sedimentary structures, or annotation of the outcrop. The range of information that can be displayed in the hotspots is vast, and can include video footage, seismic imagery, animations and 3D models.

Carol Hopkins

A photograph of part of the outcrop at Little Hilbre.

A screen shot of the start of the field trip. The annotation (right of the picture) and voice-over encourage users to make observations from a distance before moving closer and exploring freely. The blue spheres are the hotspots that reveal further information or data when selected. The white line is a 1 metre measure for scale, augmented by a linear measuring tool. A video flypast is also available.

The Challenges

There are numerous VR field trips available, with different strengths and disadvantages. Many exploit the freedom, scale and accessibility that drone image capture can provide; this has certainly excited me as, having spent years assuring field trip attendees of the features that can be seen at the top of outcrops, we can finally fly up and see for ourselves.

Our initial photogrammetric models did not provide high enough resolution when converted into VR, primarily because drones are unable to fly too near to outcrops and acquire close-up imagery. Many VR field trips have a resolution equal to 3 cm per pixel or lower, but to illustrate meaningful sedimentological features higher resolution is needed, and our aim was to resolve to coarse-grain size. Many months of experimentation with a combination of different methods of image capture and processing techniques achieved the required results, but also highlighted technical problems that would be encountered at future localities.

For example, the presence of deep shadows confuses the processing software as it relies on an algorithm that identifies similarities in adjacent areas. Occasional shadowed areas can be processed manually, but that process is time consuming and is best avoided whenever possible. Virtual field trips to carbonate outcrops in the Middle East are planned, but filming when the sun is high in bright conditions will produce numerous areas of deep shade contrasting with brightly lit areas, creating extensive processing problems.

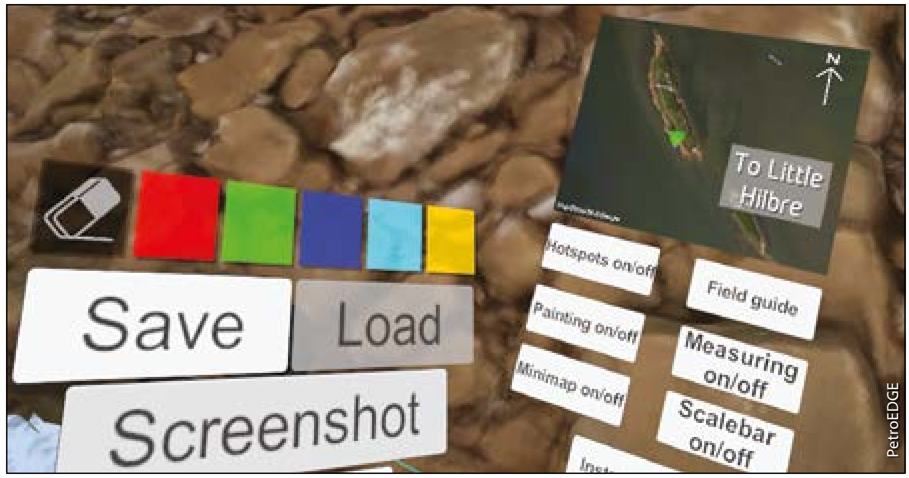
On a conventional field trip, it is possible to move behind foliage and boulders to access the outcrop, but these can obstruct drone image capture, so can limit the selection of locations. Also, some of the filming requires access to the outcrops on foot and cannot rely on flying drones into less accessible areas if high-resolution imagery is required.

Lengthy filming and processing of large outcrops can be overcome by using a combination of VR with embedded fly-past and 360-degree videos. As the user is provided with a geographical map, different sections of more extensive outcrops can be imaged and the user is transported to each area when selected on the map.

Integration with Other Training Methods

VR field trips cannot replicate all the skills transfer and learning opportunities provided by physical field trips, but we all need to be pragmatic in a changed financial landscape. Conventional field trips are costly in terms of travel, accommodation, downtime and logistics, so it is better to be able to experience many of the benefits of a field trip, albeit virtually, than to never experience them at all. The skills required to make appropriate observations and conclusions can still be taught, and serve as a reminder that the various data we are using elsewhere relates to real rocks and that interpretations should comply with our understanding of geological processes.

Using VR field trips to illustrate various aspects of training courses can be more incidental, allowing trainees to experience field trips as part of classroom courses or workshops, where travel to each locality is impractical or costly. VR modules can be tailored to include information pertinent to the course, or be integrated with other learning resources. However, it is vital that the VR field trips are valuable in their own right, and not just a new technology to play with. Unnecessary graphics and sound effects have been eliminated to help the user forget they are in VR and focus on the geology.



A screen shot of the paint palette, interactive map and tool selection palette, all attached to the handsets. The user's location and field of view are displayed on the map, along with a tab to move to another locality (Little Hilbre).

Flexibility

The information in the hotspots and field guides can easily be tailored to different audiences, including non-geoscientists, engineers, administrative staff and geophysicists. Many of these groups might not normally attend conventional field trips, but do attend classroom courses that can be enriched by examining real rocks.

The field trip leader can be in the classroom with attendees, or can join them remotely, guiding the trainees in the same way as on a physical field trip. However, the VR field trips are designed as stand-alone modules that can also be accessed by an individual without any need for a leader or instructor. Undertaking a particular module can be used as a refresher for staff, to acquaint themselves with a new environment of deposition, or as part of their personal development programme. VR field trips may also be used to equip students with field skills or to familiarise them with the locations prior to a real field trip. This serves to build their confidence and maximise their time in the field. They can be reviewed many times and help to refresh understanding, or provide easy comparison between different localities.

There is also interest from various organisations anxious to preserve educational outcrops that are threatened by weathering, quarrying or development. Putting these outcrops into VR ensures access for future students and field trippers, and provides consistency for any teaching modules that utilise these localities.

Inclusivity

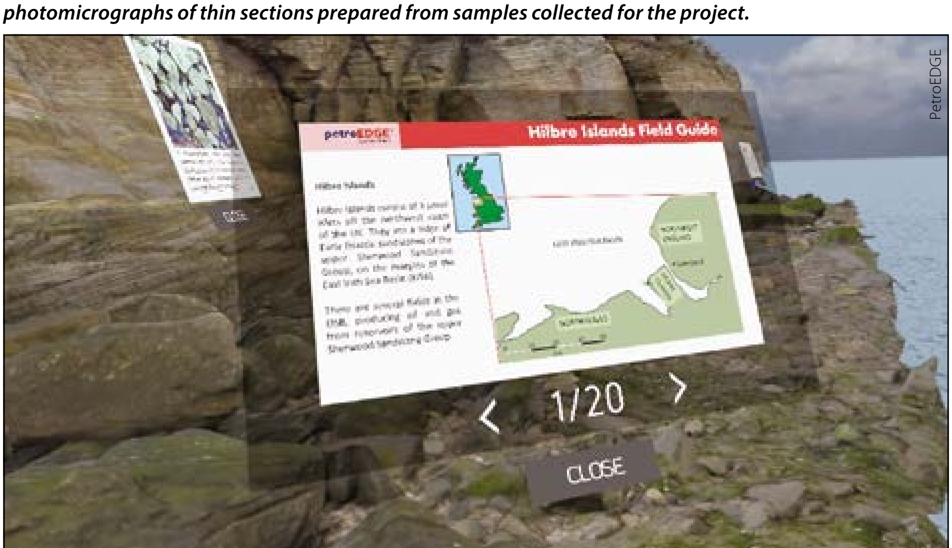
When planning a physical field trip, it can be difficult to include access to a number of good outcrops that tell a coherent story, while restricting the amount of travelling between localities. With VR field trips, a wide range of geographical locations can be combined to provide a comprehensive understanding, or for comparison of different localities.

The cost of creating VR field trips is mitigated by the unlimited number of users able to access each trip, the absence of travel and logistical costs, and the variety of roles the VR field trips can fulfil.

It must be stressed that VR field trips are not intended to replace physical field trips, but do provide additional features, such as aerial and panoramic views, and the ability to overlay data, interpretation and models onto the outcrop. They also provide inclusive access to less mobile users, or those unable to travel. Inclusivity also extends to non-geoscientists, junior staff and others who may not normally get an opportunity to visit the field. Remote localities, outcrops with restricted accessibility or ones that present particular health and safety risks can still be experienced, providing the filming team can overcome these issues safely.

However, virtual reality field trips should not just be considered a cost-effective, risk-free alternative to real field work. They offer unique opportunities to incorporate activities and features unavailable in the field, and deliver a more integrated and flexible learning resource. ■

A screenshot of the opened field guide and a hotspot. The image in the hotspot is one of several photomicrographs of thin sections prepared from samples collected for the project.



The Pre-Drill Prediction Toolbox

How sharp are the technologies in the hydrocarbon pre-drill prediction toolbox?

KIM GUNN MAVER
KGM Geoconsulting

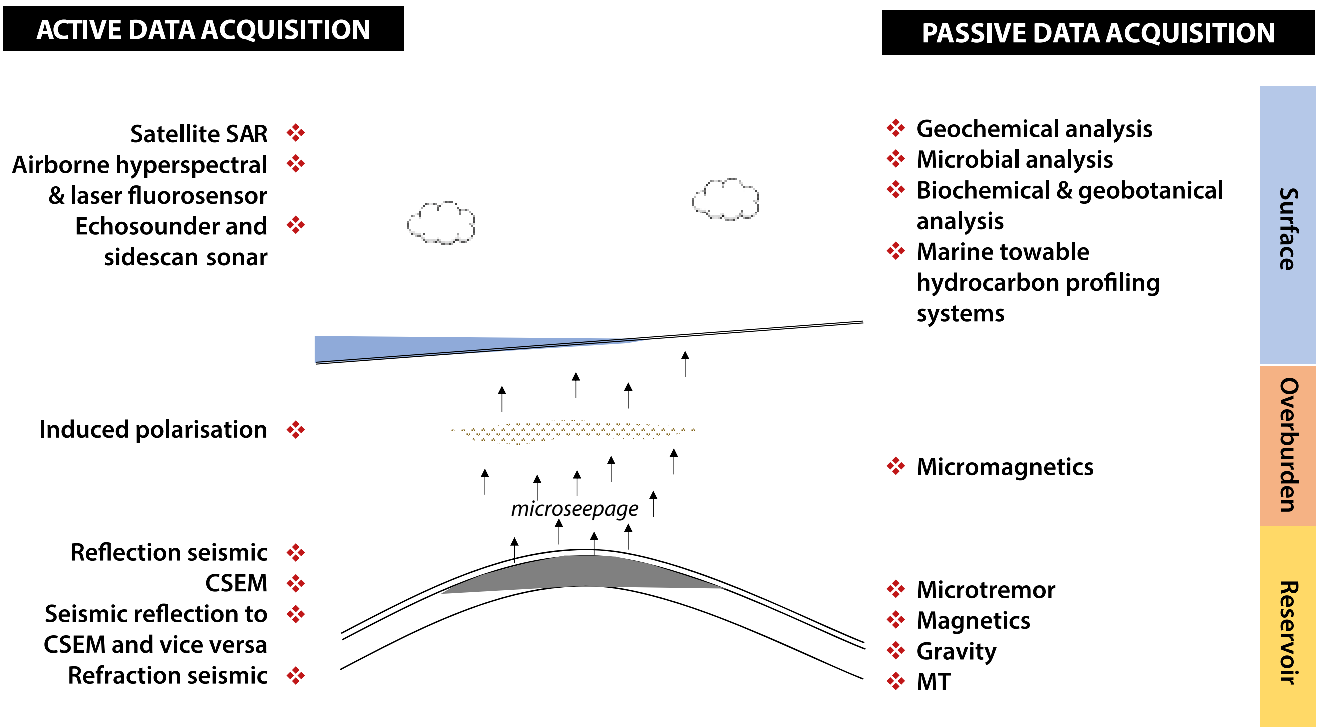


Figure 1: Technology overview of data acquisition across the reservoir, in the overburden or at the surface (ground, seabed, water column, or air).

A number of hydrocarbon exploration processes have been developed to ensure consistency and avoid personal biases when attempting to correctly rank prospects and make appropriate drill or drop decisions. One such process is the calculation of Geological Chance of Success (GCOS), which is a systematic approach to managing prospect risking by multiplying fractions representing the likelihood of each of the parameters: structure, reservoir, retention, and charge.

Each GCOS parameter is well described, and the explorationist's input and assessment is based on past drilling experience, analogue field studies, well cores and outcrops. In addition, acquired data from different technologies can be used to describe an undrilled prospect in order to assess reservoir properties and hydrocarbon presence. This is in general a reliable process. Westwood Energy Group has shown that for 1,163 wells from 2012 to 2017, the pre-drill technical success rate (assumed to correspond to GCOS) is, as expected, 22 percentage points higher than the commercial success rate, with the actual proven hydrocarbon volumes only marginally larger than the predicted volumes (Kunjan, 2018). Richmond Energy Partners have shown that the pre-drill prognosed commercial chance of success versus the actual commercial success rates of a couple of hundred wells drilled worldwide by 40 oil companies between 2009 and 2013 were within the limits of expectations (Kunjan, 2016).

However, no overview exists of the technologies available when gathering information to assign fractions to each of the four GCOS parameters. This article provides such an overview, offering a track record for the majority of the technologies as statistical probabilities and with a description of the constraints and limitations in utilising the available data and technologies.

Technology Overview

The technologies shown in Figure 1 can all provide data input to the GCOS calculation, but there are significant differences between them in acquisition approach, validity of the data and their possible impact on the determination of each of the four GCOS parameters.

Data can be acquired *passively* by measuring signals emitted by the earth or *actively* by emitting signals and recording the earth's corresponding responses (Figure 1). It can relate directly to the reservoir and hydrocarbons through an in-situ measurement from the surface, resulting in very valuable information, but this requires various degrees of processing and interpretation to convert the results to an actual prediction of reservoir properties and presence of hydrocarbons.

The other technologies measure the result of microseepage, and in some cases macroseepage, of hydrocarbons from the reservoir to the surface. Through measuring either the mineral alterations due to hydrocarbons in the reservoir overburden or traces of hydrocarbons at the surface or various surface changes due to the presence of hydrocarbons, the result of the microseepage can be mapped (Table 1). It is well documented that mature source rocks and most oil and gas accumulations leak hydrocarbons, that this microseepage is widespread in all hydrocarbon basins, predominantly vertical, and that it is dynamic. As the seepage expression can be some distance from the hydrocarbon reservoir, the resulting data needs to be carefully managed when used in the GCOS calculation.

As not necessarily all hydrocarbon reservoirs exhibit microseepage (although most do), there will be instances where a lack of overburden or surface expression of hydrocarbons is not necessarily proof that there is no deeper hydrocarbon accumulation. Hence, a false negative hydrocarbon prediction is a possible risk.

Two technologies provide quantifiable data, including reservoir properties, saturation, gross volume etc. (Table 2: Group A), whereas the remaining technologies mainly provide qualifiable information about the reservoir properties and presence of hydrocarbons (Table 2: Group B and C).

Publicly available statistics based on utilising technologies for prediction of reservoir properties and hydrocarbon presence are limited, considering the annual investment in drilling wells to explore for hydrocarbons. However, for two-thirds of the technologies some true positive statistical probabilities from historical track records are available (Maver, 2019).

Location	Technology	Average true +ve statistical probabilities
Reservoir	Reflection seismic DHI	75%
	Reflection seismic low frequencies	69%
	CSEM	77%
	MT (passive EM)	50%
	Microtremor (seismic background wave signals)	88%
	Reflection seismic to CSEM and vice versa	Not available
	Magnetics	Not available
	Gravity	Not available
	Refraction seismic	Not available
Overburden	Induced polarisation (pyrite mineral)	83%
	Micromagnetics (magnetic greigate mineral)	75%
Surface (water column, air, ground, seabed)	Geochemical analysis	93%
	Microbial analysis	84%
	Biochemical & geobotanical analysis	82%
	Airborne hyperspectral & laser fluorosensor	Not available
	Marine towable hydrocarbon profiling systems	Not available
	Single & multi-beam echosounder & sidescan sonar	Not available
	Satellite SAR	77%

Table 1: Technology overview with a description of the methods and statistical probabilities.

Direct reservoir measurements using active acquisition provide quantifiable information about the structure size, reservoir properties, presence of and hydrocarbon volume in place (Table 2: Group A). This is the reason for Direct Hydrocarbon Indicators (DHIs) seen on reflection seismic data being the technology of choice by oil companies. It also explains the current interest in Controlled Source ElectroMagnetic (CSEM) data, as that is the only other technology providing quantifiable data. CSEM is also better at predicting retention of hydrocarbons than reflection seismic DHIs (Hesthammer et al., 2010). CSEM data is also an important technology, along with Magnetic Telluric (MT) data, in cases where reflection seismic struggles or fails to image, for example in sub-salt and sub-basalt regions.

Through a direct reservoir or hydrocarbon measurement, technologies in Group B (Table 2) can provide qualifiable information about hydrocarbon charge, and potentially some information in relation to structure, but only as approximate geographical outlines. Geochemical analysis relating directly to reservoir hydrocarbons is a very powerful indicator of a working hydrocarbon system, even though it is measured at a

Table 2: Review of the data measurement type for each technology.

Data origin/value	Quantifiable data	Qualifiable data
Direct reservoir/ hydrocarbon measurement	GROUP A Reflection seismic DHI CSEM	GROUP B Geochemical analysis Microtremor Reflection seismic low frequencies MT Magnetics Gravity Refraction seismic Seismic reflection to CSEM and vice versa
Indirect reservoir/ hydrocarbon measurement	GROUP D N/A	GROUP C Micromagnetics Induced polarisation Satellite SAR Microbial analysis Biochemical & geobotanical analysis Single & multi-beam echosounder & sidescan sonar Airborne hyperspectral & laser fluorosensor Marine towable hydrocarbon profiling systems

Calculating Geological Chance of Success

The acquired data can be used as support to assign fractions to the four GCOS parameters, remembering that GCOS = Structure x Reservoir x Retention x Charge.

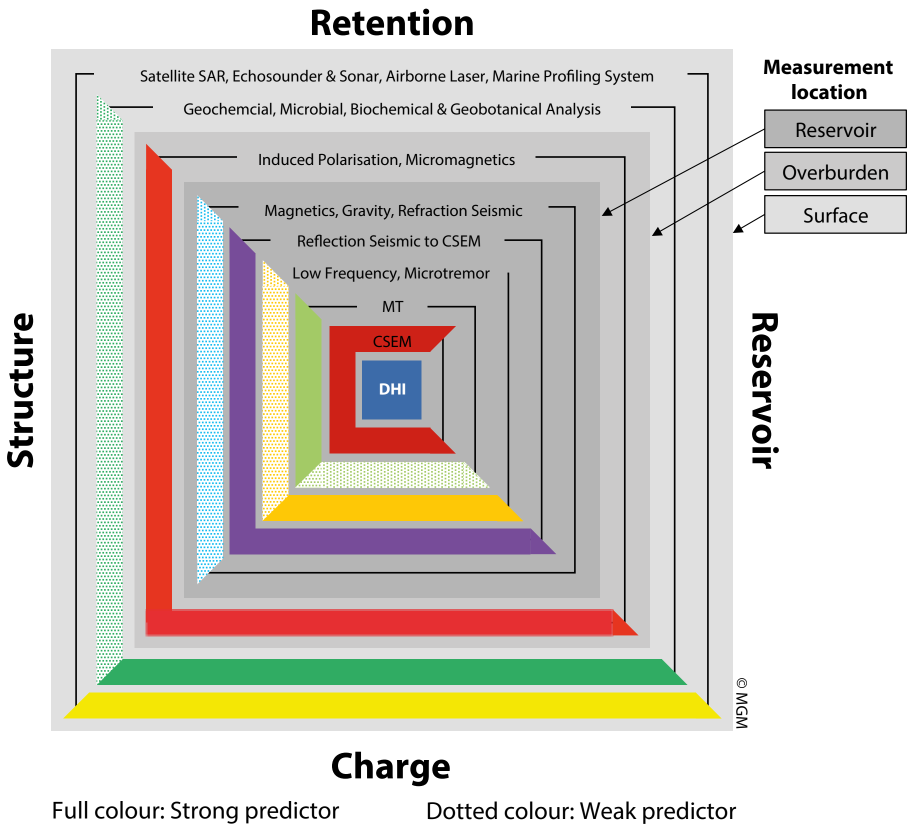


Figure 2: Technologies (full names in Table 1) that can provide input to the assessment of structure, reservoir, retention and charge. Full colour indicates a significant data impact, whereas a hatched colour indicates a weaker and more general data input. This is based on a subjective subdivision.

distance from the reservoir.

The technologies in the final group (C) in Table 2 do not provide data directly but instead provide indirect information qualifying the presence of charge, and in some cases the approximate geographical outline of structure. For example, micromagnetics and induced polarisation are technologies related to vertical hydrocarbon seepage from the reservoir forming either greigate or pyrite minerals in the shallow overburden. The magnetic mineral greigate only exists in a live seepage system and hence is a powerful charge indicator, whereas pyrite may relate to either a live or relic seepage system and can therefore result in a false positive hydrocarbon prediction. Microbial analysis, biochemical and geobotanical analysis are cost-effective technologies to indirectly detect the presence of seeping hydrocarbons by surface sampling and with satellite Synthetic Aperture Radar (SAR), in order to provide qualified charge input. The remaining technologies in Group C have not been widely applied in the industry; there are only limited case studies, and no documented track record is available.

In summary detailed quantifiable structure and reservoir information are only provided by reflection seismic DHIs and partly by CSEM, while some other technologies can provide additional information about structure. CSEM is the technology providing the most significant input relating to retention. The parameter that is best determined is charge but with variable data validity. Charge information is very valuable, as the majority of wells are dry, but the prediction of charge may also be a result of breached trap integrity, increasing the retention risk (Schumacher, 2010).

Table 1 provides an overview of the technologies where statistical probabilities derived from a historical track record are available and can provide input to the GCOS calculation. All the technologies have high average statistical probabilities, with some range of outcomes for each technology (Maver, 2019). These statistical probabilities can only be used as support in assigning fractions in the GCOS calculation, as past performance is not directly related to future predictions and the statistical probabilities are not necessarily geologically representative (Peel and Brooks, 2016). In general, it is the successfully datasets and case studies that are published (Abrams, 1996). Finally the data population size for some of the technologies is not statistically significant.

Use New Information Carefully

By integrating data from technologies and doing technical work, value and certainty will not be added to the prospect portfolio by improving GCOS. New information will add value to the exploration cycle, but not by an expectation of improving the prospect risk. New information may result in an increase or a decrease of GCOS, but the expected result (the average of all possible outcomes) is zero change. Furthermore as GCOS is typically below 0.5 it is likely that new information will actually downgrade more prospects than are upgraded (Peel and Brooks, 2015). The main added value is from identifying prospects not to drill, thereby saving the cost of likely dry holes, and by choosing which wells to drill first, optimising the revenue stream from a successful well campaign.

When including new data in the GCOS calculation, therefore, it is important to understand whether the new data is complementary to, independent of and does not replace the original information, or whether the new information updates and replaces an older piece of information (Peel and Brooks, 2015). Furthermore, to update with new information a simple Bayesian risking formulation can be utilised to help understand its impact on the GCOS calculation.

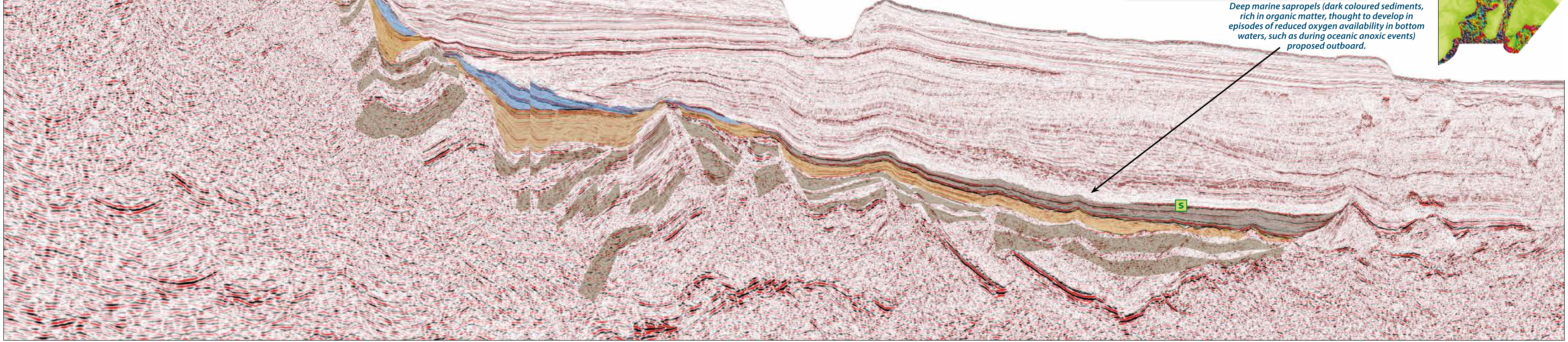
A range of technologies are available to provide input data to the four parameters in the GCOS , but the decision about which technologies to utilise will depend on a combination of cost-benefit analysis, to what extent there is microseepage from the reservoir, and the specific information required to calculate a more reliable GCOS.

References available online. ■

Offshore Somalia: The Chase Is On!

Offshore Somalia remains one of the last truly frontier passive margins in the world, with only two exploration wells offshore along the 1,000 km-long margin. In frontier basins such as this, the first step is to identify potential source rocks by integrating multiple datasets such as gravity and magnetic data, all available and relevant well information, satellite imagery and regional knowledge, coupled with seismic interpretation.

In 2015 Spectrum acquired approximately 20,000 km of long-offset 2D seismic data offshore Somalia (Figure 1), which has been used to de-risk source rock presence, distribution and maturity. There are strong indications of widespread distribution of good quality source rocks that modelling has shown to be in the oil window, potentially charging significant traps, making this a very attractive margin offering outstanding exploration opportunities in the 1st Licensing Round, launched in February 2019.



190 km-long Spectrum PSDM seismic section with brown tones highlighting the main pre-rift, syn-rift and early post-rfit inferred source rock intervals.

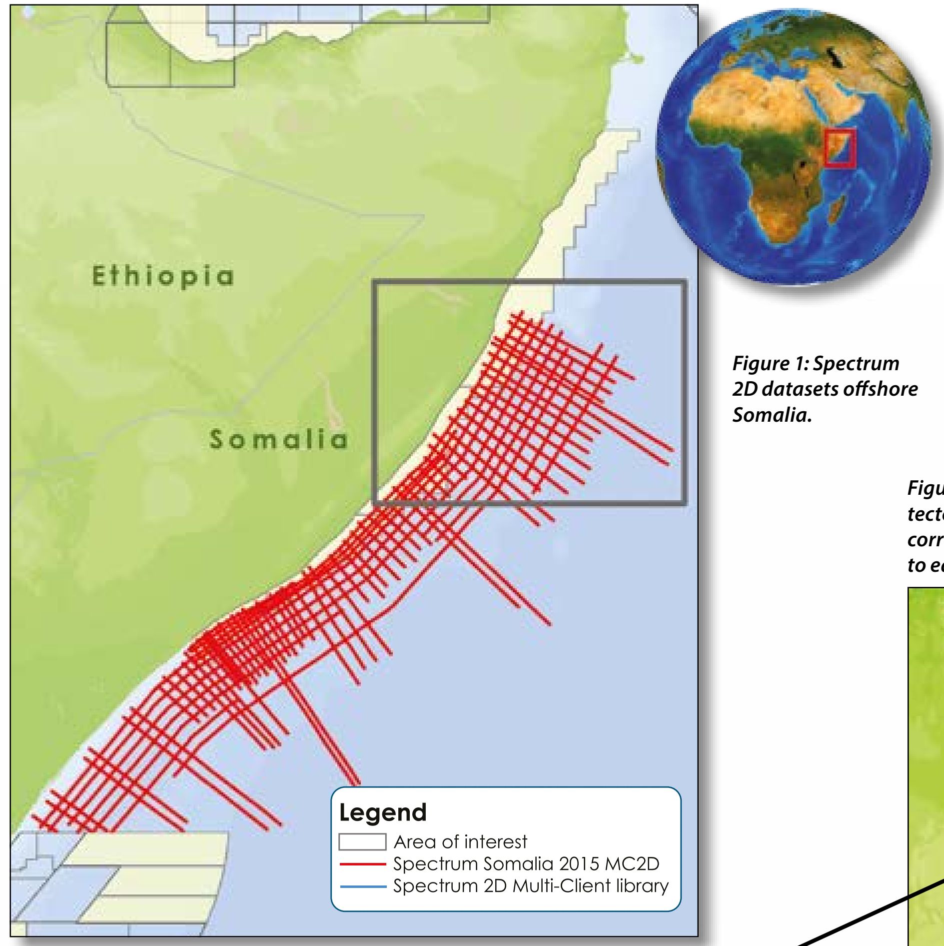


Figure 1: Spectrum 2D datasets offshore Somalia.

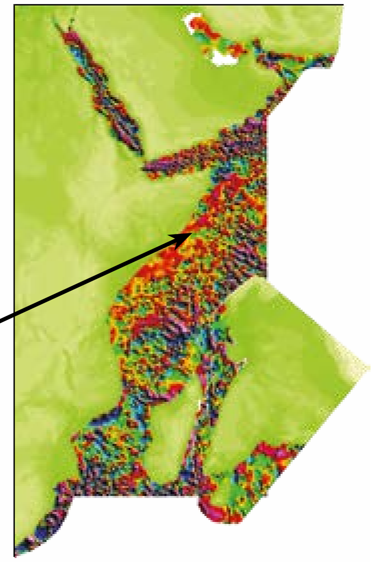


Figure 2: A Late Jurassic plate tectonic reconstruction, corresponding to the late syn-rift to early post-rift stages.

The Illusive Oil-Prone Gem

The opening of the chase for oil in Somalia's offshore.

KARYNA RODRIGUEZ, NEIL HODGSON and DAVID EASTWELL, Spectrum Geo; ABDULKADIR ABIIKAR HUSSEIN, MOPMR, Federal Government of Somalia.

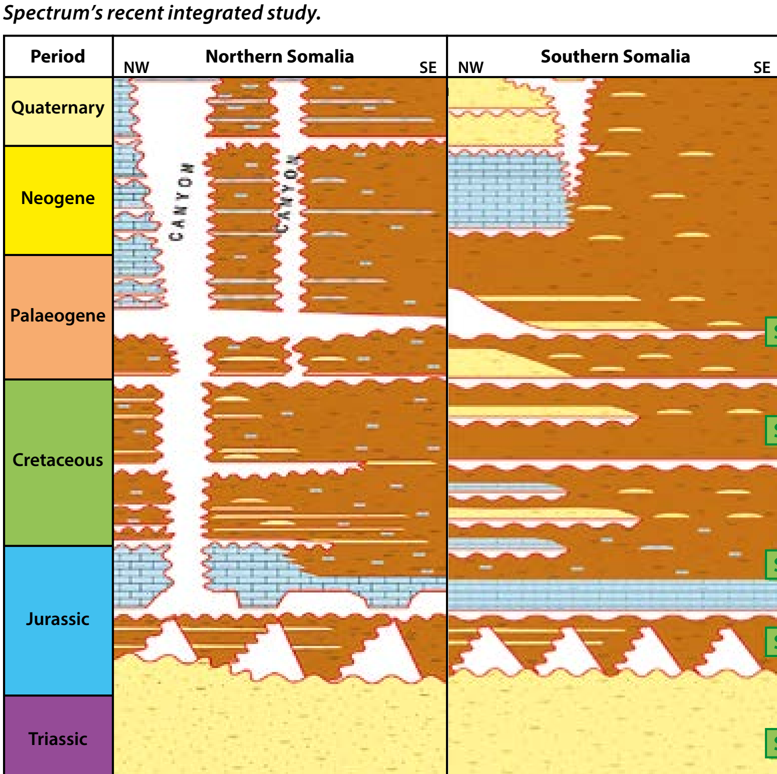
Offshore Somalia remains one of the last truly frontier passive margins in the world. Only two exploration wells have been drilled offshore along the 1,000 km-long margin, and both are in the shallow nearshore area in less than 100m water depth. In frontier basins such as this one, the first essential step is to de-risk the presence and effectiveness (total organic carbon percentage (TOC%) and maturity) of a viable source. Identifying potential source rocks with very limited well calibration is a challenging exercise which requires integration from multiple datasets to build a robust geological model that fits with observations from seismic data. Gravity and magnetic data are used as support in the reconstruction of tectonic plate positions, conjugate margin and onshore well information are integrated, regional geological understanding and records of Ocean Anoxic Events (OAEs) are taken into account, and this is complemented with seismic observations, source rock characterisation, sequence stratigraphy models and naturally occurring slick clusters identified on satellite imagery.

Source Rock Evaluation

A regional plate tectonic and palaeo-geographic reconstruction of the margin was undertaken in order to develop an understanding of depositional and stratigraphic basin evolution. This involved identifying time periods and environments where source rock may have been deposited and preserved. The picking of 'candidate' source rocks on seismic data, driven by the basin evolution model, was guided in part by the observation that high TOC% oil-prone shale sources typically exhibit a low-frequency, low internal reflectivity character.

Interpretation was then further constrained by criteria described by Løseth et al. (2011), which can be used to 'identify, characterise and map spatial distributions and variations of thick source rocks'. These mainly included a significant reduction and increase in acoustic impedance (AI) at the top and base of the candidate source rock unit respectively and a reduction in amplitude with increasing reflection angle at the top of the unit. Finally, this interpretation was integrated with observations from other non-seismic direct hydrocarbon indicators, including slick clusters from satellite imagery and pockmarks from multi-beam bathymetry. All of the evidence, data and interpretation were then synthesised to provide a concise evidence base for the presence, character and potential maturity of individual 'candidate' sources within the offshore Somali basins.

Figure 3: Stratigraphic chart for northern and southern Somalia developed from Spectrum's recent integrated study.



Seeking Potential Source Rocks

Initial Karoo rifting of Gondwana began in the Late Carboniferous/ Early Permian. Deposition of the continentally-derived Karoo Supergroup, world-renowned for its source and reservoir properties, occurred across Southern and East Africa at this time. Breakup of Somalia and the Madagascar-Seychelles-India (MSI) block occurred in the Early Jurassic. This coincided with an initial marine transgression which saw lacustrine to brackish-marine restricted basin sediments deposited in rifted half grabens formed by fault block rotation. In the Middle to Late Jurassic, a restricted seaway formed between the Indian and Somali plates. Restricted marine marls were deposited in the basin at this time (Figure 2), while shallow water platform carbonate growth occurred on the continental shelf. From the Early Cretaceous, the northward movement of the Indian plate past the Somali plate led to the formation of large-scale transpressional and transtensional flower structures in the deep offshore, creating potentially very large trapping structures, as well as partial barriers to oceanic circulation, which may have facilitated the deposition of an organic-rich Late Cretaceous source rock. In the Late Cretaceous and Paleogene, slope failure events occurred in the southern offshore. All these observations led to the development of a stratigraphic chart for offshore northern and southern Somalia (Figure 3).

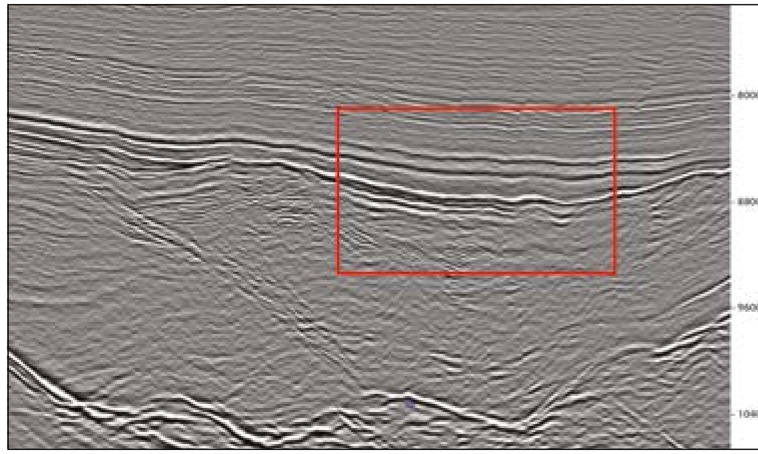


Figure 4: Early post-rift Late Jurassic candidate source rock recognised, based on basin evolution history and expected seismic character.

Based on the detailed regional geological evaluation of the 40,000 km of 2D seismic data acquired between 2014 and 2015, several 'candidate' source rocks were identified by predicted depositional environment and seismic character. In the early post-rift, Upper Jurassic marine shales are a key source in the Ethiopian Ogaden Basin and in northern Somalia (Uarandab Formation). Organic-rich shales of similar age are present in the Rovuma Basin and have moderate TOCs in the Seychelles. In the deep basin, an acoustically quiet homogeneous unit was recognised at this level and was interpreted as a deep marine organic-rich marl source (Figure 4 and deep marine sapropels proposed outboard in the foldout Seismic Line). It is suggested that this candidate source rock is a regionally extensive restricted marine shale, mapped within the Obbia Basin of northern Somalia.

No well control or oil discovery exists to date to confirm the presence or test the maturity of the interpreted source horizons. In order to provide additional evidence for the presence of a hydrocarbon-producing source the low-frequency character present at the inferred source interval on the seismic section was further supported by a significant decrease in acoustic impedance at the top of the infererred source rock unit and a dimming of amplitude with increasing angle (AVO Type IV) (Figure 5). Additionally a sea-surface slick study was employed which identified more than 80 individual non-anthropogenic sea surface slicks along the length of offshore Somalia.

Basin modelling considering four potential source rock intervals was carried out in collaboration with Leeds University. Peak maturation maps for source rocks at pre-rift (Karoo), syn-rift, Late Jurassic and Early Cretaceous levels indicate that where the sediment column is thickest in the south, shallower Early Cretaceous sources are in the oil window. Where the pre-rift, syn-rift and early post-rift is not so deeply buried in the north, these source intervals sit in the present-day oil window.

Exciting Upcoming Licensing Round

Defining source rocks in untested frontier margins can present a challenge; however, by integrating multiple datasets and geological models developed from seismic analysis, gravity and magnetic data, offset well information, satellite slick mapping and sequence stratigraphy models, we can propose various scenarios in which organic-rich sediments may have been deposited. This method combined with basin modelling has highlighted particular areas of interest for lead and prospect identification at multiple stratigraphic levels offshore Somalia.

In modern seismic data offshore Somalia we have now found the illusive oil-prone gem in East Africa's otherwise prolific petroleum systems. Source rock presence, distribution and maturity are largely de-risked for oil plays. The attraction of large oil reserves will draw the attention of the oil industry to Somalia in 2019, as this new province has now opened up its offshore waters for exploration in its exciting and hugely prospective 2019 licensing round. ■

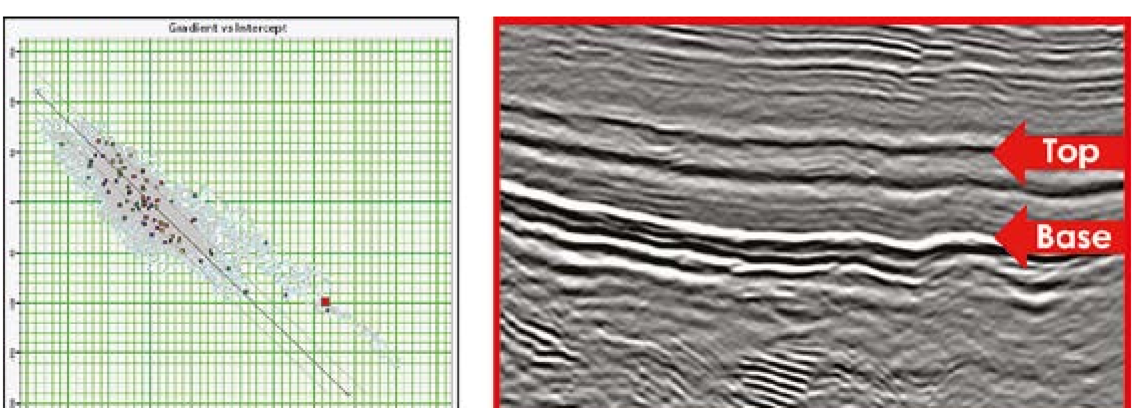


Figure 5: Source rock characterisation results for the early post-rift Upper Jurassic candidate source rock. Left: intercept gradient plot. Sequence plots as Type 4 AVO anomaly. Right: acoustically soft top, hard base, low frequency - source interval.

Finite Difference Modelling: Part IV

Let's Look at Examples

"If you can't solve something with finite difference, you can solve it with infinite indifference."
Unknown

Continuing the discussion that was started in GEO ExPro Vol. 15, No. 2. The finite difference method applied to the acoustic wave equation gives beautiful wave solutions. Read on!

LASSE AMUNDSEN, ØRJAN PEDERSEN and MARTIN LANDRØ

You might remember studying optics in school. You learnt that the concepts of reflection and refraction of light can be based on a theory known as geometric optics or 'ray theory', where light waves are represented with simple geometric lines or rays. Those who have read the book *Introduction to Exploration Geophysics with Recent Advances* (Bivrost Geo, Landrø and Amundsen, 2018) know that ray theory also applies to acoustic waves. You learnt that Snell's Law, or the Law of Refraction, was first described by the Arabian optics engineer Ibn Sahl (ca. 940–1000) and learnt the basic, quite self-explanatory laws of ray theory:

French mathematician Pierre de Fermat (1601–1665) is often called the founder of the modern theory of numbers. In optics, Fermat's principle, or the principle of least time, enunciated in 1658, is the principle that the path taken between two points by a ray of light is the path that can be traversed in the least time. Fermat's principle applies to sound and acoustic waves, too. Historically, it has served as a guiding principle in the formulation of physical laws with the use of variational calculus. Variational principles are central to modern physics and mathematics.

1. In a homogeneous, isotropic medium, rays are straight lines; rays are normal to the wave front and thus point in the direction of wave propagation.
2. At the boundary between two media of different velocities, the angle of reflection is equal to the angle of incidence; further, Snell's Law gives the relationship between the angles of incidence and refraction (see Figure 1).
3. Ray theory is a high-frequency approximation, implying that the medium must vary smoothly compared to the wavelength. Sharp discontinuities of the medium can be handled, but the maths then gets complicated.

Geophysicists use a wide range of techniques for seismic modelling, of which geometric ray modelling and FD modelling are 'end members'. Ray theory is based on the fact that wave energy in the form of rays travels along minimum time paths in the model. Ray modelling is intuitive, may neglect important wave propagation effects, but is computationally fast, and gives very accurate traveltimes and accurate amplitudes for geometric arrivals if the model is sufficiently smooth. It is an irreplaceable modelling tool in seismic interpretation. Diffractions and multiple reflections can be added, increasing computing times.

FD methods, on the other hand, are more physically complete – they solve the full differential equations. They are easy to implement but are limited by computer capabilities and are potentially *too* informative, as they include all wave phenomena, such as multiples, diffractions, and surface waves, in the most complex media. Here, we show examples of wave propagation by solving the acoustic, isotropic wave equation by the FD method for simple models. (See *Introduction to Petroleum Seismology*, Ikelle and Amundsen, 2018, for more examples.)

Waves in Concentric Spheres

If someone drops a stone into a pond, a short disturbance occurs at the point of impact. The deformed area returns to equilibrium, but the disturbance spreads gradually as concentric circles from the centre of impact. Since the energy is constant as radius increases, the

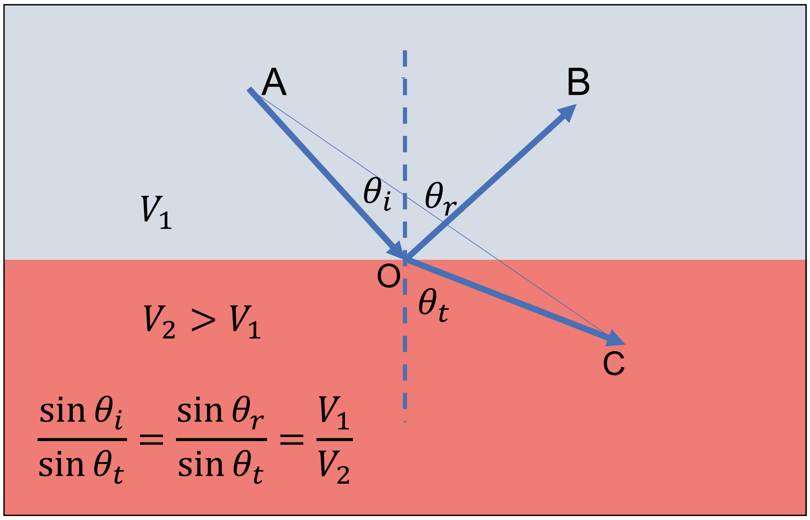


***Figure 1:** Fermat's principle leads to Snell's Law; when the sines of the angles in the different media are in the same proportion as the propagation velocities, the time to get from A to B (via the interface), and from A to C, is minimised. A ray of sound going from A to C by any other path than AO+OC will take longer.*

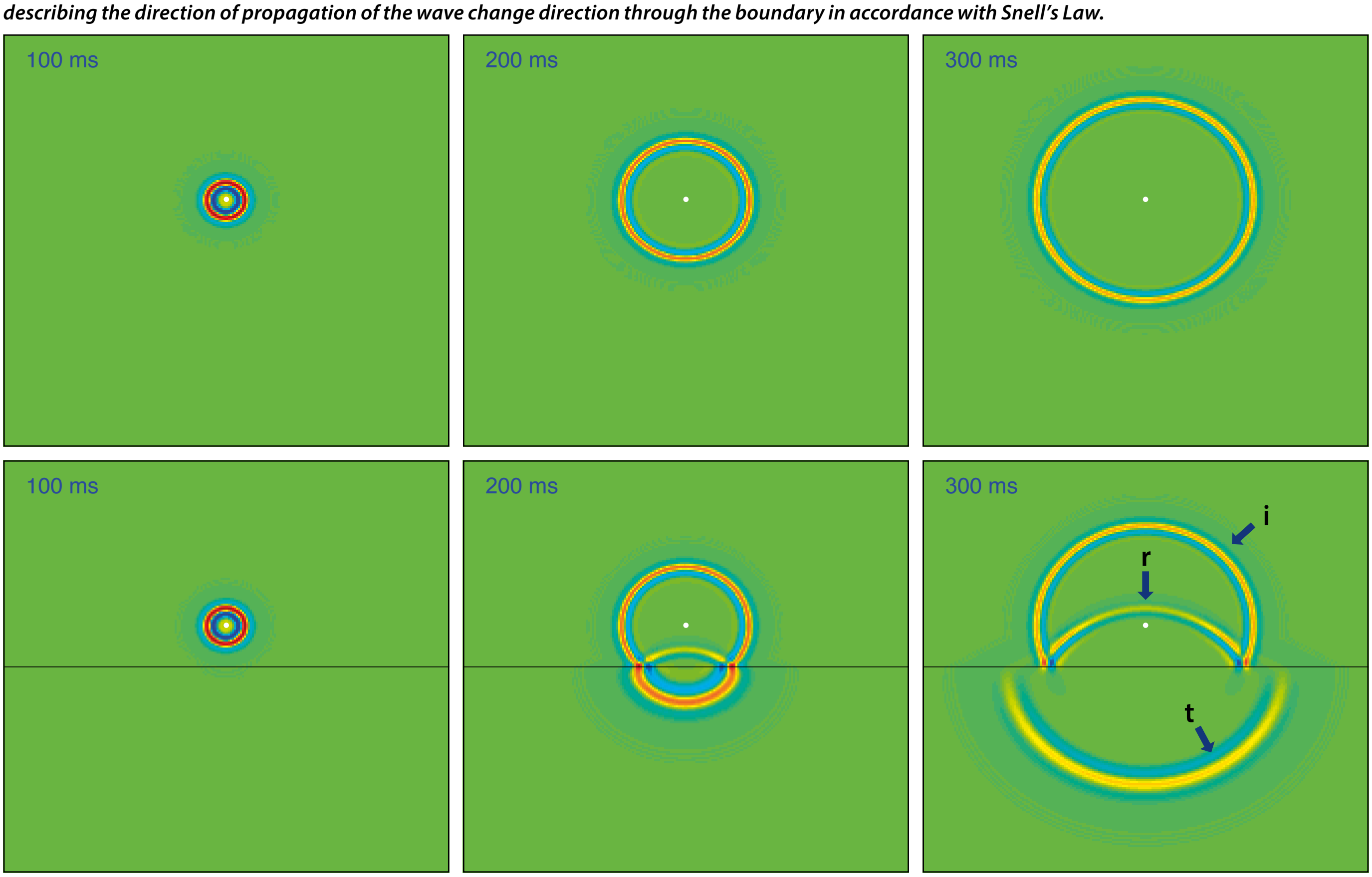
amplitude gets weaker and weaker, until we can no longer see it. This phenomenon is an example of wave propagation.

When we solve the 3D acoustic wave equation by the FD method, we obtain the same interpretation. The exact acoustic velocity at which the wave moves from one point to another depends on the physical properties of the medium. For constant velocity, the wave originating at the source expands in a series of spherical wavefronts centred on that source; a consequence of Fermat's principle: minimum traveltime implies minimum travelled distance in any direction. In Figure 2 (upper row) we show a 2D slice through the spherical wavefront where spheres become circles. One of the most important properties of the spherically expanding wave is a decrease in intensity as the wave propagates away from the source. The pressure amplitude decays as 1/distance away from the source. This is called spherical spreading loss.

Reflected and Refracted Waves

We can observe reflection and refraction in daily life. When you look in a mirror, you are looking at light that has been reflected by a surface – the mirror. A good example of reflection

***Figure 2:** Snapshots of a wavefield spreading out in time and space in a homogeneous, isotropic medium (upper row), and medium composed of two homogeneous acoustic half-spaces (lower row) with velocities $V_1 = V_2/2 = 2{,}000$ m/s. The model is 2 km x 2 km. The source location is denoted by the white dot and the interface by the thin black line. In the homogeneous medium, the wave propagates away from its source at the same speed in every direction. The wavefront is the leading edge of the disturbance. Rays (not shown) are normal to the wavefront, so at any given time, the wavefront is spherical in 3D (circular in 2D) with its centre at the source. In the two-layer medium, the wave that propagates solely within the upper layer is called the incident wave (i). After 200 ms, it has interacted with the interface. Part of the wave's energy is reflected (r) back into the upper layer and part of it is transmitted (t) into the lower medium but in a different direction (i.e., it is refracted). Notice that the wavefront defining the refracted wave is still circular, but its radius is no longer centred on the source. We describe this as a change in the curvature of the wavefront, which implies that the raypaths describing the direction of propagation of the wave change direction through the boundary in accordance with Snell's Law.*



of sound is an echo. Refraction is a slightly less intuitive concept, but it has an effect on everyday life, too. Children quickly notice that a straw in a glass of water looks (from certain angles) bent.

Consider a medium consisting of two joined acoustic halfspaces of different velocities $V_1 = V_2/2 = 2{,}000\ m/s$. The source lies in the upper halfspace, and the wave that is emanated is called the incident wavefield. At the interface a reflected wave and a refracted (or transmitted) wave are formed. While reflection is a change in direction of the incident wave upon striking the interface, refraction is the change in direction of the wave passing from one medium to the other caused by different velocities.

When we solve the acoustic wave equation through finite differences, the solution obeys the laws of reflection and refraction, which arise as a consequence of continuity of the pressure field and the vertical component of displacement across the interface. Again, the source excites a spherical wave as seen in Figure 2 (lower row). When the wave reaches the interface between the two media, a portion of its energy returns to the upper medium. This is the reflected wavefield. The remaining energy enters the lower medium. This is the refracted or transmitted wavefield.

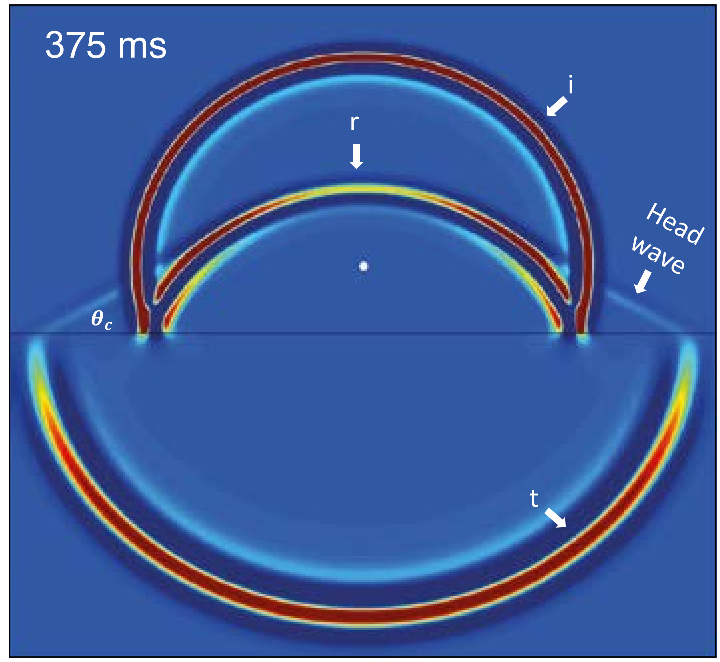


Figure 3: FD modelling produces the head wave (critically refracted wave) when the velocity of the lower layer is higher than the velocity of the upper layer. The head wave connects the spherical transmitted wave and the spherical reflected wave. (Colour scale in comparison to Figure 2 changed for display purposes.)

The Head Wave

In the example above, where a spherical wave is incident on a plane boundary, and $V_2>V_1$, a 'head wave' is formed on the boundary in addition to the reflected and refracted waves (see Figure 3). A head wave is a refracted wave which enters and leaves a high-velocity medium at the critical angle, as determined from Snell's Law ($\sin\theta_c = V_1/V_2$).

When the incident spherical wavefront hits the interface at critical angle, the refracted wave travels horizontally in the second medium with velocity V_2, while the incident and reflected waves travel horizontally with velocity V_1 just above the boundary. In this case, a part of the boundary between the onset points of the reflected and refracted waves is disturbed, and this disturbance is radiated to the upper layer in the form of a head wave with plane wavefront, leaving the interface at the critical angle. The associated ray path makes the angle θ_c from normal. The waveform of the head wave is the time integral of the waveform of the incident wave, which implies that the head wave has a smoother waveform than the waveform of the incident wave. In addition, it has a longer tail and a faster rise (see Ikelle and Amundsen, 2018).

Although the head wave travels further than the direct arrival (which travels from source to receiver without hitting the interface below the two) before it can be recorded at the top of the upper layer, it travels along the interface at a faster speed than the speed of the direct arrival. Therefore, the head wave at a sufficiently large source-receiver offset can be recorded prior to the time of arrival of the direct wave.

Geophysicists study subsurface velocity and layer interface structure by analysing the first arrival times of waves at the surface of the earth: the seismic refraction method. Refraction seismology is most easily understood through the two-layer model described above.

Italian physicist and mathematician Francesco Maria Grimaldi (1618–1663), left, was the first to describe the diffraction of light. The Grimaldi crater on the Moon is named after him. The mathematics of diffraction is very complicated, and a detailed theory was not worked out until 1818 by the French physicist Augustin-Jean Fresnel (1788–1827), right.

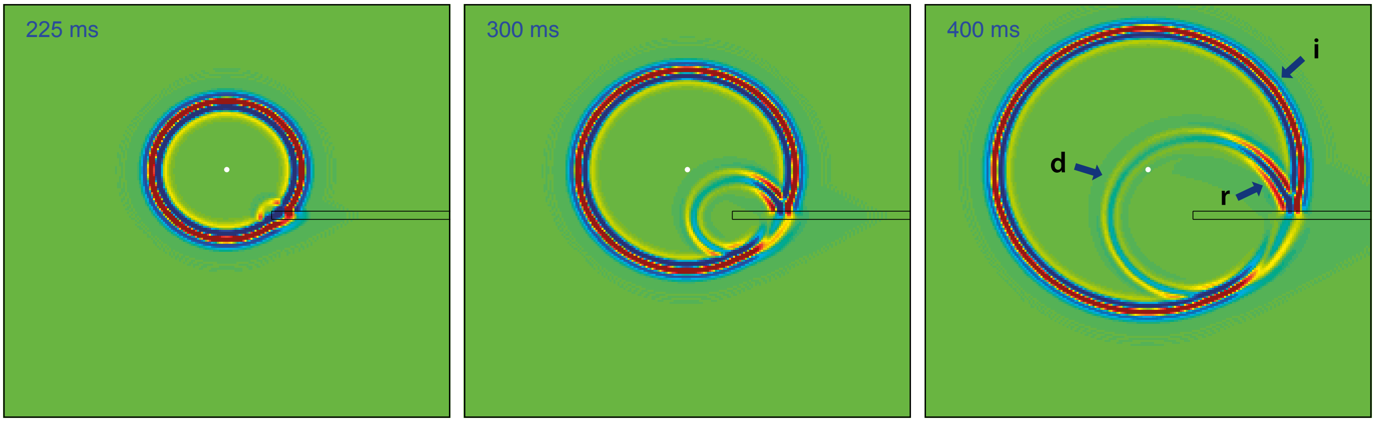



Figure 4: Snapshots of diffraction of a wavefield by the edge of a reflector slab. The theory of diffraction explains how energy can propagate into geometric shadow zones and the effect is verified by FD modelling.

The Diffracted Wave

Diffraction is when light passing an obstacle is seen to penetrate into the geometric shadow, and today refers to various phenomena that occur when a wave encounters an obstacle or a slit.

Water waves have the ability to travel around corners and obstacles and through openings. Sound waves and acoustic waves do the same. For example, when a set of plane waves passes through a gap in a barrier, diffraction is seen as curved waves coming out the other side. We also observe that the diffraction effect is greatest when the wavelength of the waves is similar in size to the gap. This is a prominent result that follows from theory: the diffraction effect is normally apparent only when the obstacle's size is close to the wavelength of the wave.

Another example is audible sound waves which easily diffract around common objects in our surroundings. The speed of sound in air is 343 m/s, so that the wavelengths of sound frequencies audible to the human ear (20 Hz–20 kHz) are between approximately 17 m and 17 mm. The middle C musical note at 264 Hz has a wavelength of 1.3m, comparable to room dimensions – so that the C sound from around a corner is audible.

The FD solution of the wave equation produces diffractions. Figure 4 shows a wave pattern produced at the termination of a reflector slab. Observe how the diffraction wavefront, denoted by d, develops. ■

Australia's Big Outdoor Museum

A group of Australian geologists takes a trip down memory lane – through a stunning and beautiful national landscape region, steeped in rich natural and cultural heritage.

ANGUS M. ROBINSON, Leisure Solutions®

The magnificent Flinders Ranges, which is an Australian National Landscape and is now looking at World Heritage status, comprises a number of serial sites within a topographically and environmentally varied geographic region of South Australia, which contains outstanding scenic, environmental, cultural, historical and, above all, scientific value. The area was described as 'one great big outdoor museum' by Antarctic explorer Sir Douglas Mawson, one of Australia's most distinguished geologists.

A Reunion Geotour

In 1968 the geology graduates of The University of Melbourne necessarily made career decisions that determined the direction of the next phase of their lives, but most responded to the lure of the mining resources boom of that time and became exploration geologists.

In September 2018, 50 years on, a seven-day, 50th anniversary geotour was organised, commencing in the heritage mining site of Broken Hill, in western New South Wales, to commemorate the class excursion to attend the Annual Conference of The Australasian Institute of Mining and Metallurgy in 1968. As well as a visit to current Broken Hill tourism attractions, the 2018 trip was followed by a tour of the Arkaroola Wilderness Sanctuary of the North Flinders Ranges, Wilpena Pound, the Brachina Gorge Geotrail, the Ediacara Biota, and a visit to a heritage vineyard in the Clare Valley en route to Adelaide. It concluded with a memorable reunion dinner at the historic Adelaide Club.

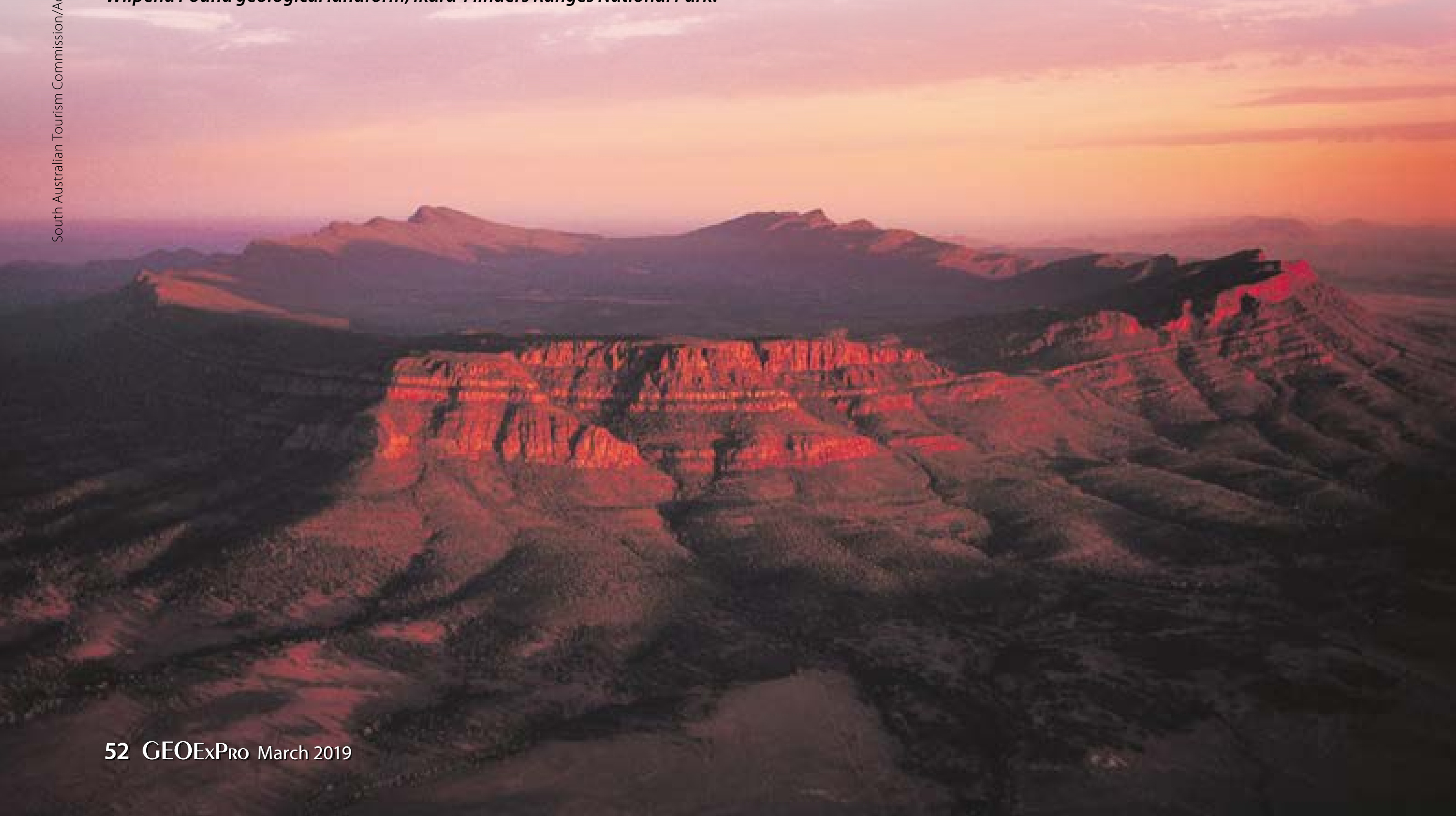
The geologists, including their partners, were led by Angus M. Robinson, and in this article he shares a few of the highlights of their trip.

Broken Hill

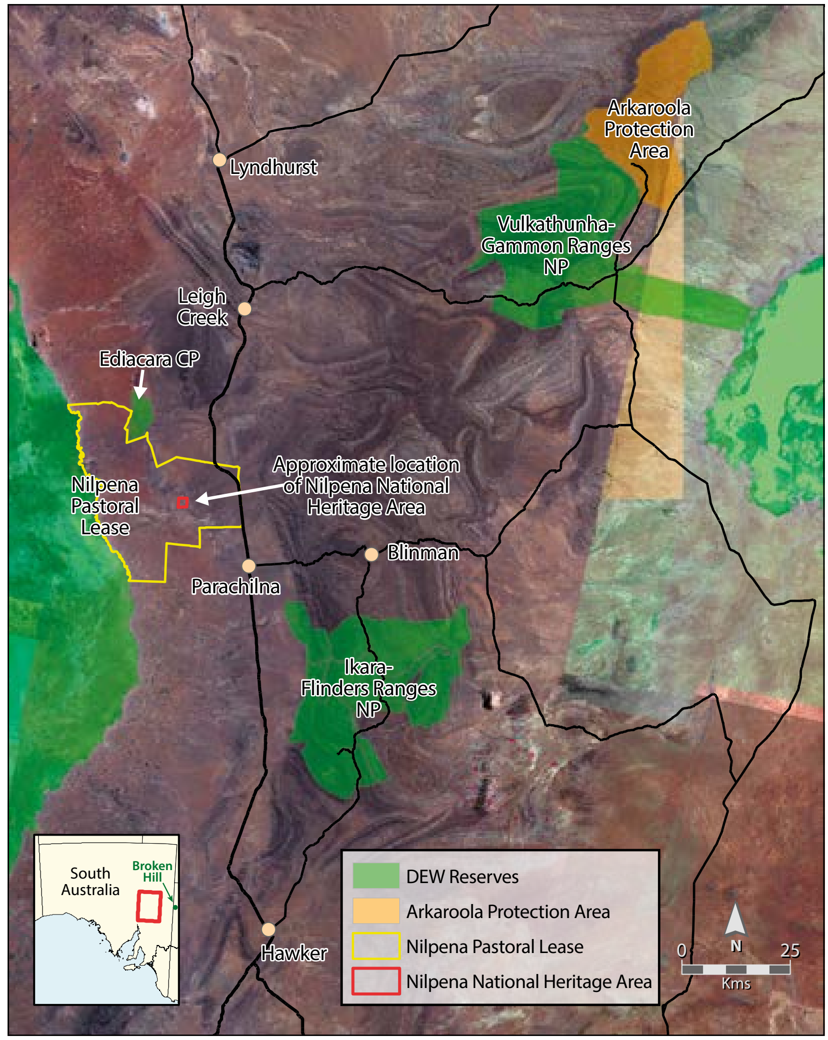
In 2015, Broken Hill Heritage City, New South Wales, was recognised as Australia's first heritage listed city, having been included on the National Heritage List alongside the Australian War Memorial, the Sydney Opera House and the Great Barrier Reef. This listing was in recognition of the city's significant mining history and contribution to the Australian and international mining and resources industry. With what was once the world's largest silver/lead/zinc ore body slowly coming to the end of its mining life, the population has had to rely on other means of employment, such as nature-based and cultural tourism, to stimulate its economy.

Wilpena Pound geological landform, Ikara-Flinders Ranges National Park.

South Australian Tourism Commission/Adam Bruzzone



For the short time that was available to spend in Broken Hill on the second day, we selected the world-famous Pro Hart Gallery, the Silver City Mint and Art Centre (which features the Big Picture – an enormous diorama of the Broken Hill region), as well as the Albert Kersten Mining Museum Geo Centre – as the pick of the attractions to visit. We also travelled to the remnant Line of Lode Gossan, the heritage Browne's Mine Shaft, the Living Desert Sanctuary Park, and the Sculptures in the Desert display.



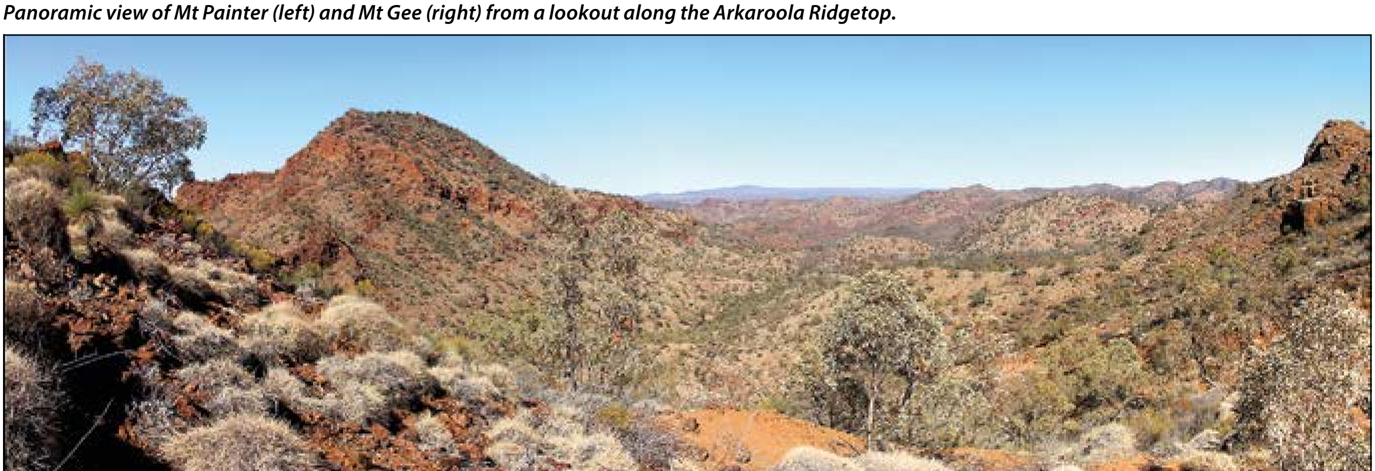
Map of the Flinders Ranges area with location of places named in the text. Map courtesy of Protected Areas Unit of the South Australian Department for Environment and Water (Flinders Ranges World Heritage Nomination).

Arkaroola: Geological Hot Spot

The next day we travelled all day on outback roads to arrive at the Arkaroola Wilderness Sanctuary situated some 600 km north of Adelaide in the Northern Flinders Ranges. The Sanctuary was established in 1968 by the eminent Australian geologist Dr Reginald Sprigg AO, who in 1946 had discovered the Ediacara biota, an assemblage of some of the most ancient animal fossils known. Dr Sprigg was also involved in uranium and petroleum exploration with the Geological Survey of South Australia and with various companies which he helped establish, including SANTOS, Beach Petroleum and Geosurveys of Australia. He acquired Arkaroola, a derelict pastoral lease, and transformed it into a wildlife sanctuary and wilderness reserve, now an outstanding world-class ecotourism attraction.

Arkaroola is one of Australia's outstanding geological 'hot spots' and is an outdoor museum of nationally and internationally significant geological phenomena and a window into Australia's deep geological time. We enjoyed Arkaroola's unforgettable encounter with the timeless terrain – and the unique natural beauty of the Arkaroola Wilderness Sanctuary. On day four, travelling in specially modified open-top 4WD vehicles, we were taken on a half-day, guided ridgetop tour of the spectacularly rugged country. Inspiring images of red granite mountains (such as the uranium ore-bearing peaks of Mt Painter and Mt Gee) and golden spinifex-covered hillsides give way to a breath-taking view across the Freeling Heights, Lake Frome and the desert beyond. For night sky watchers, Arkaroola features three fully equipped astronomical observatories that are available to professional and amateur astronomers and visiting astronomical societies and clubs.

Panoramic view of Mt Painter (left) and Mt Gee (right) from a lookout along the Arkaroola Ridgetop.



Blinman Heritage Mine and Ediacara Fossils

Inspecting the world-famous Ediacara fauna fossil site at Nilpena Station.

Departing on day five, we travelled south through the Flinders Ranges to visit the Blinman Heritage Mine located at the small village of Blinman. This is situated within the Blinman Diapir, which covers an area of approximately 44 km^2 and consists of a mass of brecciated and crumpled sedimentary rock. The ore body at the Blinman Mine comprises dolomite impregnated with copper minerals. In the oxidised zone, over 90m thick, the main supergene copper minerals are cuprite and malachite. Below this level the ore consists of the sulphides chalcopyrite, bornite and chalcocite. Underground mining to a depth of 165m was undertaken intermittently between 1862 and 1908. The Blinman mine represents one of the early Australian copper deposits worked by Cornish miners.

Arriving that evening at the Prairie Hotel at Parachilna, an oasis on the cusp of the rugged Flinders Ranges to the east and desert plains sweeping toward Lake Torrens on the west, we enjoyed the cuisine of the hotel restaurant, which is renowned for innovative dishes with Australian native and 'Flinders Feral Food' twists, and with a focus on local and South Australian produce.

Day six featured a fascinating visit to the Ediacara fauna fossil site at Nilpena Station. This is one of the most important fossil sites in the world, representing the earliest evidence of complex life on Earth. The Ediacaran Period is a globally recognised geological era between 635 and 545 million years ago and named after the Ediacara Hills of the Flinders Ranges.

Wilpena Pound and the Brachina Gorge

In the afternoon, we travelled along the 20 km-long Brachina Gorge Geotrail. Highlights were the 'hieroglyph' stromatolites described by Sir Douglas Mawson; the GSSP golden spike at the Ediacaran basal boundary; the post-glacial carbonate and iron-rich sediments; and a chance to straddle the Eon boundary between the Proterozoic (Neoproterozoic) and Phanerozoic (Cambrian). We were also thrilled to glimpse the beautiful yellow-footed rock-wallaby.

The shy yellow-footed rock-wallaby is only found in western New South Wales, eastern South Australia and isolated parts of Queensland.

A visit through the famous Wilpena Pound embraced by the Ikara-Flinders Ranges National Park included admiring the spectacular geological landscapes, sighting emus and a wide range of other bird species, red and western grey kangaroos, and the stately river red eucalypt trees (*Eucalyptus camaldulensis*). We also visited the historic 'Old Wilpena' Station (homestead) before arriving to stay the night at the nearby Rawnsley Park Station resort and enjoy a very pleasent dinner in the Woolshed Restaurant.

Southern Flinders Ranges and Clare Valley

On our final day we travelled to the township of Hawker, the gateway to the Flinders Ranges featuring the impressive Jeff Morgan Gallery, home to a number of spectacular, painted panoramas of the Flinders Ranges and an extensive minerals collection.

From Hawker, we then travelled along

Geology of the Flinders Ranges

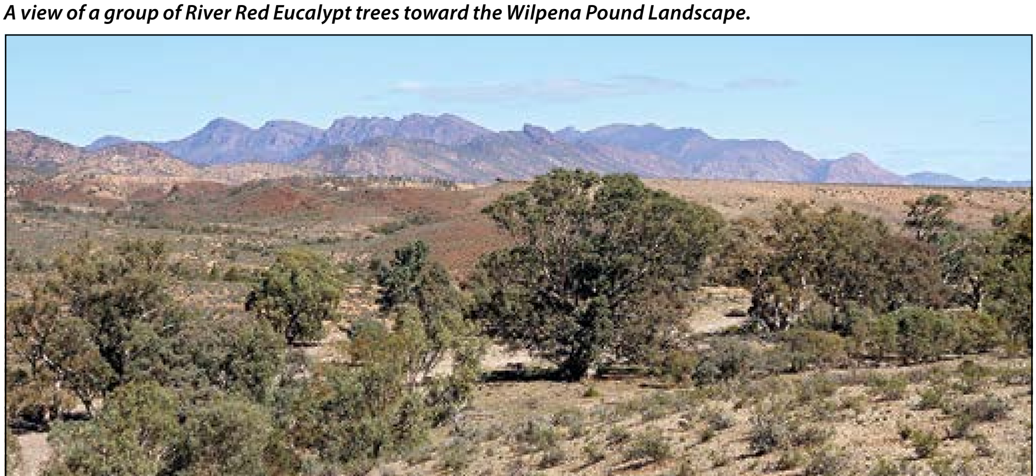
The geology of the Flinders Ranges comprises a single, depositional system that has existed for more than 300 million years; this system has been described as the 'Adelaide Rift Complex'. These sedimentary rocks are the repository of a record of Earth and life history from the Neoproterozoic to the Cambrian (approximately 830–500 million years ago) that includes major changes in the Earth's physical environment and key evolutionary events in the emergence of animal life.

The geological heritage includes the Global Stratotype Section and Point (GSSP) for the Geological Ediacaran System and Period, the period during which the first large soft-bodied animals evolved, leaving fossil impressions on sandstone beds of the Pound Subgroup geological formation of the Flinders Ranges.

Ediacara fauna species, Nilpena Station.

the R M Williams Way through Cradock, Orroro, and Jamestown to the Sevenhill Cellars south of the township of Clare. Sevenhill was settled by the Society of Jesus (Jesuits) in 1851 to produce sacramental wine. While this tradition continues today, Sevenhill is also highly regarded for its premium table wines, which are recognised for the regional qualities that have put the Clare Valley wineries, including Kilikanoon, on the world stage.

A view of a group of River Red Eucalypt trees toward the Wilpena Pound Landscape.



Grand Finale – Adelaide Club

Founded in 1863, and located in the heart of Adelaide's arts and cultural precinct, the historic Adelaide Club proved the perfect venue for a splendid farewell dinner for the Geology Tour Alumni members and partners, who reflected on their enjoyable journey from the heritage mining locale of Broken Hill, travelling together through a stunning and beautiful national landscape region of Australia, steeped in rich natural and cultural heritage.

References available online.

Acknowledgments

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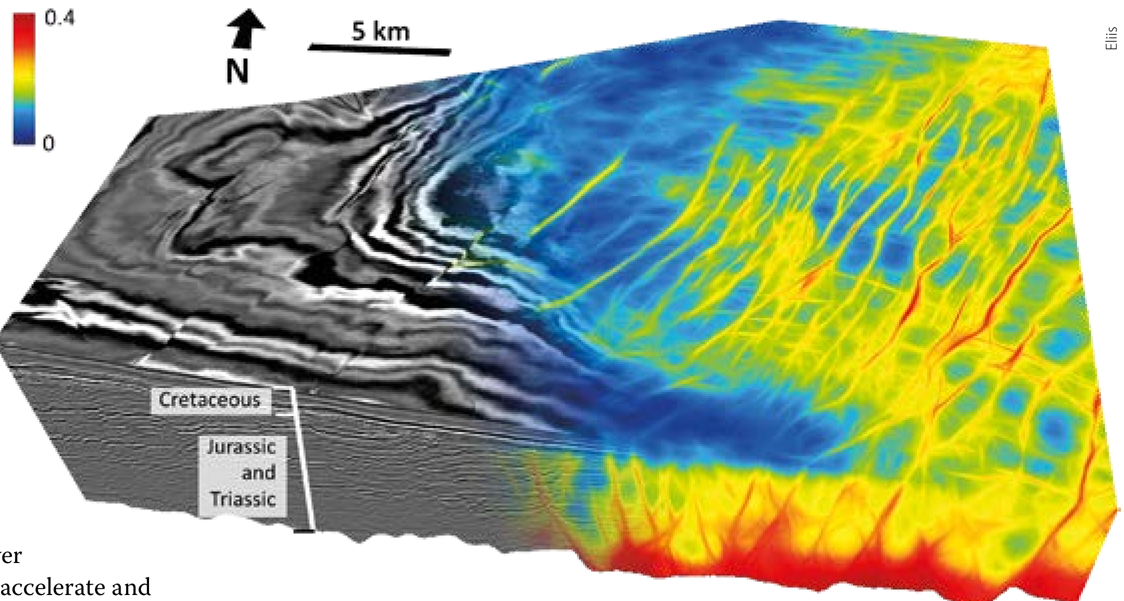
To Boldly Go Where No Interpreter Has Gone Before

The last frontier in seismic interpretation, the automatic detection of faults, is getting a step closer.

SVEN PHILIT, FABIEN PAUGET, SEBASTIEN LACAZE, Eliis; **CAROLINE GUION;** Eliis Inc.

In order to build an accurate geological model of the earth, it is essential for the seismic interpreter to understand clearly the structural network of the seismic dataset. This has been traditionally achieved by manually picking the faults identified on seismic images, which is both a tedious and time-consuming task. Great efforts have therefore been made over the last two decades to accelerate and automate the detection of faults. Several seismic attributes such as *coherency*, *variance* and *chaos* have been used to capture the fault locations, but with limited success due to the impact on the attribute values of seismic signal heterogeneities in the vicinity of the faults.



The Exmouth Basin block HCA2000A imaged as a merged composite of the seismic data on the left and the Fault Plane attribute on the right.

The methods that have to date delivered the best results are based on the structure-oriented *semblance* attribute, with the Fault Likelihood method developed by Dave Hale in 2013 at the Colorado School of Mines being one of the best-known techniques. More recently, machine learning approaches have sparked a lot of interest, but they require a large amount of data to train the software. Hence, without sharing huge datasets amongst the oil and gas community, quickly obtaining accurate results through machine learning methods may remain a considerable challenge for the foreseeable future.

However, alongside these efforts a simple innovative three-step design method has become available for detecting and creating faults following a semi-automatic workflow.

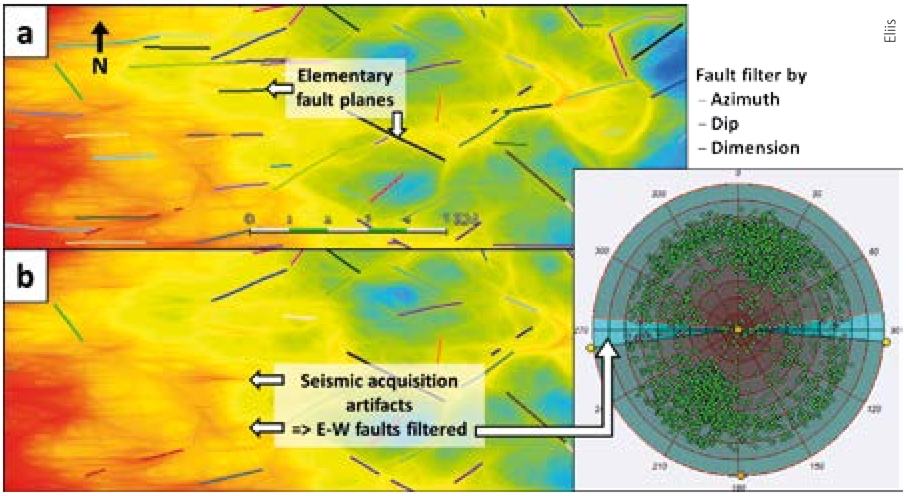
Towards the Automatisation of Fault Extraction

In the first step, a new attribute called *Fault Plane* is derived from the *optimised variance* of the seismic volume. The variance of each voxel is computed from the average vector field and the maximum variance along a scanning disk in the three dimensions of the volume is detected for the best combination of strike value (0°–360° horizontally) and of dip value (0° and 90° vertically). The result of this computation, which does not require the calculation of full dip and strike volumes, is the Fault Plane attribute volume.

In the second step, the extrema of the Fault Plane attribute are extracted through a thinning process, whereby the maxima of the gradient vector are detected. The *thinned Fault Plane* volume thus created highlights the skeleton structure of the fault network.

In the third step, groups of voxels are created from the skeleton of the thinned Fault Plane volume and linked together to form fault patches. Those patches, based on several customisable parameters such as the value of the voxels, the dimension of the groups and their planarity, are sorted to keep only the most significant ones, which are transformed into elementary fault planes. These elementary fault planes are made up of fault sticks along the inline and crossline directions closest to the perpendicular of the fault plane azimuth.

Once the elementary fault planes are automatically generated, the challenge is to reduce and simplify the structural framework by quickly sorting, organising and merging the resulting objects. The technology allows the user to sort the faults by dip, azimuth and size, the values of which are filtered by means of an interactive *stereonet*. The resulting objects are distinct fault sets sorted by fault types: regional/local, fault/fractures, azimuth range, dip range, reverse/normal faults. Additionally, a semi-automatic fault-merging assistant is available to solve the jigsaw puzzle of



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Fault Plane attribute in time-slice and fault orientation filtering tool. Deformation artifacts at the top of the block linked to seismic acquisition caused the generation of faults that are not filtered in (a) and filtered in (b).

elementary fault planes. The tool detects which elementary planes are the most likely to be part of a single fault plane and merges them together into a brand new fault. The merging proposal is performed as a function of the vicinity, azimuth and dip of the fault planes and reduces the number of fault objects, thereby cleaning the output of the automatic fault extraction with a rapid hands-on solution.

Application in Marine Seismic

The method described above was tested on the Exmouth sub-basin, located in the Carnarvon Basin, offshore North West Australia, which has proven oil-bearing reservoirs in fluvio-deltaic sands of the Mungaroo Formation (Middle to Late Triassic) and deltaic sediments of the Barrow group (base of the Early Cretaceous). The basin is made of complex faulted Permian, Triassic and Jurassic intervals related to the Late Triassic to Late Jurassic rifting of the Exmouth Plateau. The main fault set of the studied zone is essentially striking north-north-east.

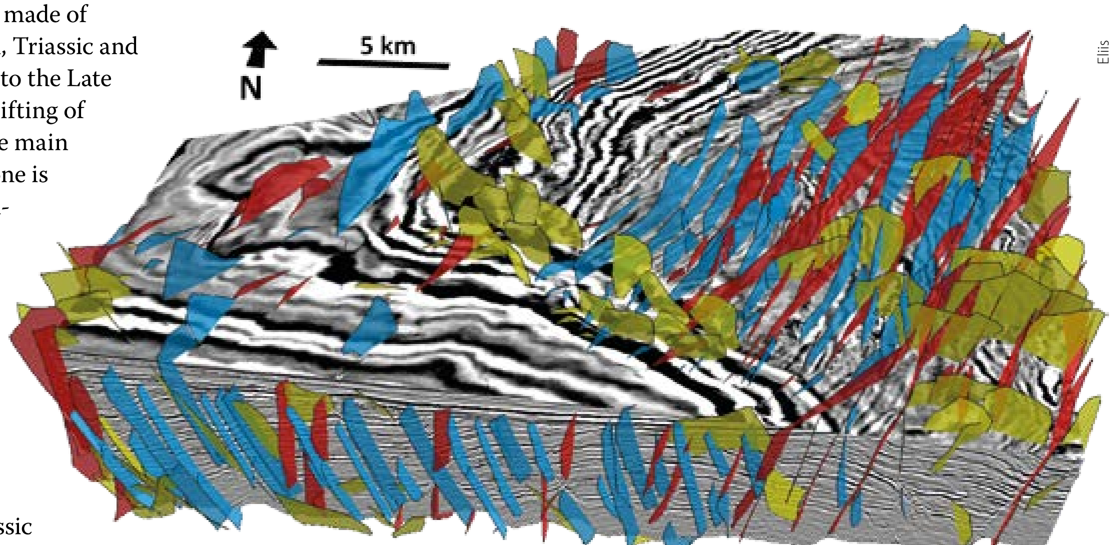
The result of the Fault Plane highlights the contrast in deformation in the different stratigraphic intervals of the basin: the interpreter can easily observe a dense fault network in the Triassic and Jurassic intervals. With closer observation, it can be noted that the geometry of the fault planes fairly captures the geometry of the deformation and fault relays. By applying the automatic fault extraction workflow to the 650 km^2 Exmouth seismic dataset, more than 2,200 elementary fault planes were created in a few hours. Obviously, the structural interpretation time has been drastically reduced by delivering fault sets in a fraction of the time needed to manually pick the faults, even when factoring in the time spent in sorting and merging the elementary fault planes that were automatically picked. After applying the filtering and merging tools, the elementary fault planes were combined into a set of 1,500 faults with structurally consistent geometries.

Ready for Take-off

The semi-automatic fault extraction presented here is now ready to be implemented in industrial seismic interpretation workflows. The method presents the benefit of a simple workflow and avoids falling into the classic pitfall of cumbersome computation. As a consequence, the speed of the Fault Plane workflow is comparable to that of the Fault Likelihood method, and significantly faster than manual picking. Contrary to machine learning approaches, the method also does not require a large training dataset, giving it the great advantage of being independent of third-party information. Moreover, the workflow is customisable and can use attributes other than the variance as input to the computation of the Fault Plane. After fault extraction, the elementary fault planes are combined quickly thanks to the orientation filtering tool and the fault merge assistant. The interpreter keeps control of every step of the workflow and can adapt it to the structural style of the investigated seismic.

Acknowledgements:
The examples presented in this article were obtained using PaleoScan™, software developed by Eliis. The authors would like to thank Geoscience Australia for their permission to publish the data from block HCA2000A (Exmouth). ■

Final fault sets after global management (fault orientation filtering and merging of the elementary fault planes).



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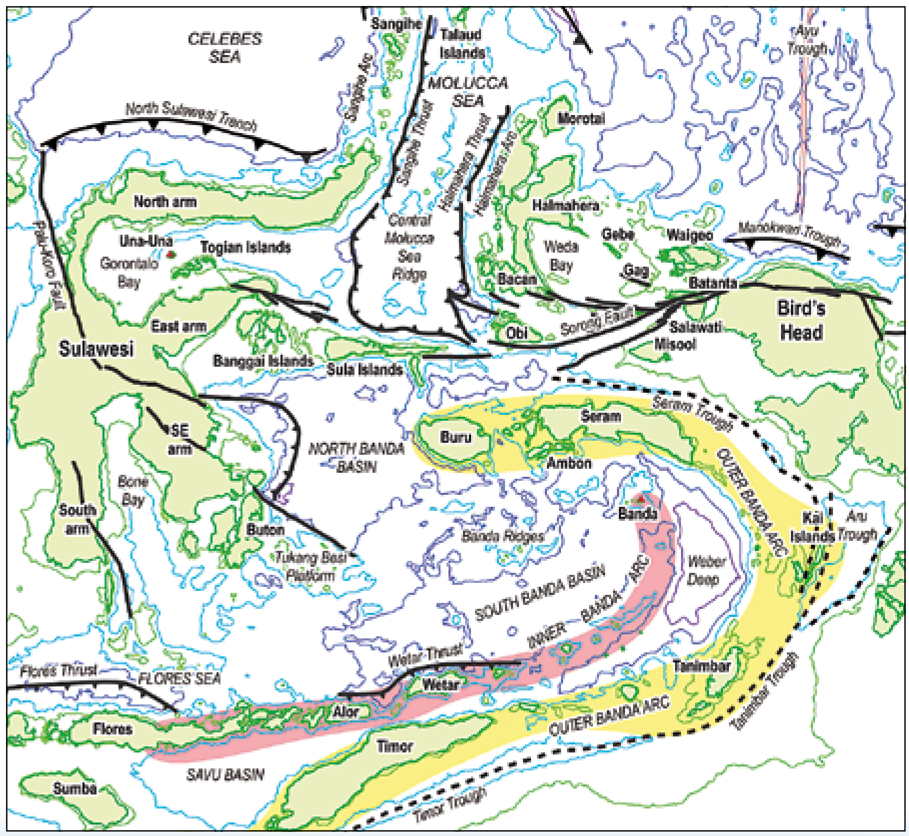
New Views of Eastern Indonesia

Subduction has driven change but the implications for hydrocarbons are different from those previously interpreted.

PROF. ROBERT HALL
South East Asia Research Group,
Royal Holloway,
University of London

Anyone scientifically familiar with eastern Indonesia will know of two things: that it is crossed by the Wallace Line, a famous biogeographic boundary between Asia and Australia, and secondly, that the geology is very complex. The biological diversity, including strange endemic species such as tarsiers, babirusa and marsupial bear cuscus, and unusual fossils such as pygmy elephants, has often been attributed to long isolation of the region, but recent studies suggest it is very young. The diversity is, in fact, linked to geological change, as Alfred Russel Wallace realised more than 150 years ago, although at that time continents were thought to be fixed. Plate tectonics explained change as the result of the collision of South East Asia with the Australian continent due to convergence between the Eurasian, Australian and Pacific plates, but recent work has shown that the results are different from those previously suggested. Rapid and recent tectonic processes causing emergence



Geography of eastern Indonesia with principal tectonic features.

View looking west towards the mountains which bound the western side of the Palu valley and Palu Bay, Sulawesi and follow the trace of the Palu-Koro Fault. This was the location of the earthquake in 28 September 2018. The tsunami that followed devastated the city situated on the low-lying ground behind and south of the distinctive yellow bridge, which was also destroyed.

Robert Hall

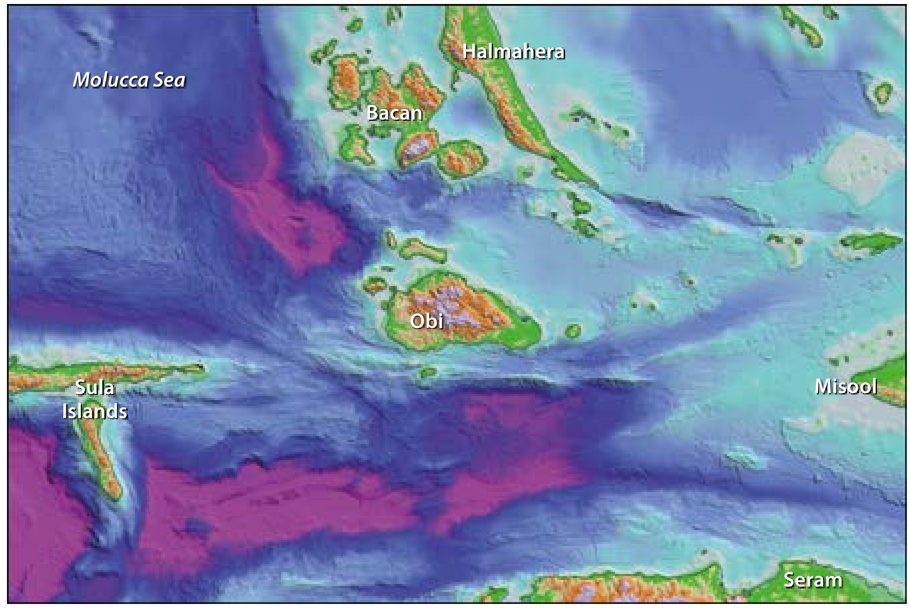
of land and subsidence of basins are now interpreted as a result of extension driven by subduction, rather than multiple collisions.

Geological Exploration of Eastern Indonesia

Although there is hydrocarbon production in areas such as East Sulawesi, Seram and the Bird's Head of New Guinea, and the region is well known for numerous active seeps and mud volcanism, exploration has been limited. On land this reflects remoteness, a relatively small population, lack of infrastructure, and challenging terrain, vegetation and climate.

The majority of the islands have been geologically mapped at a reconnaissance level, but most remain under-investigated. Timor, with a long dry season and relatively limited vegetation cover, is the best studied, but the rainforest islands from Sulawesi to the Moluccas in the Banda Sea are much less well-known. Until recently, for example, the most extensive surveys of Seram, the largest island of the northern Banda Arc, were those of the Dutch in the early 20th century.

Offshore, exploration was limited by similar factors, with a small number of scientific cruises, few seismic surveys and little drilling due to high costs. Larger basins were crossed by only a few regional seismic lines. So although evidence of hydrocarbons and Australian continental crust may be attractive, the geological complexity is challenging. The lack of exploration meant that major features, such as the troughs that surround the Banda Arc, were traced and interpreted in different ways, with considerable disagreement between tectonic models.



Part of eastern Indonesia: SRTM topography on land and satellite gravity as background, northern part of the offshore region, with detailed multibeam bathymetry for most of southern offshore area. The image shows strands of the Sorong fault, the southern end of a deformed sediment wedge in the Molucca Sea, subsided carbonate reefs south of Misool and the western end of the Seram Trough north of Seram.

New Data Improves Tectonic Models

Widely accepted models interpreted fragments of continental crust to have been sliced off the Bird's Head of New Guinea by strike-slip faulting as Australia moved north, and carried west to collide in Sulawesi. This concept was proposed by Warren Hamilton in the 1970s and was given the name 'bacon slicer'. The Sorong Fault crosses the northern Bird's Head and was traced westwards, based on very limited offshore data, and interpreted to link to major faults in Sulawesi. However, the distribution of microcontinental fragments in eastern Indonesia is difficult to explain by strike-slip movements and it was observed in the 1980s that Australian continental crust in the Outer Banda Arc islands must have been within the arc before collision with the Australian margin. There were major disagreements about the ages of the ocean basins within the Banda Arc,

which some suggested to be Mesozoic while others interpreted as Cenozoic.

These controversies reflected the quality of information. On land, mapping was dependent on inaccurate paper maps, limited air photo coverage and a few airborne radar surveys. There was little dating of rocks and minerals: sedimentary, igneous and metamorphic – most radiometric ages were acquired by the problematical K-Ar technique. Both on land and offshore, 2D seismic data was sparse, and traces of major structural features were often speculative.

From the 1980s, satellite-derived marine gravity measurements improved mapping of offshore bathymetry. In the late 1990s, academic marine geophysical surveys and dredging showed the ages of Banda oceanic basins were Neogene, and a new phase of seismic acquisition began offshore, initially with widely-spaced regional lines.

On land, from the early 2000s, new public domain images from Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) provided views through clouds, forest cover and mountains. They showed structural detail, and combined with GPS dramatically improved our ability to locate, sample, map and interpret the geology.

Offshore, multi-client surveys undertaken in the last 20 years have acquired seismic data that has steadily improved in abundance and quality. Recent multibeam marine bathymetric surveys now provide better resolution than SRTM (initially 90m, now 30m pixel size). They were undertaken to aid sampling of sea floor seeps, but also revealed structural features in great detail. Thus, the interpretation of high resolution seafloor images can be linked to structures imaged on land. This has made it possible, for example, to trace the troughs around the Banda Arc to within a few tens of metres, and link onshore and offshore faults.

Dating Uplift and Subsidence

Although there are still few wells and little sampling offshore, mapping of structures from land to offshore provides the basis for interpretation and indirect dating of features on seismic lines and multibeam maps by dating rocks on land.

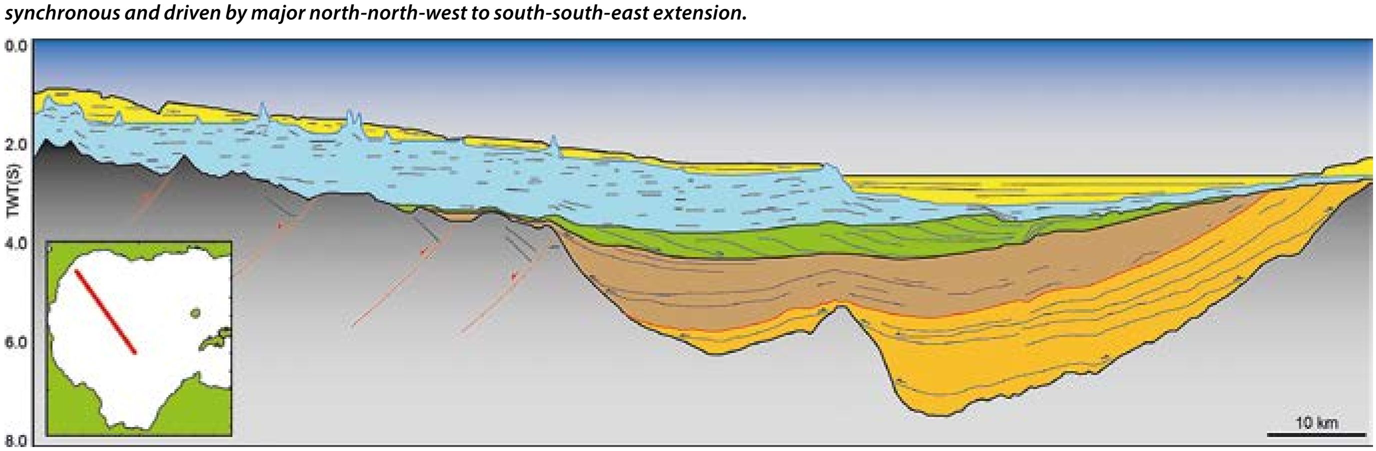
In the last few years studies between Sulawesi and the Bird's Head by the South East Asia Research Group at Royal Holloway have yielded major surprises. Radiometric dating, particularly using the Ar-Ar method and U-Pb dating of zircons, and low temperature thermochronology, have shown that previously undated metamorphic and igneous rocks considered to be Palaeozoic to Mesozoic are very much younger, commonly Miocene and Pliocene. The youngest metamorphic rocks recently dated in the North Moluccas have ages of less than 1 Ma. Many of these rocks, visible on the high resolution imagery, are parts of metamorphic core complexes or exhumed in strike-slip fault zones, implying major extension.

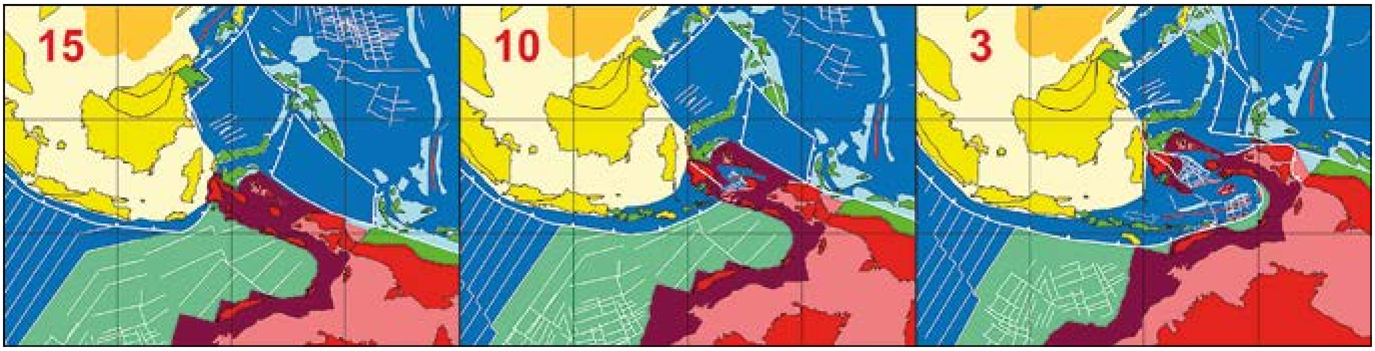
Massive granite body and granite dykes cutting metamorphic rocks in Sulawesi Neck. The granites are 3 Ma old.

Offshore, common features in many areas on multibeam images are spectacular reefs, with features including rimmed platforms and pinnacles, but now at depths up to 2 km. Close to Sulawesi subsidence of reefs is clearly very young and is interpreted to be synchronous with exhumation and elevation of metamorphic core complexes and granites on land which are 3 Ma or younger.

On the north side of the Seram Trough reef carbonates record multiple episodes of rapid late Pliocene and younger subsidence linked to northward thrusting of the Seram fold and thrust belt. Mapping of major fault systems shows how the Sorong Fault system breaks up after crossing the Bird's Head into multiple splays at its ▶

Interpreted seismic line crossing north-western Gorontalo Bay beneath the lines of pinnacle reefs seen at the top of the blue unit. In the centre of the line there is about 5,000 ms TWT of sediment interpreted to be of Neogene age. The basin is undrilled. On land about 50 km to the west are exhumed granites 3 million years old. Subsidence of reefs, and uplift and exhumation of granites and metamorphic rocks, are interpreted to be approximately synchronous and driven by major north-north-west to south-south-east extension.





Tectonic reconstructions of the Banda Arc development at 15 Ma, 10 Ma and 3 Ma showing rollback of the Banda subduction zone into the former Banda Embayment with extension of the upper plate leading to extreme extension of the former Sula Spur and formation of North and South Banda Basins, floored by oceanic crust. Rollback of the North Sulawesi subduction zone began in the last few million years and resulted in extension, uplift of metamorphic core complexes and subsidence of reefs.

western end, which are not linked to strike-slip faults on Sulawesi. It is now clear that faults shown on many older geological maps are commonly speculations or non-existent and owe their continued appearance to repetition and recycling rather than evidence.

A New Picture

The geological interpretation of the region in terms of multiple collisions of tectonic slices moving from the east has been significantly modified. There was certainly a collision in the Early Miocene of an Australian continental promontory, the Sula Spur, with the North Sulawesi volcanic arc and parts of the Eurasian margin in western Sulawesi. This was the first contact of the Australian continent with South East Asia. Subsequently, a few fragments of continental crust became mixed in the Sorong strike-slip fault zone with arc and ophiolitic fragments from the Philippine Sea plate at the northern margin of the Australian continent between the Bird's Head and the Sula islands.

However, during the Neogene most fragmentation was due to extension, related first to subduction rollback into the Banda Embayment, which continues today, and younger rollback-related extension related to subduction of the Celebes Sea at the North Sulawesi trench. Extension has been extreme: the middle and lower crust have been exhumed in core complexes, and rocks from the base of the crust and sub-continental lithospheric mantle are found in strike-slip fault zones. The very young age and high rates of Neogene extension which formed the high mountains and deep basins are becoming clearer as our work proceeds.

Implications for Hydrocarbons

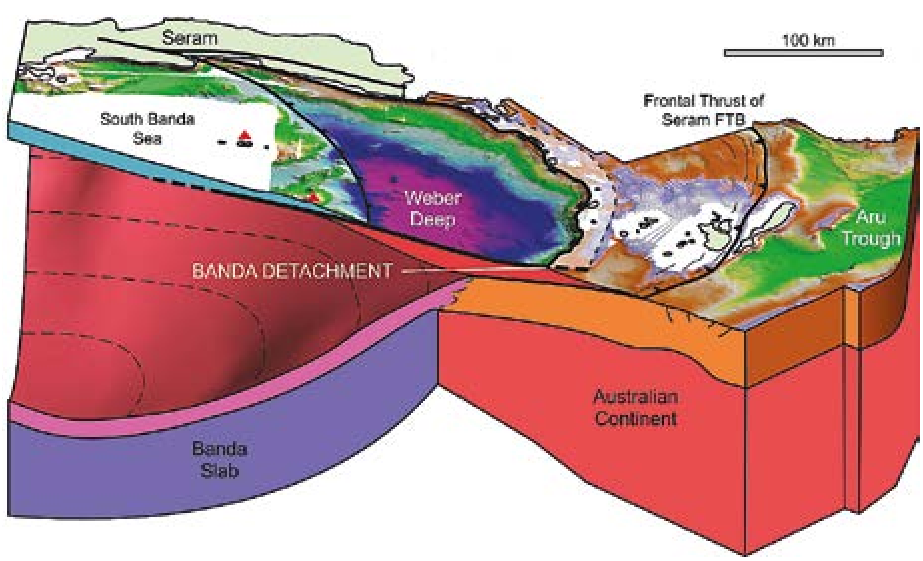
Our tectonic model for eastern Indonesia continues to develop as, for example, new dating is carried out and interpretation of SRTM, multibeam and seismic data proceeds. Studies using seismic tomography, which images the mantle, provide an important independent way to test and evaluate different tectonic models. Thus, they can be used with greater confidence to identify areas that are more likely to be successful in exploration, potentially explaining intervals of faulting and subsidence. New sources and major inputs of sediment were mainly not related to collision, but to uplift driven by extension. Numerical modelling will provide estimates of heatflow which can be used to assess basin histories and implications for maturity. It is clear that models developed in other tectonic settings, such as older Atlantic-type passive margins, need to be used with caution since in eastern Indonesia extension-related processes have been very much faster.

Geological observations from eastern Indonesia support molecular biological studies showing the speed and young age of change and the resulting spectacular consequences on palaeogeography and life.

Acknowledgments:
The author would like to thank all the companies who have helped SEARG with its eastern Indonesia projects, particularly those who have provided data: CGG, Fugro, GDV, Niko, PGS, Searcher and TGS.

Additional figures and references available online. ■

3D cartoon showing the highly extended Weber Deep above the subducted Banda slab. This marks the final stage of subduction rollback into the Banda Embayment, which is probably ongoing today. Metamorphic rocks in nearby islands around the arc have Pliocene radiometric ages. The 7 km Weber Deep in the eastern Banda Arc, south-east of Seram, is the Earth's deepest forearc basin.



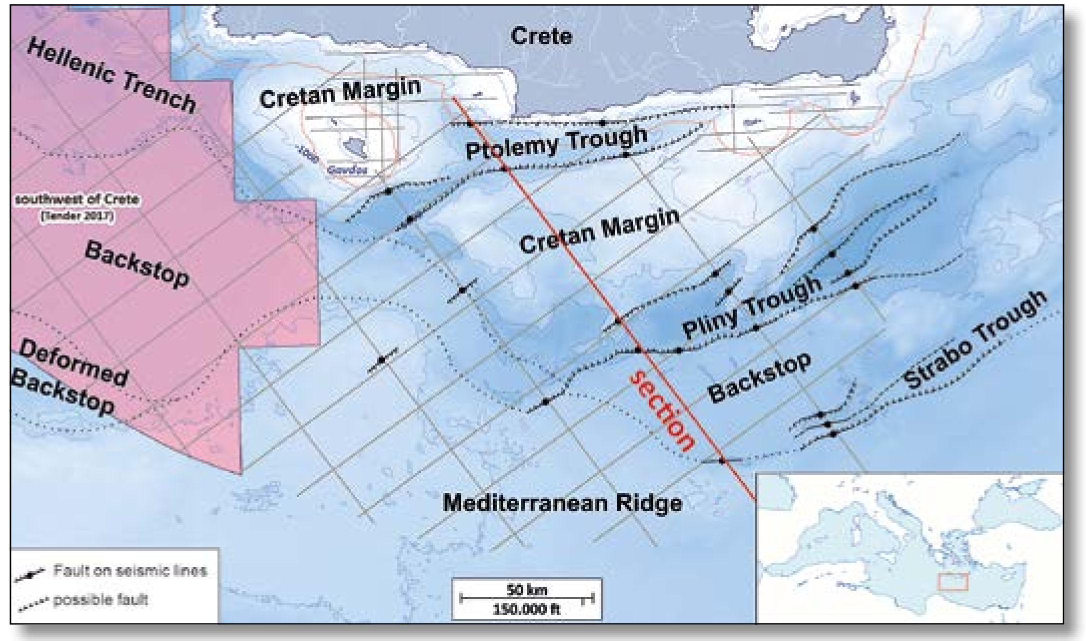
Offshore Exploration in Greece

Deepwater exploration and drilling

The Mediterranean Ridge and its backstop constitute a huge structural feature several hundred kilometres long. The structural style is not homogeneous along strike. The region was affected by thrust and strike-slip faults, activated after the collision of the African and Eurasian plates, and the resulting complex tectonics make 2D seismic interpretation difficult and often questionable.

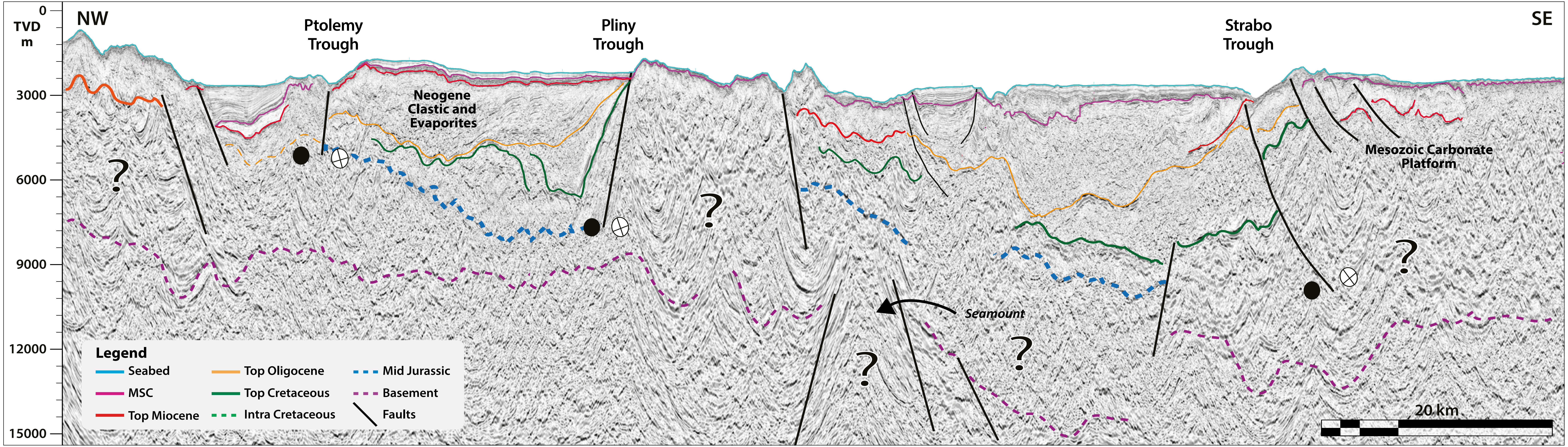
However, the new PSDM high quality seismic data acquired by PGS show that the tectonic complexity in the region is manifested by three different pull-apart basins, which have been created since the early Miocene. These basins were filled with mixed siliciclastic (flysch sediments) and slope carbonate deposits, both of which could be excellent reservoirs.

HHRM
HELLENIC HYDROCARBON RESOURCES MANAGEMENT



Map showing the location of the seismic line below in relation to major structural features in the region.

Interpreted 2D PSDM seismic line showing the key identified unconformities, which correspond to main tectonostratigraphic events.



Catching the Deep Sea Wave

The underexplored deep waters of the east Mediterranean are ready to be investigated.

Until recent years, technological constraints have limited the possibility of exploring in frontier deepwater environments, especially in the Mediterranean Sea. However, the petroleum industry has now begun to show considerably more interest in investigating these waters, particularly following recent discoveries in the Eastern Mediterranean, such as Zohr, Leviathan, Tamar, Aphrodite and Calypso.

Exploration History in Greece

Hydrocarbon exploration in Greece dates back to the beginning of the 20th century, but activities were carried out in a rather sporadic and unsystematic way until the 1960s and were mainly focused on onshore areas, characterised by surface oil shows, especially in western Greece. It was not until the 1970s that things changed with the discovery of the Prinos and South Kavala fields, which remain the only currently producing fields in the country. However, very little was done with regard to exploration activity offshore, even following the discovery of the Katakolon field in the western Peloponnese in the early 1980s, until 2012 when an Open Door invitation was launched.

Since then, Greek E&P potential has attracted growing interest, with a number of major companies being awarded licences in 2018, including Total, Exxon-Mobil, Repsol and Edison.

Geological Provinces

With the exception of hydrocarbon production in the northern Aegean Sea from the Prinos and South Kavala fields, exploration activity today is focused on the Ionian Sea and the offshore frontier areas south of Crete, as well as a number of onshore areas in western Greece.

The Thrust-Fold-Belt (TBT) province of western Greece is believed to be an analogue of the proven hydrocarbon provinces in Albania and Italy. Block Ioannina (on the border with Albania), in particular, lies on trend with the Shpirag discovery in Albania.

The hydrocarbon potential targeted in the Ionian Sea geological province is mainly contained within carbonate reservoirs, as well as in the clastic series present there. Abundant carbonate build-ups and calci-turbidites are the main potential drilling targets for the oil and gas companies active in these blocks.

On the other hand, the offshore areas covering the west of Crete and blocks south-west of the island, as well as the open acreage south of Crete, are frontier regions with very little exploration history. Zohr analogues seem to be the main target for the companies active here.

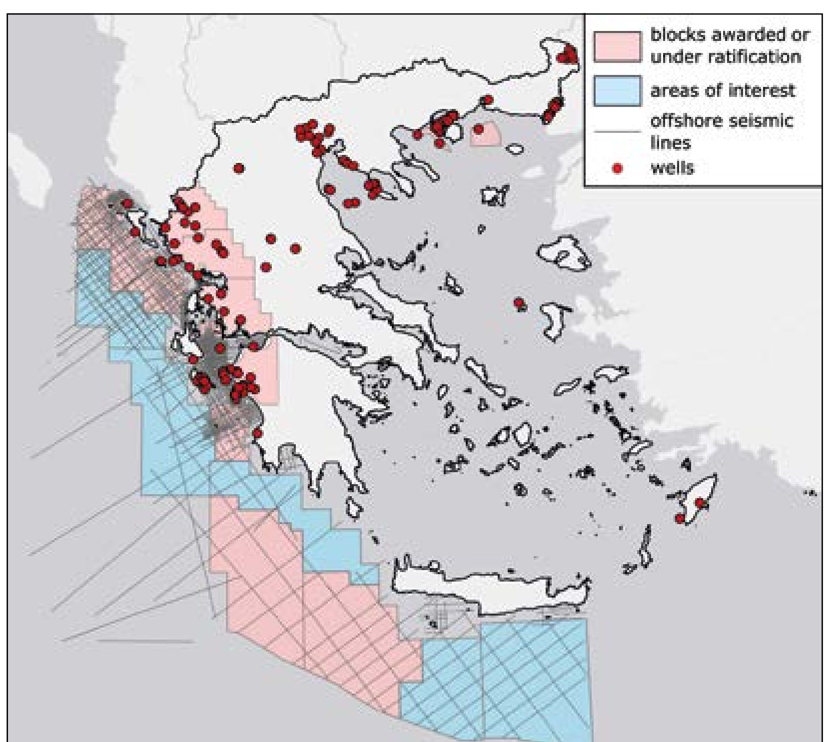
Advantageous Timing

As a result of the active compressional tectonics, Greece is primarily a mountainous country, with more than 300 mountains, about 40 of which exceed elevations of 2,000m. It is also characterised by deep sea waters, which reach depths of over 3,500m. The blocks offered for offshore exploration lie in areas with water depths ranging from a few hundred metres to 3,500m.

Clearly, this is not an easy environment for oil companies to work in. However, the industry's deep sea technology is already well developed and successfully tested; an exploration well in very deep water (3,400m, Total's Raya-1 well in Uruguay) is a part of the drilling trend in worldwide exploration.

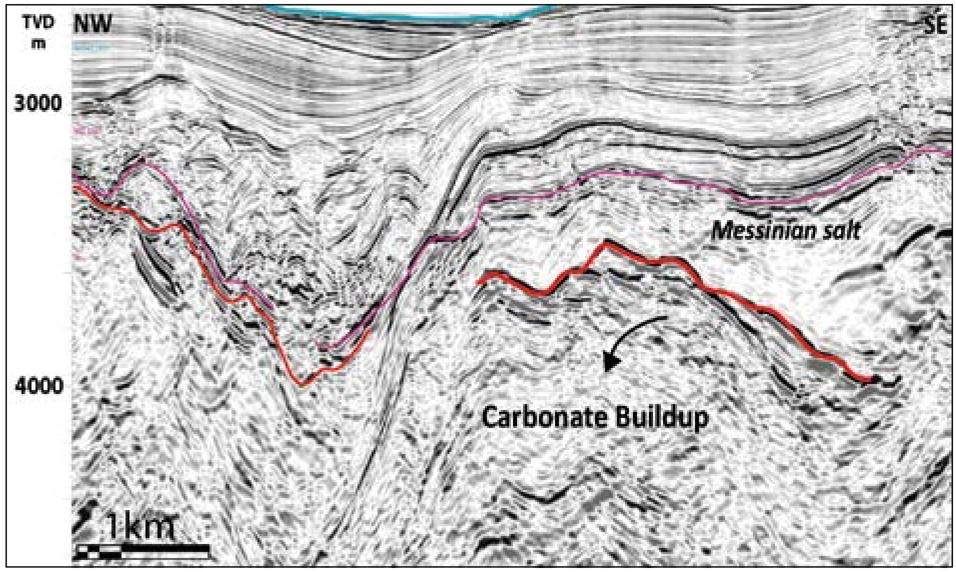
The Greek E&P industry timing could be considered

Greece's blocks and wells.



quite advantageous, as the initial wells in the country in these ultra-deepwater settings are likely to be spudded at the end of the first or the second exploration phase in the majority of the concessions. That should result in drilling activity some time around 2024–2025, which should coincide perfectly with the technological advancements. Therefore, besides the economic benefits, Greece will be placed in the centre of deep sea drilling innovation, and will provide an environment for new technologies to be applied.

Equally important is the fact that regulations governing deepwater activities will be in place at the same time. At the moment legislation throughout the world does not really cover such environments, but it is also true that the majority of law-making bodies worldwide are currently working intensely on issues such as the safety of offshore installations.



Carbonate build-up near Gavdos Island, which lies about 30 km south of Crete.

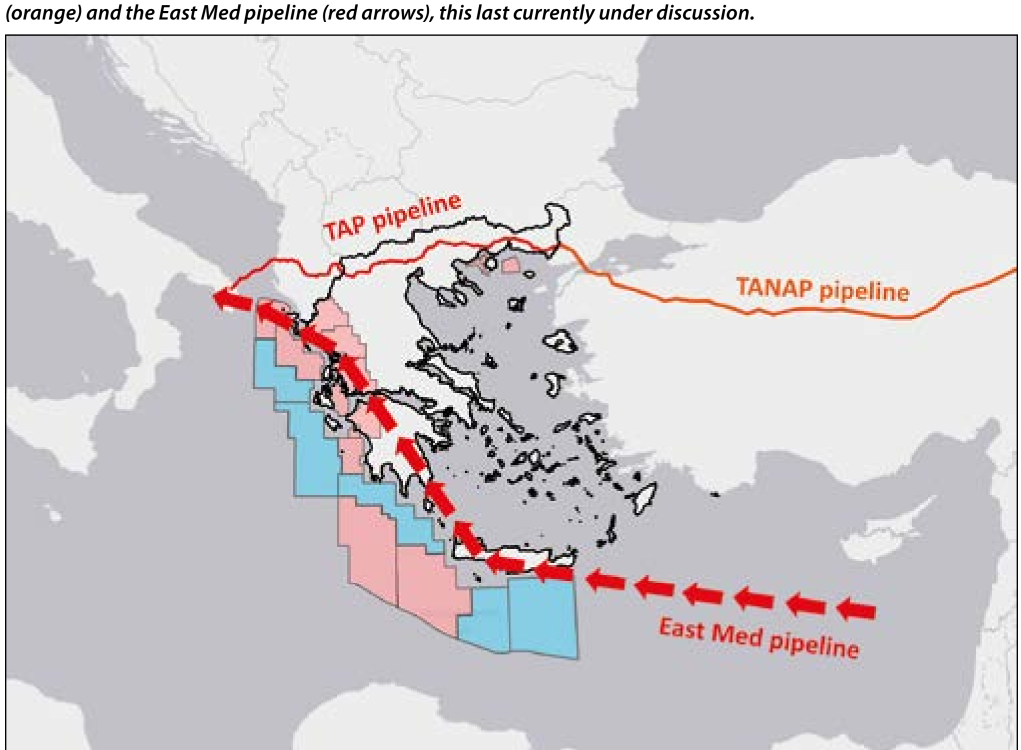
Major Midstream Projects

Greece is located in the south-eastern part of Europe and this location works in its favour. The country already has a number of local pipelines in place but, most importantly, major projects are currently either under construction or in the pre-development stage.

The Trans-Adriatic Pipeline (TAP), which is being built at the moment, will run across northern Greece and Albania to connect with the Italian pipeline network. To the east it will be connected at the Greece-Turkey border with the Trans-Anatolian Pipeline (TANAP). Its purpose is to bring gas from the Caspian area to western Europe, forming part of the Southern Gas Corridor.

The second major pipeline project is the East Med pipeline, which is currently under discussion. It will connect the offshore gas reserves from Cyprus and Israel in the Levantine Basin to Greece and on into Italy via an interconnector. It is designed to initially transport 10 Bcm a year.

The major pipeline projects in the area are the Trans-Adriatic Pipeline (red), the Trans- Anatolian Pipeline (orange) and the East Med pipeline (red arrows), this last currently under discussion.



Greece's state oil and gas company, HHRM SA (Hellenic Hydrocarbon Resources Management SA), to date has evaluated and approved over 100,000 km^2 of exploration acreage. Given that E&P activities require long-term investments in order to contribute to a country's economic growth and competitiveness, the company has already acknowledged the fact that, in the near future, Greece will require a specialised and highly skilled workforce able to operate in the manner of international oil companies.

Will Greece ride this wave of innovation successfully? Well, only time will tell, but things surely look very promising right now… ■

Great Geologists

JANE WHALEY

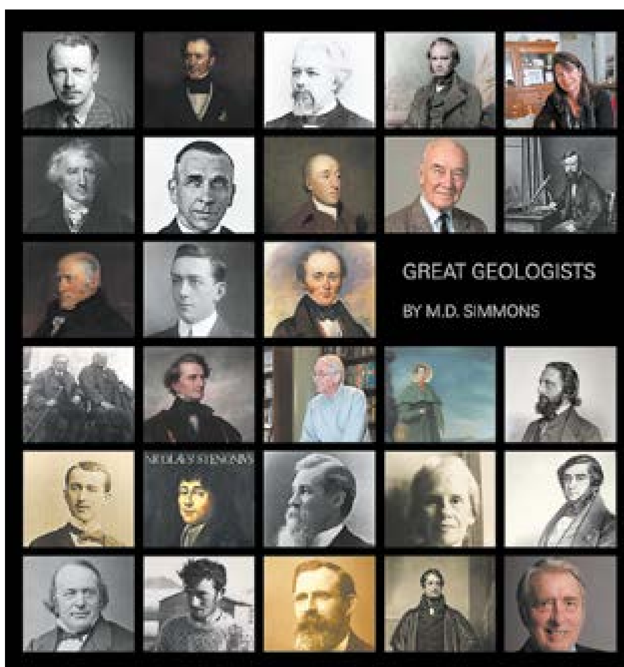
A history of some of the greatest geological minds introduces us to important geological controversies.

As Mike Simmons says in the introduction to this book: "The history of geoscience is marked by the work of exemplary scientists, who through their endeavours, changed the way we think about the Earth, its history, processes and resources." Having discovered that no one had attempted to collate the life stories of such scientists, Mike decided to compile a collection of short biographies – and this eminently readable and fascinating book is the result.

A Journey of Ideas

Mike selected 36 eminent scientists to represent the many people who have influenced the earth sciences, and in telling their stories, starting with Nicolas Steno in the mid-17th century and ending with several geologists still with us today, he also takes us on a journey through the development of thinking and ideas in geology. There were the ongoing tussles throughout the 18th and 19th centuries between those who believed in a creationist 6,000-year-old Earth and those who realised that much deeper time was needed to explain most geological phenomena. There were verbal battles and spats between those who believed in Uniformitarianism, such as Hutton and Lyell, and advocates of Catastrophism, proposed by Cuvier and others. In later years, similar ideological arguments centred on Wegener's theory of continental drift, which led to the concept of plate tectonics, as shown by the maps of seafloor spreading produced by Marie Tharp. She is one of only four women included in the book, since for many years geology was not considered a suitable subject for females to study. Other ideas, such as James Dwight Dana's synclinal theory, may now be largely disproved and forgotten, but they played their part in the progression of the science of geology.

We hear about brilliant lecturer Adam Sedgwick (his dictum "I cannot promise to teach you all geology; I can only fire your imaginations" clearly worked for one of his students, a certain Charles Darwin), who had a long running battle with his equally eminent erstwhile friend, Roderick Murchison, about the boundary between the Silurian and the Cambrian. This was ultimately solved by Charles Lapworth with the introduction of the Ordovician. Two men, Ben Peach and John Horne, have their stories told together, because their work unravelling the complex geology of the Scottish Highlands, and thus the theory of thrust tectonics, was so intertwined.



There are well known names in the story of geology: William Smith, the maker of the first geological map of England and Wales; Mary Anning, fossil-hunter extraordinaire; and Peter Vail, who was instrumental in the development of the theory of sequence stratigraphy. Others are, to me at least, less well known – Henry Sorby, Alexander Karpinsky and Maureen Raymo, for example – but Mike very succinctly identifies the significance of each person and their work in the development of the earth sciences.

The great geologists described in this book come from very varied backgrounds. There are Victorian gentlemen scientists and polymaths; dedicated academic researchers; inspiring teachers; professional mineral and oil explorers; and enthusiastic amateurs who made breakthroughs often initially derided by the professionals. Mike brings his chosen subjects to life in brief potted biographies, each only a few pages long but full of information, summarising their lives and how their ideas fit into and helped develop the bigger picture of geological knowledge. It is very well illustrated, not just with pictures of the subjects and their work, but of important places in their lives. Each great geologist comes with a short list of references, which demonstrates the extensive reading and research Mike has put into learning about each of his subjects.

Free Gift to Geoscientists

This excellent book is a free gift to the geoscience community from Mike and his employers, Halliburton. It is available as a downloadable e-book from the address below. There are limited hard copies available via Mike. It is also available for loan via the Geological Society Library and British Lending Library and will be raffled by *GEO ExPro* at upcoming conferences.

As the author explains, this is a personal selection, and also inevitably UK-centric and biased towards stratigraphy, Mike's area of expertise. So who would you add to the list? ■

Great Geologists

By M. D. Simmons. Halliburton

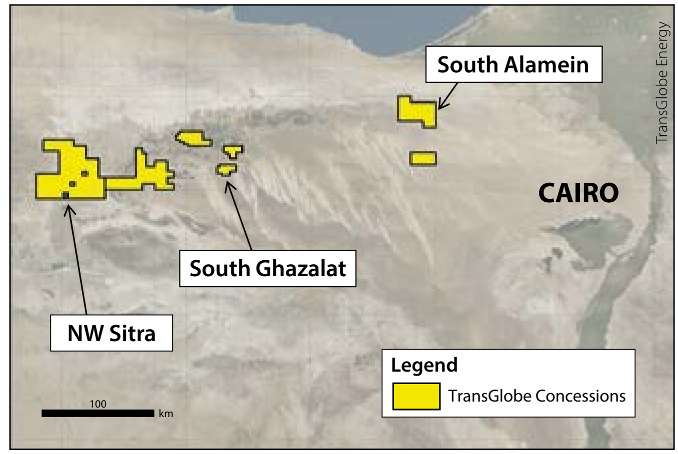
https://joom.ag/ggLa

Mike.Simmons@halliburton.com

Egypt: Western Desert Confirmation

In November 2018 **TransGlobe Energy** announced a potential light oil discovery with its **SGZ-6X** exploration well on the **South Ghazalat** concession in **Egypt's Western Desert**, about 300 km west of Cairo. The company has now confirmed this to be a major discovery, having announced that on test the well flowed a combined 3,840 bopd of light (35–38° API) oil from three intervals in the Cenomanian Upper and Lower Bahariya Formations. Based on these positive results, it will begin preparing a development plan for the field.

Since 2012 TransGlobe has steadily built up its acreage position in the Western Desert and now has approximately 4,625 km^2 covering three concessions: South Alamein, North West Sitra and South Ghazalat, operator in all three. The company committed to a work programme of US$8 million at South Ghazalat in the first phase, consisting of 3D seismic and two wells. It acquired about 400 km^2 of 3D seismic during 2015 and with the completion of SGZ-6X has met the financial commitments for the current exploration phase.



The 1,414 km^2 South Ghazalat PSC is located in the prolific **Abu Gharadig Basin**, a deep east–west trending asymmetric graben, about 300 km wide and 60 km north–south. ■

South Africa: Play Opener

In early February **Total** announced a significant gas-condensate discovery in the **deepwater Outeniqua Basin**, 175 km off the southern coast of **South Africa**. The **Brulpadda** well discovered 57m of net pay in Lower Cretaceous post-rift reservoirs, and drilling continued to find further reserves in the Brulpadda Deep prospect before reaching TD at 3,633m. The well is a play opener in this underexplored area, where several other prospects have been identified in a deep marine fan sandstone system within combined stratigraphic/structural traps. Potential for a multi-billion barrel resource has been suggested.

Brulpadda is in **Block 11B/12B**, which covers an area of 19,000 km^2, with water depths ranging from 200 to 1,800m. The prospects lie in the south-west corner of the block. Total initially tried to drill the well in 2014, but the attempt had to be abandoned due to harsh weather conditions, which will undoubtedly be an important issue to consider in development plans. The *Odfjell Deepsea Stavanger* semi-submersible rig re-entered the well, which is in 1,431m of water, in December 2018,

Following the success of Brulpadda and confirmation of the play potential, Total and its partners Qatar Petroleum (25%), CNR international (20%) and Main Street, a South African consortium (10%), plan to acquire 3D seismic this year, followed by up to four exploration wells on the licence. ■

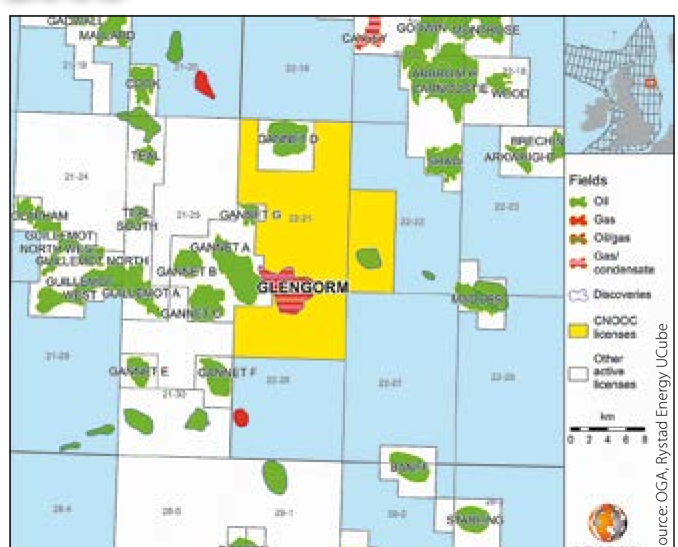
UK: Largest Discovery Since 2008

A major new gas find is the largest discovery in the **UK** offshore for eight years. **Glengorm**, announced by operator **CNOOC** in late January 2019, is reported to hold recoverable resources of **250 MMboe**. It is located in **Licence P2215** in the **Central North Sea** in waters of approximately 80m and was drilled to a total depth of 5,056m. The well encountered net gas and condensate pay zones with a total thickness of 37m in a high quality Upper Jurassic reservoir.

CNOOC Petroleum Europe Limited, a wholly-owned subsidiary of CNOOC Limited, is the operator of Licence P2215, holding 50% interest, while Total and Euroil both hold 25%.

According to Total, Glengorm lies close to existing infrastructure operated by the company, suggesting tie-back possibilities, such as to the Elgin-Franklin platform or the Culzean project, which was discovered in 2008 and scheduled to start production this year. It also presents some upside potential with several other prospects already identified on the same block.

This discovery in the mature UK Central North Sea province has caused great excitement, confirming the considerable remaining potential in the region, especially since Glengorm was first mapped as a prospect around 20 years ago. However,



as the gas is reservoired in a complex high-pressure, high-temperature environment, further evaluation and development could prove both technically challenging and expensive. ■

The Importance of Mentoring

Geoscientist **Paola Tello Guerrero** explains why she thinks mentoring is important – for both sides of the relationship.

At what stage in your career did you first find a mentor?
At a crucial moment, when I moved continents for work. I applied to the EAGE mentoring programme after moving from Colombia to England with just five years of work experience. I can proudly say I have a fantastic mentor; she is not just an excellent senior professional in the same area in which I work, with plenty of experience; she is a really good person, with a sense of humour and is very committed to social causes.

What does your mentor do for you?
Listen and guide. She has a bigger picture of the issues I present to her and guides my ideas to progress when I feel I cannot. She also joins me in celebrating my professional victories.

What do you think is the best way to find a mentor?
Firstly, have clarity: understand both where you are and where you want to be. If you don't have a clear landscape, then write down the options that you know you don't want, so at least you will know where you don't want to end up. Secondly, decide on the profile of your mentor. Ideally you want somebody working in the same area of work but at a higher level. You can also choose your hero – the professional you want to be in a few years.

Finally, research your prospective mentor before contacting them. There are many mentoring programmes where the organisers do the profile matching for you, otherwise you will need to choose someone yourself. Try to understand how to introduce and create the link with your mentor. It always helps to think what you can bring to your mentor, because this is not a one-way relationship and there should be benefit to both sides.

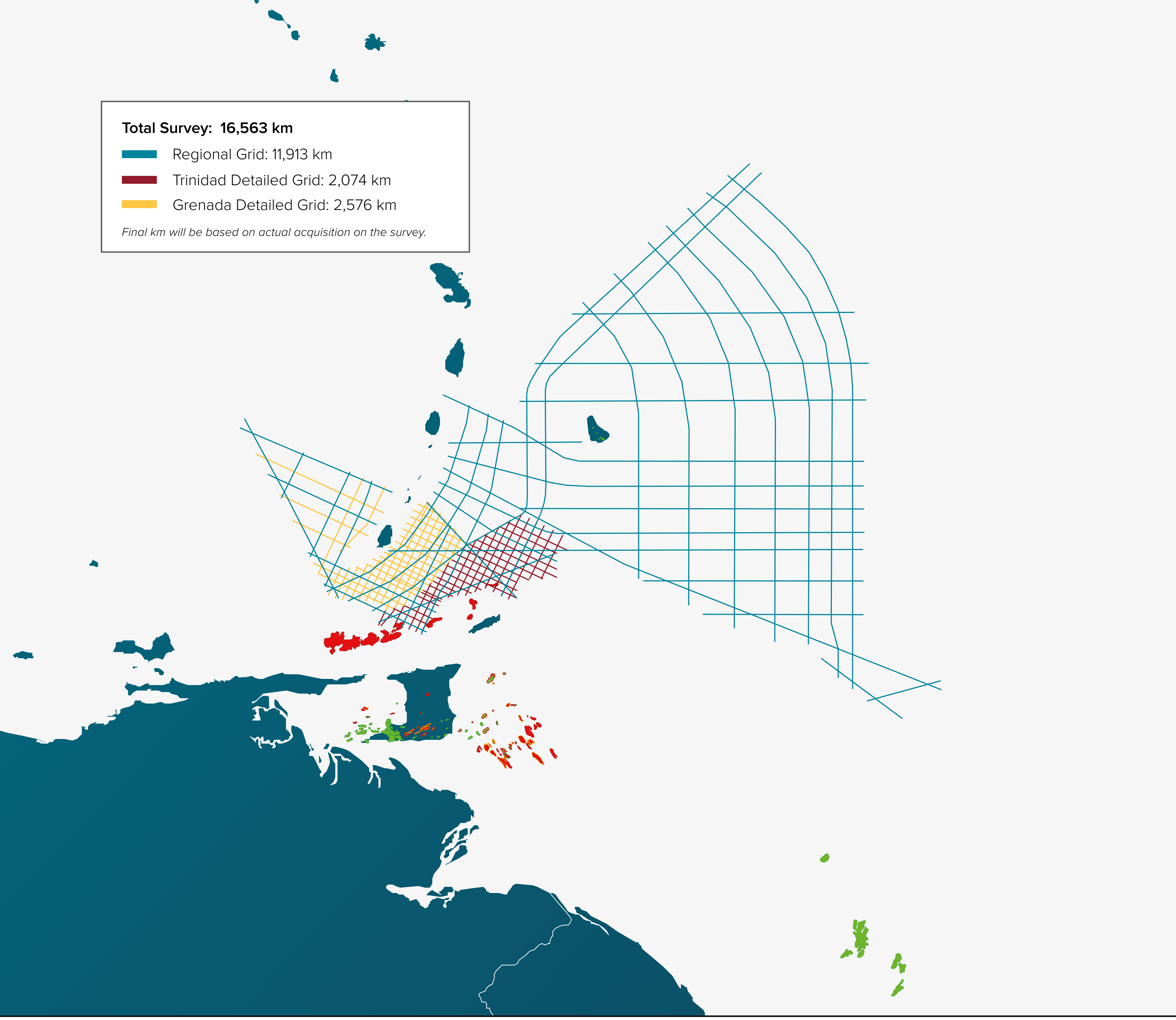
What is the most import aspect of being mentored?
It is neutral input – they are not your family, your colleagues, or your friends. It is a special relationship because they want the best for you, but they don't get involved. It helps to have clear communication, and lot of honesty and clarity. You can have more than one mentor, it all depends on your projects and your dreams.

What do you think mentors get out of the experience?
This can be an intergenerational and sometimes multicultural experience, and we all know that these things make us grow as a person. I hope my mentor understands a little bit more about Latin culture, has revived her interest in climate change and enjoys grappling with my ideas and challenges.

What qualities make a good mentor?
- An open mind: a mentor must be willing to propose creative approaches to the mentee;
- Generosity: a mentor wants to share their experience, their time and their advice;
- Kindness: most of the time the mentee is full of doubts and mentoring can be either a good or bad experience, depending on whether the mentor is able to get the best out of the mentee.

When do you expect to take on the role yourself?
I am already mentoring a younger professional, and that's the value of a mentoring programme – it multiplies. You support one person and that person will support somebody else. Mentoring means reviving your earlier career steps while helping others to be more effective. ■

Paola Tello Guerrero was born and educated in Colombia and is a physicist at ALS Petrophysics in Guildford, UK. She participated in Homeward Bound 2018, an all-female-scientist Antarctic expedition, and is part of a global initiative of women working for climate action. She founded 'Antarctica for the Brave', an educational project for children that combines climate change and equality.


Total Survey: 16,563 km
Regional Grid: 11,913 km
Trinidad Detailed Grid: 2,074 km
Grenada Detailed Grid: 2,576 km
Final km will be based on actual acquisition on the survey.

Will US Oil Take Over the World?

Is the continuing rise in production from unconventional sources in the US financially viable?

"In a major shift, the United States is set to produce more oil and liquids than Russia and Saudi Arabia *combined* by 2025." This is the conclusion of a forecast by Rystad Energy, which states that, using its base case oil price scenario, US liquids production is forecast to surpass 24 MMbopd over the next six years.

The US, Russia and Saudi Arabia have regularly swapped places in the list of top producers, but this would be the first time since 1970 that the US market share has been greater than the sum of the production of the other two. The scenario assumes that average oil prices stay above $50. This rise in production is, of course, driven by tight oil from major US shale basins such as the Permian in East Texas and New Mexico.

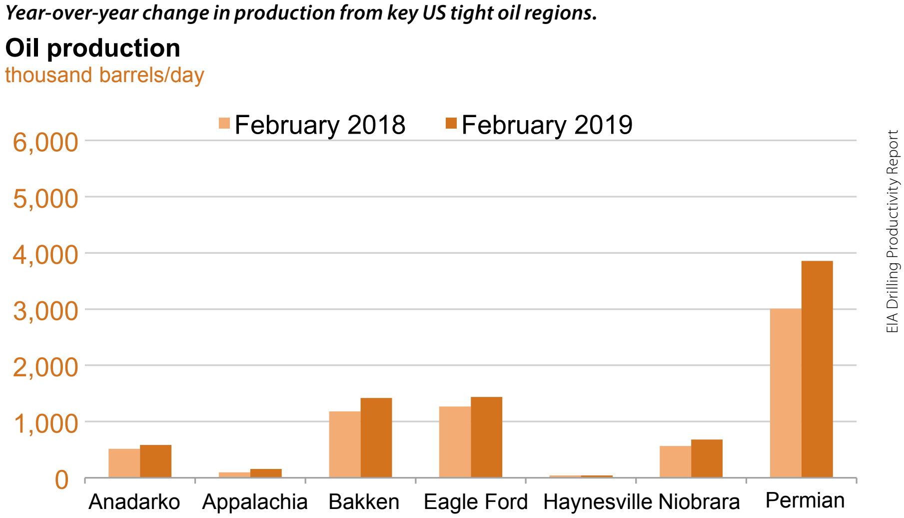
Other commentators, however, point to the high decline rate of tight oil wells, which means that more and more have to be drilled to keep up this production rate. Energy specialist Art Berman stated recently that only 33% of tight oil companies had positive cash flow in Q3 2018 and that capital expenses have exceeded cash from operations in almost every quarter for the last decade. While drilling costs have dropped significantly, tight oil still remains a marginal business, and several analysts have pointed out that US producers are finding it hard to generate cashflow at present prices, as operators have to drill yet more wells to meet growth targets.

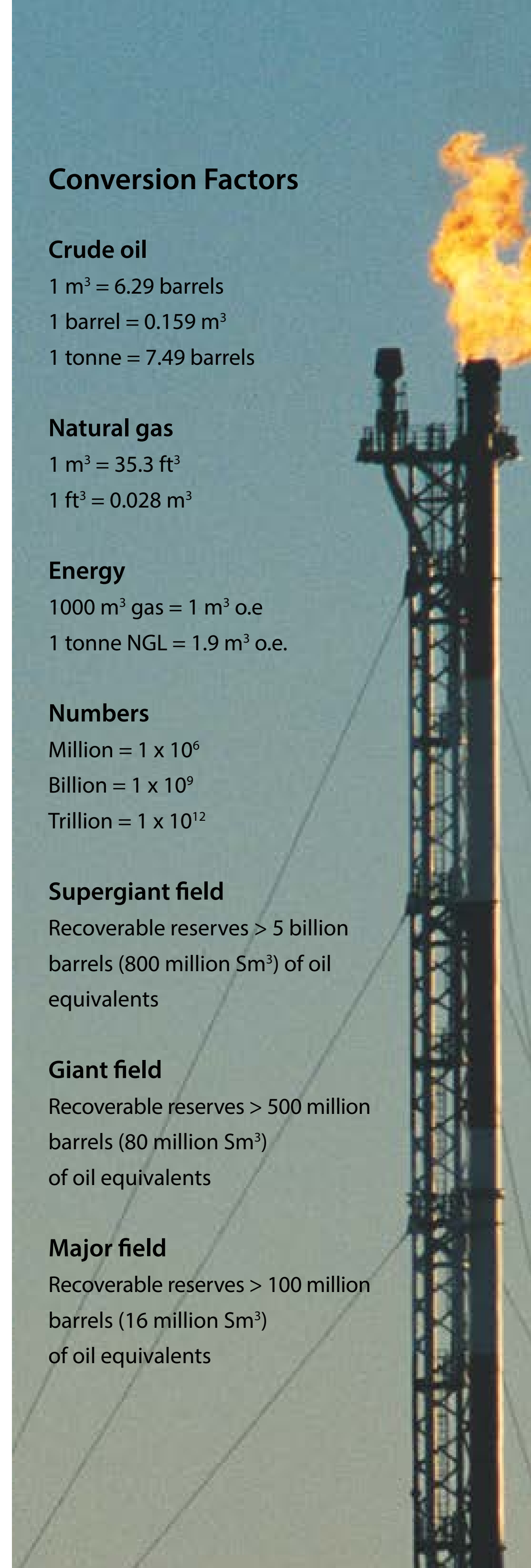
In addition, an investigation by the *Wall Street Journal* in January suggests that "thousands of shale wells drilled in the last five years are pumping less oil and gas than their owners forecast to investors". The journalists analysed 16,000 wells operated by 29 of the biggest producers and compared well productivity estimates made by shale oil companies to projections from third parties, based on public data performance. They found that two-thirds of projections made by companies between 2014 and 2017 in America's four hottest drilling regions appeared to have been overly optimistic. Several companies, it should be added, disputed these findings, partly because few organisations actually disclose how they come to the figures in their forecasts.

Rystad, however, believes that US shale oil production will continue to increase for some time to come, because about 70% of the economically recoverable resources in its base case oil price scenario have yet to be developed.

Jane Whaley

Year-over-year change in production from key US tight oil regions.





Conversion Factors

Crude oil
1 m³ = 6.29 barrels
1 barrel = 0.159 m³
1 tonne = 7.49 barrels

Natural gas
1 m³ = 35.3 ft³
1 ft³ = 0.028 m³

Energy
1000 m³ gas = 1 m³ o.e
1 tonne NGL = 1.9 m³ 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 Sm³) of oil equivalents

Giant field
Recoverable reserves > 500 million barrels (80 million Sm³) of oil equivalents

Major field
Recoverable reserves > 100 million barrels (16 million Sm³) of oil equivalents

Historic oil price