THE GLOBAL ENERGY SECTOR FROM A SUBSURFACE PERSPECTIVE

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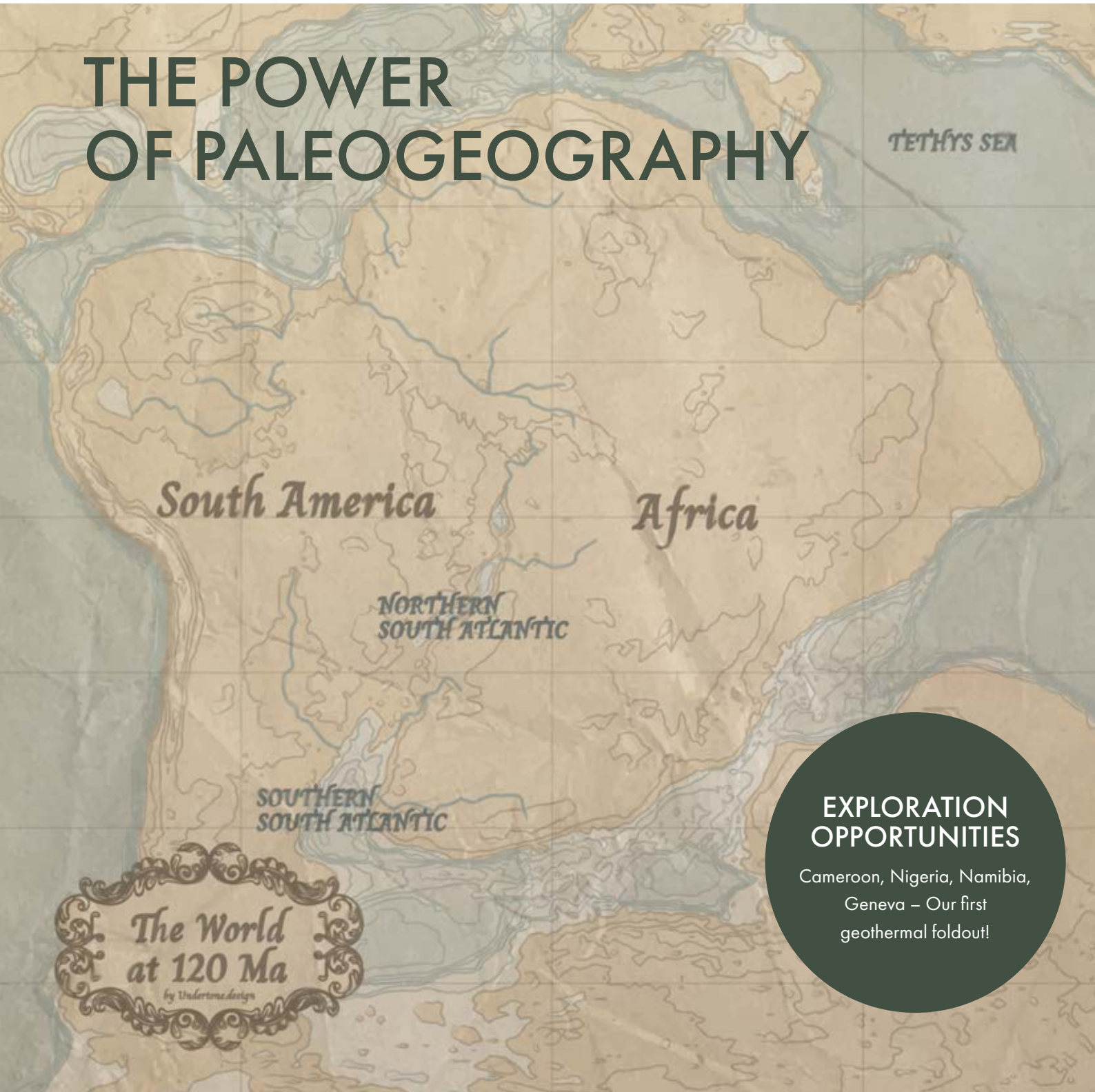
# THE POWER OF PALEOGEOGRAPHY

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COVER ILLUSTRATION: FABIO CRAMERI

# Nearology and paleogeography

ONLY RECENTLY I heard a new term that circulates amongst the oil company investor community: nearology. It is used to describe the strategy, or better, the marketing strategy, of some players to claim that their acreage offers high potential simply because it is located close – or near – to where a recent promising discovery was made.

**"This reiterates the need for members of the geoscience community to challenge claims based on nearology and to put in simple terms that the likelihood of finding oil and gas does not necessarily increase as you go nearer a major find."**

Among geoscientists, there is no need to explain why such a marketing strategy is mired with problems. But for those without any geological knowledge, for those seeking to invest their hard-earned money into a vehicle that may return a decent profit, it is simply a matter of sending false hopes.

Instead, what these players should adopt is paleogeography. As we will show with some great examples in our cover story, provided by our readers from all over the world, it is the understanding of the evolution of landscapes and the drift of continents that will allow explorers a much better handle on reservoir, seal and source rock distribution. Only then, even without having drilled a single well, a framework will be in place to better predict the presence or absence of these key ingredients for every play.

This also reiterates the need for members of the geoscience community to challenge claims based on nearology and to put in simple terms that the likelihood of finding oil and gas does not necessarily increase as you go nearer a major find.

*Henk Kombrink*

## BEHIND THE COVER

Geoscientists like maps. That is a fact. Vintage maps often have that additional appeal, simply because they allow reminiscing about the times when explorers roamed the oceans and far-away lands in search of hidden riches. With that in mind, and given the theme of our cover story on the Power of Paleogeography, we asked Swiss geologist and designer Fabio Crameri to create a paleogeographic map in a vintage style. In the light of Africa Oil Week, and with the Namibia hotspot at the back of our heads, we chose the South Atlantic in Aptian times as a good candidate. Please see more of Fabio's work at *undertone.design*.


**Comments: magazine@geoexpro.com**
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## Drilling deep for science and exploration

**Two wells currently being drilled in China are an example of going to places where no one has gone before**

A FEW MONTHS AGO, a series of press releases were issued around the same time, announcing the drilling of two ultra-deep wells in the area of the Tarim Basin in China. Apart from a mention that the wells would target an interval older than the Cretaceous, not much more geological detail could be distilled from these statements.

It is not a surprise that it is rather complicated to find more information about the two wells drilled by CNPC on the internet, but a recent report written by Enverus for the Seapex Press sheds a little bit more light on what these boreholes are about.

Both wells are being drilled for scientific and commercial reasons, i.e., the exploration for oil and gas at deeper intervals. With an expected terminal depth of between 10,000 and 11,000 m, they will take almost two years to complete. In addition, at one of these wells, CNPC is expecting ten different pressure cells to be penetrated, adding to the complex nature of the operation.

The oldest stratigraphic unit from which oil and gas production currently takes place in the Tarim Basin is the Ordovician at 7,000 m. This means that it could be the more than 485 million years old Cambrian the wells are after. Even without knowing the exact geological setting, the fact that it is even tried to find oil and gas in strata this deep and old is quite remarkable. It would take a long time to convince exploration managers to invest in drilling to these depths in most of the currently active petroleum basins across the world.

## Grenadier, a turning point for Angola's pre-salt play?

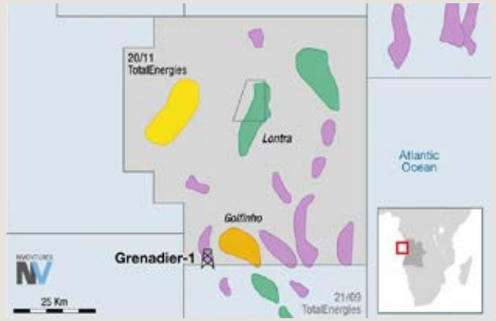
**If positive, the well may breathe life into the fascinating Angolan pre-salt play, thereby potentially extending the country's run as a major deepwater oil producer in sub-Saharan Africa**

TOTALENERGIES is drilling Grenadier-1, on block 20/11 in the Kwanza basin offshore Angola. The Valaris DS-12 drillship is carrying out the work for TotalEnergies and partner Sonangol in 1500 m water.

Given the proximity of the Grenadier-1 location to the Golfinho discovery (10 km), it is likely that the current well is targeting a similar pre-salt carbonate structure. These carbonate bodies lie within the late rift section in the Apto-Barremian and have developed over basement highs forming a 'string of pearls' fairway along the basement ridges. TotalEnergies signed a sale and purchase agreement in 2019 for the block, where multiple discoveries have been made previously.

Blocks 20 and 21 have a long history of exploration in the Kwanza Basin. In the late '90s, it was one of the first deepwater salt basins to be tackled after phenomenal success was achieved drilling similar targets offshore Brazil such as Tupi. With great results to the north in post-salt successions in the Lower Congo basin – for example Girassol – BHP at the time acquired large 3D datasets to image the pre-salt, attempting to tie the previously conjugate South American Santos and Campos basins in terms of both geology and oil potential.

*Peter Elliott, NVentures*




PHOTOGRAPHY: JUNIPERPHOTON VIA UNSPLASH

# Nodes are gaining ground

**In 2023, more surveys have been performed using nodes on the seafloor than traditional towed seismic on the NCS**

"OCEAN BOTTOM seismic is considered to provide the highest quality acquisitions", said Mehul Supawala, Vice President Technology & Innovation at Shearwater, during a keynote speech at the NCS Exploration Technology conference in Oslo in September.

Supawala noted that during the last ten years, there has been a shift in how seismic acquisitions are performed on the Norwegian Continental Shelf (NCS). In 2013, more than 80 per cent of the surveys were carried out using towed streamers. This year, nodes and hybrid surveys are estimated to account for more than 60 per cent.

One reason is likely the companies' increased focus on near-field exploration. Further, improvements in recent years have made the technology more competitive, including smaller, less power-consuming nodes.

"Nodes that originally weighed over 100 kg, now weigh less than 20 kg. Recently, we have even seen nodes weighing 4.5 kg", Supawala pointed out.

Mikael Trulsvik, Director Business Development – Europe in TGS, confirmed that the trend of increased node use is global. It is estimated that nodes have reached a 33 per cent seismic market share worldwide in 2023 (2013: <10 per cent).

He further noted that the node market is tight. The global node population counts about 120 – 135,000, and most of those are currently in the water.

All node session presenters envisioned even more cost-effective, faster to deploy, and better nodes in the future. Keywords are optimization of survey designs, improved node handling systems, and the use of AI and modern technology in vessel positioning, data processing and interpretation, and workflows.

*Ronny Setså, GeoPublishing*

Improvements in technology, size, and node handling systems make nodes more viable for seismic acquisitions.

# Advancing Ocean Bottom Node surveys through autonomy

**In hydrocarbon exploration, innovation is essential for improving efficiency and sustainability, particularly in node operations**

BY INCORPORATING Autonomous Underwater Vehicles (AUV) and utilizing the latest machine learning advancements, ocean bottom node (OBN) deployment and recovery can be far more efficient. This will make the high-quality data from OBN more accessible to the broader industry.

PXGEO's MantaRay is based on the Saab Sabretooth AUV. The Sabretooth platform has been operating and developed for over a decade by the Swedish defense contractor. It is a fully electrically powered vehicle designed for autonomous operations and handling extensive payloads. Its reliance on electrical systems improves reliability and reduces maintenance. Enhanced with a variable buoyancy system, the MantaRay is neutrally buoyant and can operate in depths ranging from 5 to 3,000 meters and achieve speeds of up to five knots.

Using stereographic cameras and AI-powered 3D visual recognition, MantaRay ensures precise node placement and retrieval during its pre-programmed mission. Operational modeling has shown that MantaRay can reduce survey duration by 50%, resulting in faster seismic data delivery while minimizing operational exposure and environmental impact.

These technological advancements allow for faster, more efficient, and environmentally friendly operations, creating a promising future for ocean bottom node seismic.

*Erik Burlid, PXGEO*

PHOTOGRAPHY: INAPRIL; SOURCE: PXGEO

# Finding solutions to the energy trilemma: Affordability, security, and climate impact

**The 2023 AAPG International Conference and Exhibition (ICE) to be held in Madrid, Spain, aims to bring together geoscientists from all around the world, providing them with a unique platform to exchange and present their knowledge, insights, and research findings**

THE CONFERENCE OFFERS an unparalleled opportunity for collaboration, discussion, and networking among professionals in the geosciences field. This year's conference theme, "Geoscience Solutions to the Energy Trilemma", aims to connect our professional community with the current challenges that the Global Energy Sector is going through: reliability, affordability, and sustainability.

Petroleum Geoscientists and Engineers have contributed greatly to human progress, finding, and developing reliable and affordable energy for decades. Our latest challenge is to expand our impact to the sustainability part of the equation. ICE 2023 will address old and new challenges and the opportunities they represent for the oil Industry professionals' future.

Overall, this gathering of geoscientists fosters a collaborative and inclusive environment where ideas can flourish, new solutions can be developed, and the geosciences community can collectively work towards a more sustainable and prosperous future.

*Further information at: ICEevent.org*

# The helium well that produces 93% $CO_2$

**Europe currently does not have its own helium supply and therefore fully relies on import. However, soaring helium demand and prices have now made it economic to explore for reservoirs with very low helium concentrations**

IN THE USA, 0.3% or 3000 ppm helium in the gas stream is regarded as the cut off for profitable onshore production. Yet, French company 45-8 Energy has identified a prospect that contains an order of magnitude less helium that it hopes to start producing soon.

The prospect is situated in the hamlet of Fonts Bouillants, around 250 km south of Paris at the boundary between the Paris Basin and Massif Central. As the village name already suggests, natural spring water rich in gas wells up here along the Saint Parize fault, a regional fault that possibly extends into basement rocks. The gas migrates along the fault from great depths before mixing with groundwater near the surface and subsequently surfacing altogether.

Field analysis of the gas composition at the Fonts Bouillants spring found the gas to be made up of 430 ppm helium, 93% $CO_2$ and 7% $N_2$. Further analyses have also shown that $CO_2$ behaves independently from $N_2$, indicating they each have a different source.

The exploration licence for the Fonts Bouillants prospect extends to 100 m depth. 45-8 Energy will drill to below the groundwater aquifer to produce the gas, upon which the $CO_2$ and helium are separated at surface. The $CO_2$ will be sold to the local food producers and other industries. Production is scheduled to start in May 2024.

*Mariël Reitsma, HRH Geology*

PHOTOGRAPHY: JORGE FERNÁNDEZ SALAS VIA UNSPLASH; LÉONARD COTTE VIA UNSPLASH

## An arena for a new ecosystem

**A handful of countries have taken the lead in developing technology and knowledge for the exploration and extraction of deep-sea minerals. In December, we are bringing industry professionals, the geoscience community, policymakers, and other stakeholders together to learn and share results, knowledge, and opinions**

A POTENTIAL NEW global industry is emerging. Several countries worldwide are preparing for the deep dive. The demand for critical minerals might be greater than what land-based mining and recycling can provide in the coming years, and the value chains are highly geographically concentrated, making them vulnerable to political instability, geopolitical risks, natural disasters, and possible export restrictions.

The race towards the production of deep-sea minerals has started. In Norway, the Norwegian Petroleum Directorate has released a resource assessment, and the government has put forward a parliamentary proposal on opening the extended Norwegian Continental Shelf for mineral activities.

Internationally, companies are positioning themselves in the Clarion-Clipperton Zone in the Pacific Ocean as the International Seabed Authority (ISA) is developing exploitation regulations. It is expected that ISA will adopt the regulations in 2025.

At the 3rd annual conference on Deep Sea Minerals in Bergen, Norway in December, companies, institutions, academia, and other stakeholders will network, share, and learn from each other.

Topics will include technologies for exploration, exploitation and processing, environmental assessment and monitoring, public perception/license to operate, showcases, methodologies, and workflows.

*More information at: deepseaminerals.net*


## A karstified, erosional landscape may be key to store energy in Geneva

**Well results and seismic data have now allowed the mapping of an extensive karst and paleo drainage system that could host the porous sands needed to store thermal energy**

NEW 3D SEISMIC data reveals unexpected karsts and erosional morphologies developed at the Cretaceous Paleogene Transition in the Geneva Basin, western Switzerland, opening new avenues for an underground thermal energy storage system.

The Geneva Basin is currently the focus of intense geothermal exploration activities as part of the energy transition agenda of the Canton of Geneva. This has promoted drilling of geothermal exploration wells and recently the acquisition of 3D seismic data, the results of which are further discussed on pages 92-96.

The 3D seismic reflection dataset revealed a spectacular morpho-tectonically modulated landscape formed during the Cretaceous-Paleogene transition when the area was subaerially exposed.

Several subcircular and irregular karst-related depressions have been mapped, transitioning into a zone characterised by an extensive canyon system.

Before the 3D seismic was acquired, the GEo-02 exploration borehole accidently drilled one of these karst features. It recorded approximately 150 m of well-sorted, porous quartz-rich Siderolithic sandstone. This is the thickest known subsurface occurrence of this unit to date in the west of Switzerland.

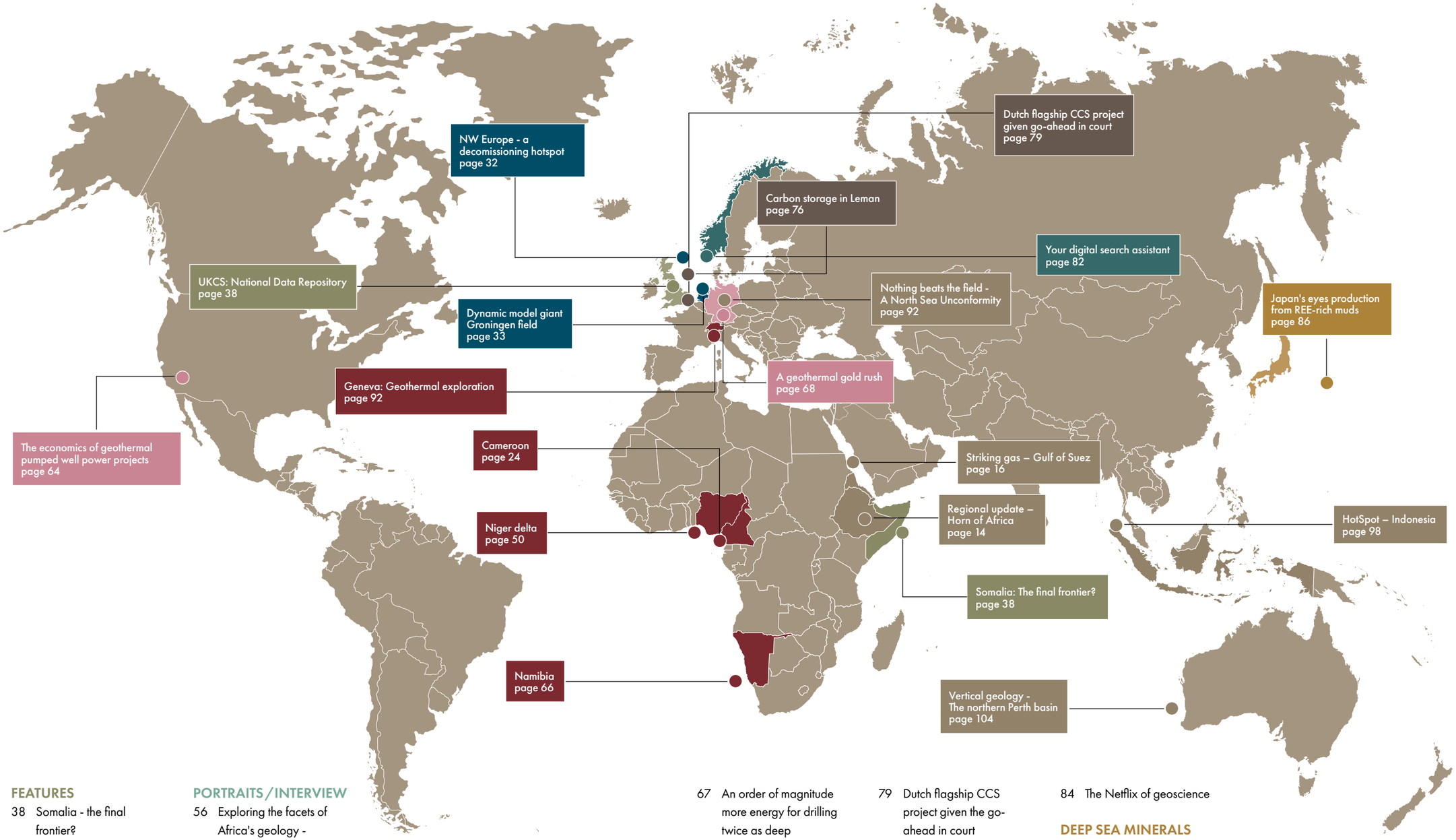
*Andrea Moscariello, Ovie Emmanuel Eruteya and Aurelia Criniere, University of Geneva*

*More information at: unige.ch/ge-rgba*


SOURCE: UNIVERSITY OF GENEVA

CONTENT





# From near misses to commercial success

**The Horn of Africa is waiting for its first exploration breakthrough, which may come sooner than later**

THE HORN OF AFRICA, comprising Eritrea, Djibouti, Ethiopia and Somalia holds many ancient geological trends including the failed Karoo and Jurassic and Cretaceous rifts that record the fragmentation of Gondwana super-continent with numerous reported oil seeps. Despite that, and the efforts of a wide range of companies working from pre-seismic 1940s to the present day, there is no oil or gas production. As we shall see, explorers ranging from NOCs and major IOCs through to ambitious juniors have come close.

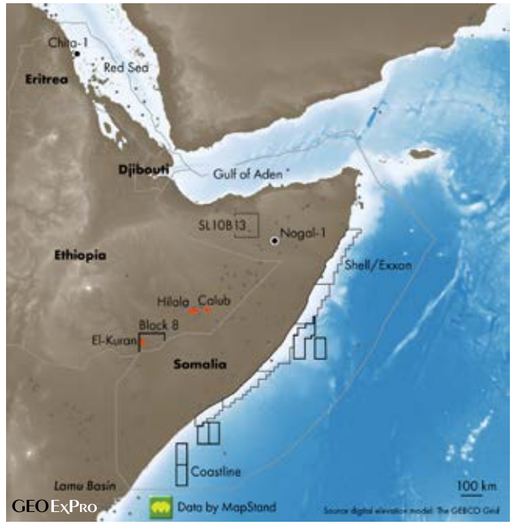
In Eritrea's offshore salt basin in the northwest of the region, exploration in the 1950s led to numerous oil discoveries. Recent drilling took place in 2005 when Perenco drilled the Chita-1 well in the Defnin Block, situated in the Red Sea Basin. The Ministry of Energy and Mines continues to offer through direct negotiations all available open acreage in the Red Sea and Mekele Basins for licensing.

In recent years there has been a lot of discussion on the development of the reported ~4 TCF Hilala and Calub gas fields in Ethiopia's Somali (formerly Ogaden) region. These two fields were discovered by Tenneco in the early 1970s. However, Tenneco was expelled by the former socialist government of Ethiopia in 1977, together with many other western companies. A former USSR company, Soviet Petroleum Exploration Expedition (SPEE) took over operatorship of the two fields, but a lack of progress since has led the authorities to cancel the POLY-GCL contracts in 2022.

The nearby El-Kuran gas field, which is reported to host 1.6 TCF, could tie in with the Hilala and Calun fields and create a material gas project in the region. New Age Limited is currently in the process of surrendering Block 8 as they were most likely awaiting the development of the neighbouring Hilala and Calub fields before committing to appraisal drilling.

Djibouti has seen very little exploration activity and has designated blocks covering the Guban and Red Sea Basins. In 2011, Oyster Oil and Gas was awarded four blocks in the country but it is thought these have been relinquished at the end of the first exploration phase.

Over the last 30 years or so, exploration activity in Somalia has been limited. Peace returned to Somalia in 2009 and the stable government has encouraged two 2D offshore seismic campaigns in 2014 and 2015. These lie in the southern part of Somalia's Indian Ocean margin and include the extension of Kenya's Lamu Basin, with reported multi-billion-barrel prospectivity.




Somalia's passive margin contains classic clastic plays and large carbonate build-ups and is often referred to in industry publications as "the most exciting unexplored margin in the world." Shell and partner ExxonMobil are the current holders of five blocks and, as a result of the 2020 1st Somalian Licensing Round, Coastline Exploration was awarded seven additional offshore blocks. Coastline is planning to acquire a new 3D seismic in the frontier province in 2023-2024 (see page 38-40).

Conoco's Nogal-1 proved a petroleum system in Puntland in 1990. In Somaliland, Genel Energy and RAK Gas currently hold licences. Genel is planning the Toosan-1 wildcat in the SL10B13 block in mid-2024.

In summary, the Horn of Africa has been the site of numerous hydrocarbon exploration attempts in the past, and near misses abound. Tackling these now proven hydrocarbon systems with modern seismic imaging technology is the key to bringing commercial success. ■

*Ian Cross - Moyes & Co*

# A deeper oil-bearing reservoir in the Gulf of Suez

**Operator Cheiron finds oil in the pre-Miocene Nubia sandstone for the first time in the GNN oil field area**

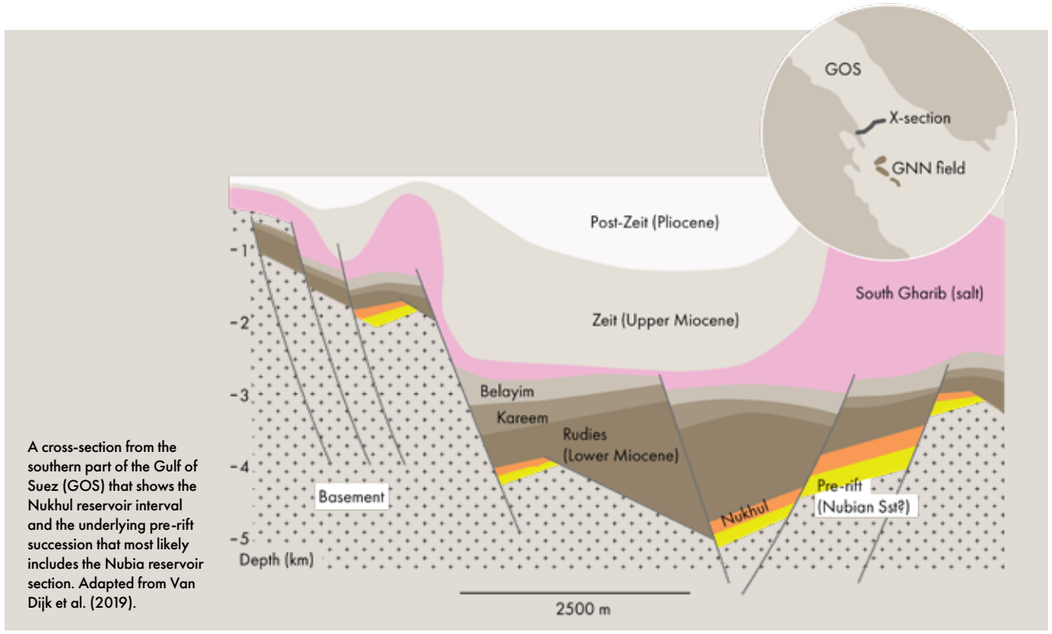
IN AUGUST, Cheiron announced the discovery of a 165 feet oil column in pre-Miocene Nubia Formation sandstones in exploration well GNN-11. The well was drilled into a fault block to the east of the GNN oil field. According to the operator, it was the first time that the Nubia Formation was proven hydrocarbon-bearing in the area - production from the GNN field takes place from the Lower Miocene Nukhul Formation.

We asked if Cheiron was able to share a seismic line with us, illustrating the geological setting of this recent find. Unfortunately, we did not hear back from them. The nearest seismic data we could get instead was from the Red Sea, which is a different setting altogether, so for this article we have re-drawn a cross-section that was published by Jan Pieter van Dijk in a 2019 paper entitled "Hydrocarbon Exploration and Production Potential of the Gulf of Suez Basin in the Framework of a New Tectonostratigraphic Model." The manuscript is also available via ResearchGate.

Even though the location of the section is about 20 kilometers to the northwest of the GNN field area, if the geological setting is somewhat comparable, it can be concluded that the Nubia Sandstone Formation may not have been that much deeper than the Nukhul sands itself and could in fact be directly underlying the Nukhul reservoir. The well may have been drilled in an area where either the Nukhul was missing due to erosion or faulting, or the proven column extended into the underlying Nubian sands.

In order to plan the well in this area, the quality of seismic data must have improved significantly over the past decades. A person with knowledge on the matter told us: "Getting decent imaging through the (Miocene) Zeit evaporites has always been a challenge, as previously one could never see what you were drilling for. I had to drill a well on PSTM 2D data in the Gulf of Suez in the mid 1990's and we just drilled into "the least bad seismic." The well was a duster, which is no surprise!"

The Nubia discovery in the GNN area has confirmed the exploration potential of the mature Gulf of Suez and Cheiron and partner Kufpec are now planning on drilling at least three more wells in the concession area. ■



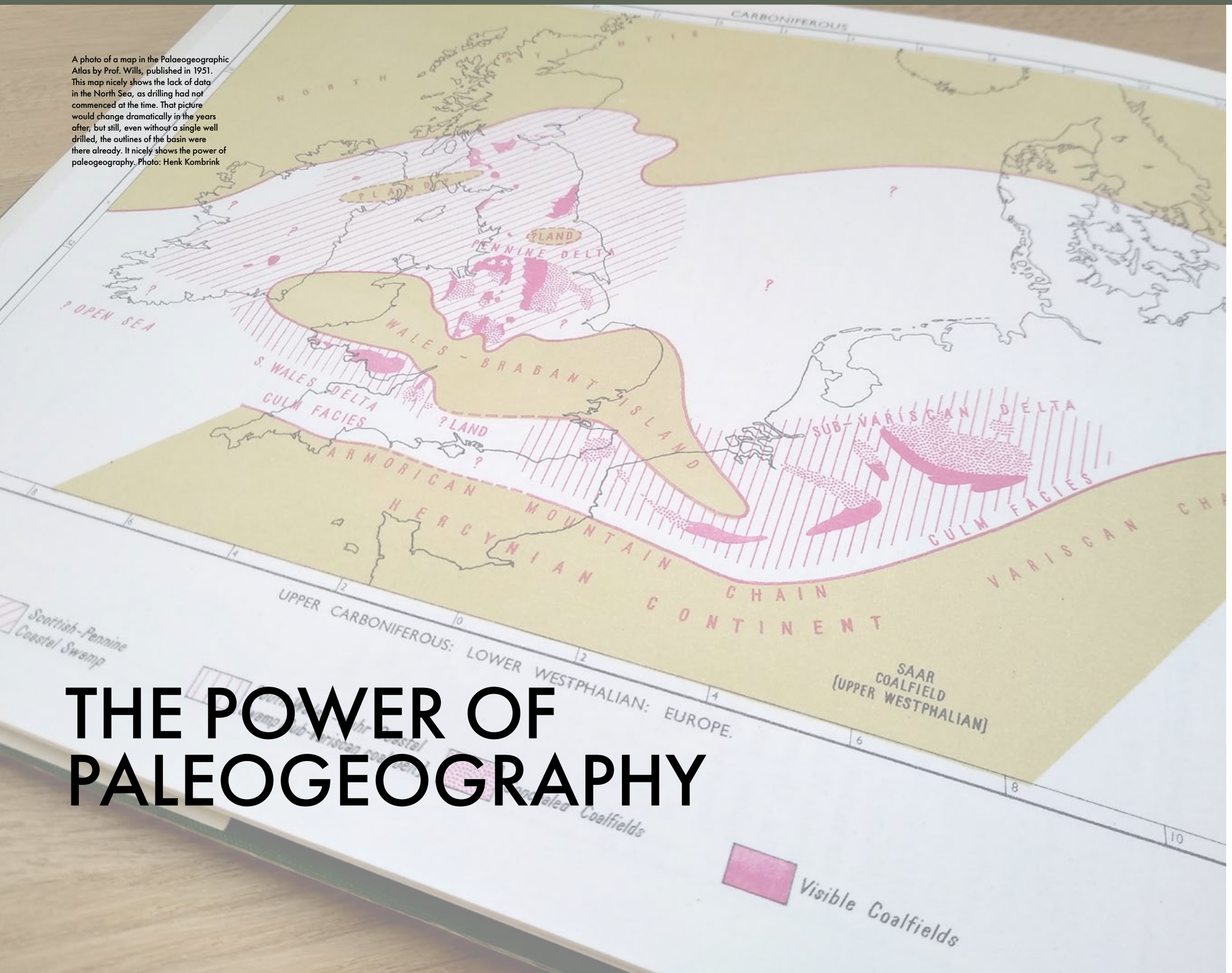

A cross-section from the southern part of the Gulf of Suez (GOS) that shows the Nukhul reservoir interval and the underlying pre-rift succession that most likely includes the Nubia reservoir section. Adapted from Van Dijk et al. (2019).

# COVER STORY

"Paleogeography is not only about de-risking a play, it is also about better understanding the risks and maybe, on that basis, not to drill a well at all."

*Jan de Jager - Geologist*

COVER STORY




A photo of a map in the Palaeogeographic Atlas by Prof. Wills, published in 1951. This map nicely shows the lack of data in the North Sea, as drilling had not commenced at the time. That picture would change dramatically in the years after, but still, even without a single well drilled, the outlines of the basin were there already. It nicely shows the power of paleogeography. Photo: Henk Kombrink

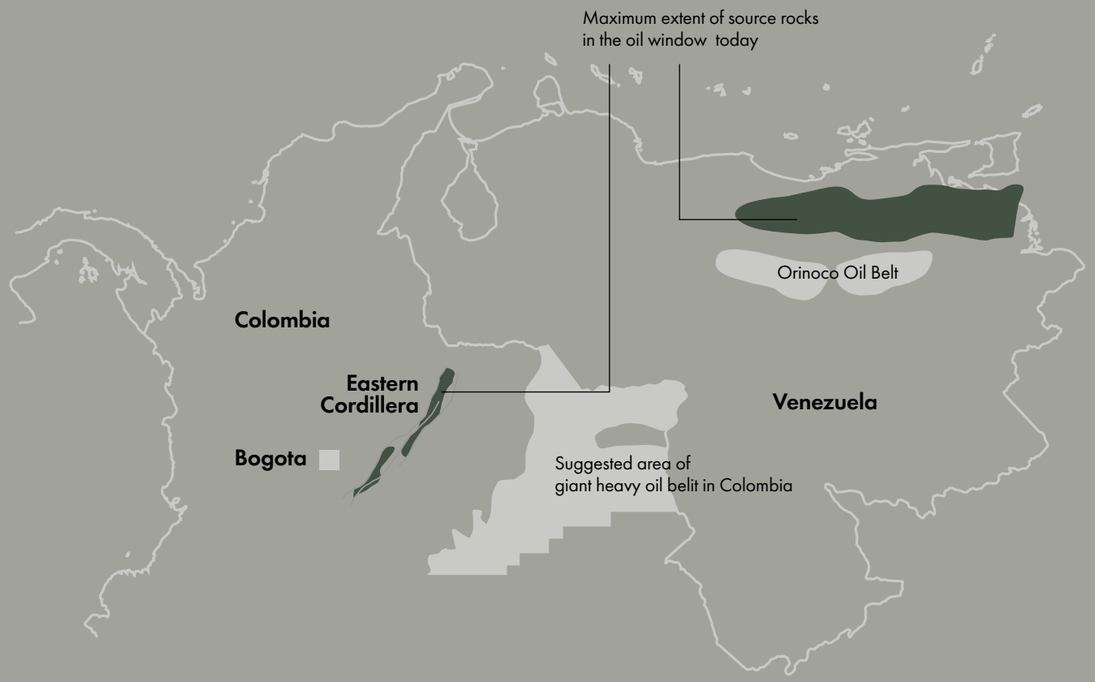
# THE POWER OF PALEOGEOGRAPHY

**HENK KOMBRINK**

**THIS COVER** story is the result of the input from many. And we got the input in a slightly unconventional way. Rather than approaching people who we think have knowledge on the matter, we put out a request on LinkedIn to ask for ideas on how paleogeography has helped people's or companies' exploration efforts. And the response has been amazing. From places all over the world we received emails, direct messages and even phone calls from enthusiastic geologists who were keen to share their stories.

This article summarises in a concise way the highlights of the material we received, whilst at the same time honouring the global distribution of the content we were provided with. In no way these case studies are being described at length, but by providing a glimpse we hope that the message gets across of how paleogeography has been used in the past and how it continues to be applied today.Before we start delving into the individual case studies on the next few pages, it is important to remind ourselves of an important insight provided by Jan de Jager from the Netherlands. In an email, Jan reiterated that paleogeography is not only about de-risking a play, it is also about better understanding the risks and maybe, on that basis, not to drill a well at all. There is one example here that is very much applicable to that! Up to you to find out which one it is! ▸

# ON THE LOOKOUT FOR AN ORINOCO HEAVY OIL BELT IN COLOMBIA



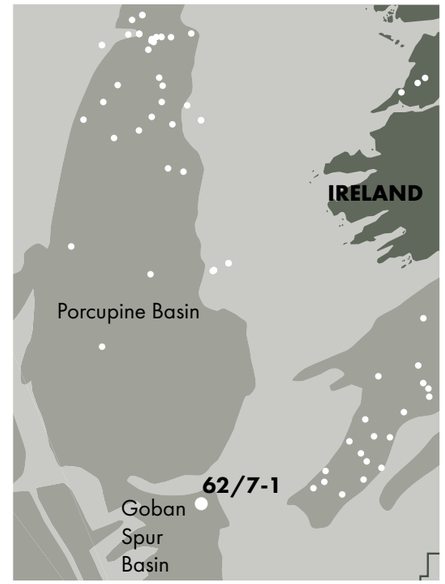

Many geologists in Colombia grew up with a pressing question in their minds: "Is there an equivalent of the Orinoco Heavy Oil as present in Venezuela in our country? And it was not only geologists in Colombia who were fascinated by this question; some of the world's majors were intrigued by it too, and even had acreage in the area where they expected the heavy oil to be. However, no heavy oil in the same quantities as found in Venezuela was ever discovered in Colombia. A paleogeographic reconstruction by a team from Ecopetrol ultimately provided an answer to this question. The answer lies in source rocks. In contrast to Venezuela, the main Cretaceous source rock in Colombia was uplifted into the Eastern Cordillera to an extent that the kitchen was reduced in size dramatically - see map. For that reason, no massive volumes of oil were generated and no migration took place in the same way as we see across the border.

There is oil in Colombia, but it is found closer to where the current source rocks are and in smaller volumes. It took an extensive study by the Ecopetrol team to properly reconstruct the uplift of the Eastern Cordillera and provide the scientific basis for understanding the lack of an "Orinoco Heavy Oil belt" in Colombia. But it was the paleogeographic reconstruction and the subsequent understanding of the timing of uplift that solved the puzzle and formed the answer to the question that had not only bothered Colombian geologists for a long time, but also resulted in unsuccesful exploration by majors.

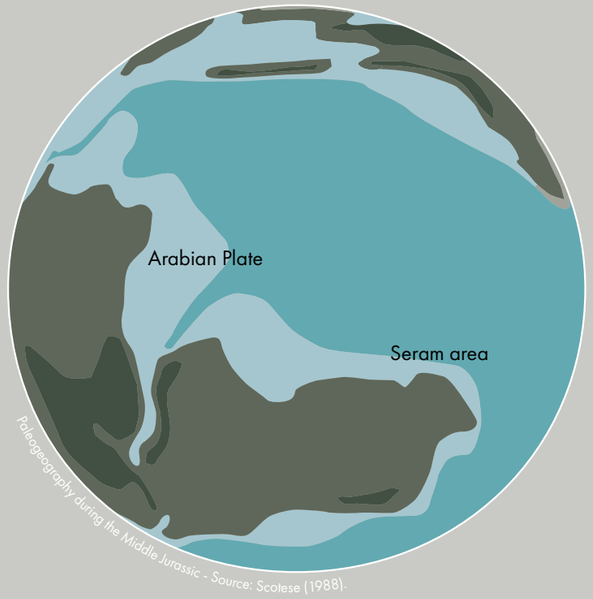


## DRILLING A WILDCAT IN IRELAND

It is 1982. 3D seismic did not yet exist and 2D only gave away so much when compared to today's standards. For that reason, paleogeography played an even more important role in those days. The 62/7-1 well drilled by Exxon offshore Ireland, 200 km off the coast, is a very interesting example in that regard. As Conor O'Sullivan from Jacobs noted in a message to us: "Exxon had built up a series of paleogeographic maps from both industry and academia over several years and were targeting Middle Jurassic shoreface sandstones. While they only found oil shows, they did manage to find those very high quality shoreface sands, which is pretty impressive." Patrick Shannon, who was working at the Petroleum Affairs Division of the Irish Department of Energy at the time, wrote to us: "When this well was drilled, it was a real frontier area with no well control at all. Only about two other wells had been drilled in the waters of the North Atlantic before. And while paleography played a role in planning the well, Exxon's pioneering work on seismic stratigraphy at the time also formed a strong basis for drilling the well."




## MIDDLE EAST AS AN ANALOGUE



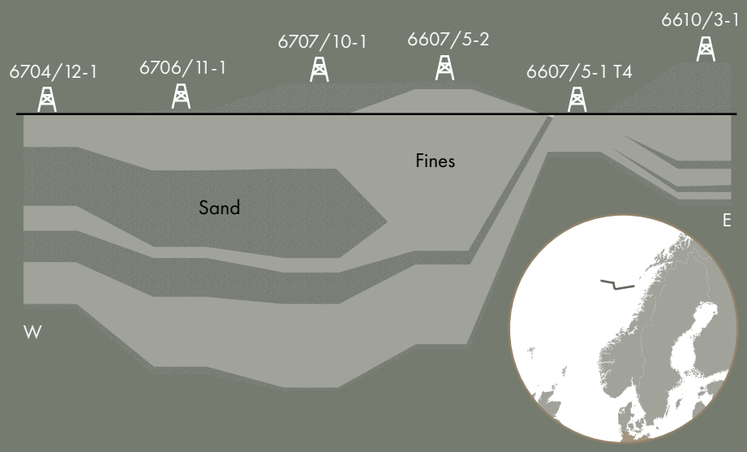
Paleogeography during the Middle Jurassic - Source: Scotese (1988).

The Seram fold and thrust belt in Eastern Indonesia is an underexplored area. Yet, it shares many characteristics with fold and thrust belts with proven hydrocarbon potential in the Middle East, such as the Zagros Mountains. Kim Morrison from Lion Energy, the company that holds significant acreage in Seram, drew the parallel during a Seapex Conference presentation in Singapore in 2019.

The main carbonate reservoirs share similar depositional environments, as the paleogeographic map shown here further supports, and source rocks from laterally equivalent anoxic marine carbonates are also considered to be similar between the two areas.

For that reason, Lion Energy regards the Seram fold and thrust belt as a highly prospective area and has acquired an extensive offshore 2D survey in 2020 (664 km) and onshore in 2022 (200 km) and now have some exceptional fold-belt prospects with areal closures up to 100 km$^2$. Thanks in part to the information drawn form paleogeographic analogues. ▶

# MORE SAND OFFSHORE!




Looking at this cross-section from the Norwegian Sea, showing Upper Cretaceous and Paleogene sediments, a surprising thing seems to happen. The amount of sand increases going westwards, away from the coast.

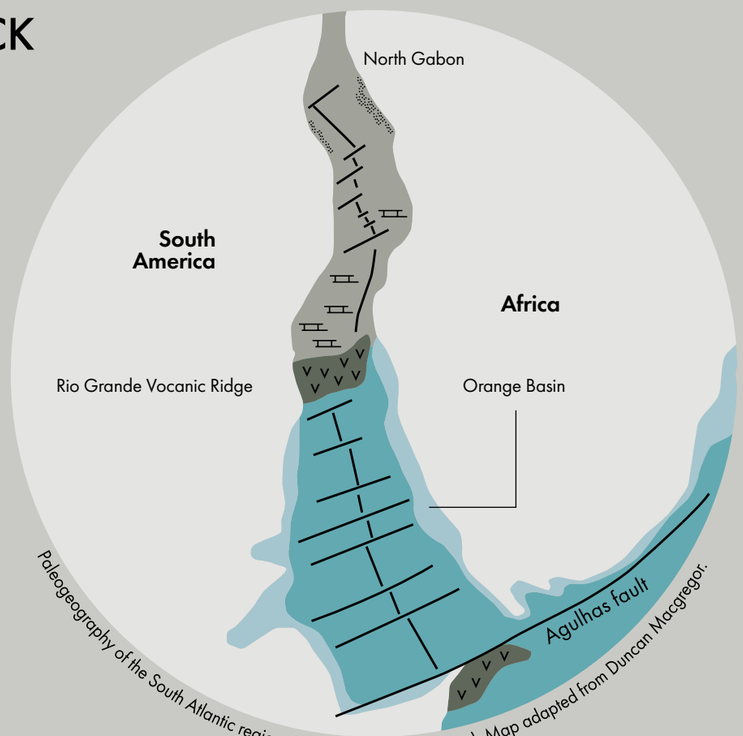
Paleogeography is needed to explain this. In Late Cretaceous times, Greenland was located much closer to Norway and because of the assymetry of the rift, Greenland was in fact the source of the sediments that we see in the western part of this cross-section. What seems to be distal now was in fact proximal in Late Cretaceous times!

# THE SOURCE ROCK FOR VENUS

Duncan Macgregor and his colleague Colin Reeves are working on a project that will result in the creation of a series of paleotectonic and paleogeographic maps of the African continent. The 19 maps will be made available via the website africangeologicalatlas.com and are free to use for non-commercial purposes.

Here, we show a paleogeographic map for the Late Aptian (118 Ma), when the South Atlantic had opened. As the basin experienced restricted circulation, deposition took place of what later turned out the source rock for the Venus discovery in the Orange Basin.

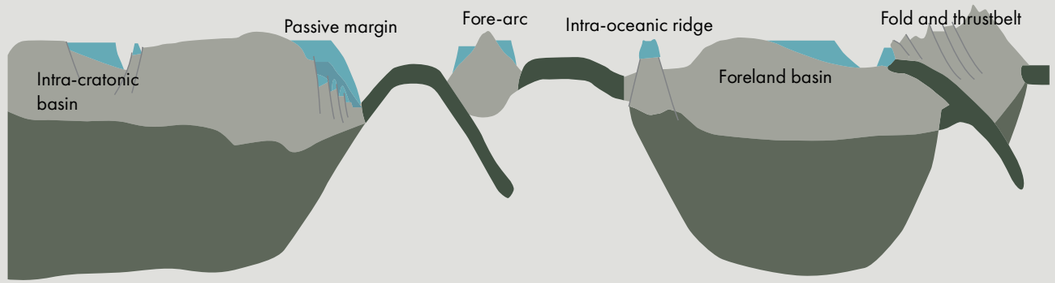
Another important learning from this map is that searches for analogues are more valid across rather than along the Atlantic margins.




Paleogeography of the South Atlantic region during the Aptian (118 Ma). Map adapted from Duncan Macgregor.



# CARBONATE PLATFORMS




In a recently published paper in Lithosphere, Aurélie Tassy and co-authors discuss the global geodynamic control on Phanerozoic marine carbonates through an exhaustive study of 120 representative and well-documented cases. More than any other sedimentary system, the architecture of carbonates are heavily dependent on the type of basin in which they form.

The figure above, which is an adapted version of the one that was published in the paper, shows the main basin types recognised and in blue the typical outlines of the resulting carbonate deposits that may form in these settings.

# PALEOGEOGRAPHY AND BUSINESS

The production of paleogeographic maps is an economically usefull exercise for consultancy companies such as ours", says Andy Horbury from Cambridge Carbonates. "This can be achieved under two basic formats; a subscription model, often with regular updates, or a more laissez-faire model, where work is done on more of an 'as required' basis.

Of the two, the subscription model is more suited to larger consultancy groups because it requires much more active marketing and management, and builds up company value; whilst the laissez-faire model is better suited to smaller consultancies who are obliged to divert to other project work when it becomes available. Our experience is of the latter form of production."

"For our company, our mapset is a repository of information such that we do not need to be constantly 'reinventing the wheel', whilst it has allowed us to build up over time a product of significant quality, the likes of which would not be possible as a standalone project over a short period."

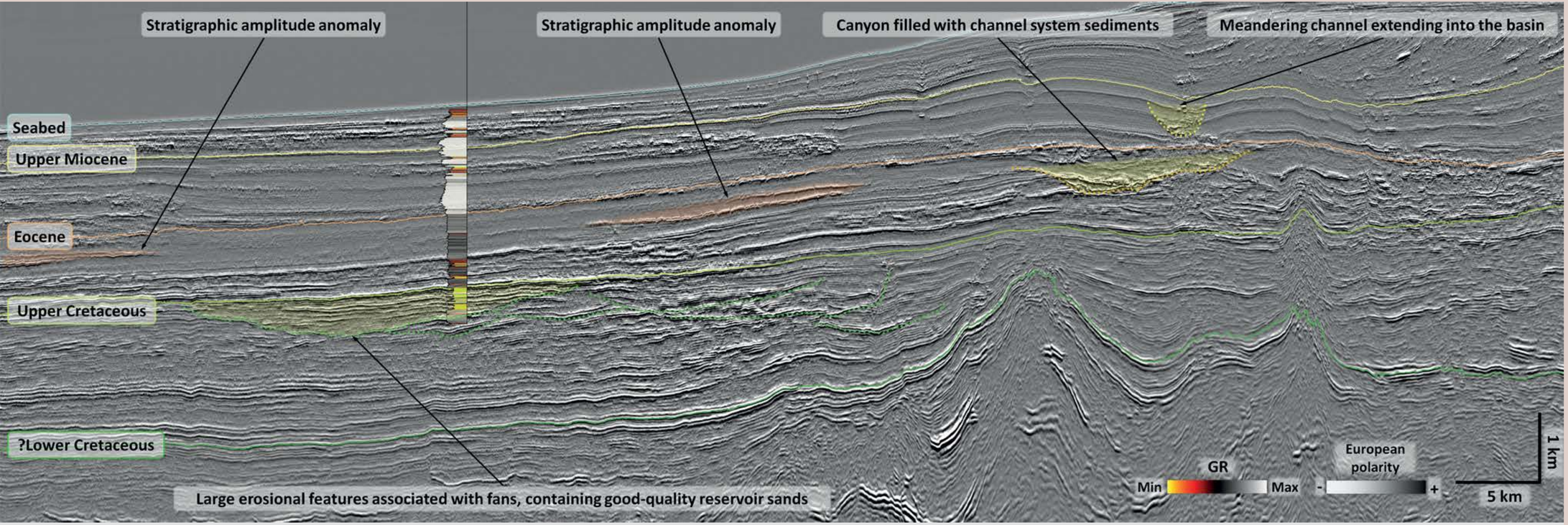
Dr. Andy Horbury
Cambridge Carbonates

**"For our company, our mapset is a repository of information such that we do not need to be constantly 'reinventing the wheel'..."**

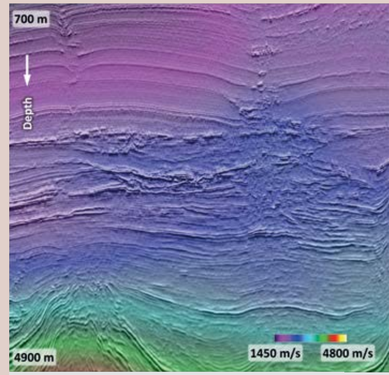
■

# Cameroon:
## Douala Kribi-Campo Basin – Seize the opportunity!

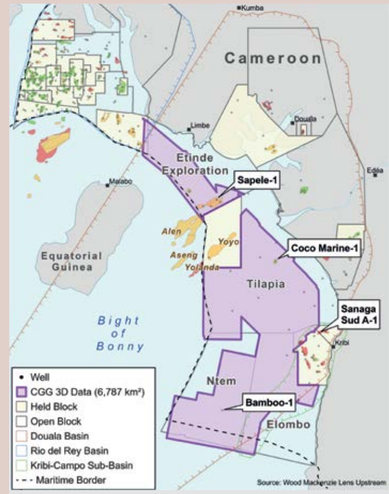
Offshore Cameroon is a proven petroleum province with commercial production from the Douala Kribi-Campo Basin (DKC) and the prolific Rio del Rey Basin (RDR). The recent joint cooperation agreement between Cameroon and Equatorial Guinea will lead to the development of the Yoyo and Yolanda discoveries and open up the underexplored deep-water DKC Basin. CGG, together with Société Nationale des Hydrocarbures (SNH), has completed a basin-wide PSDM reprocessing project, which, coupled with favourable government terms, provides the opportunity to accelerate exploration in Cameroon.




An arbitrary seismic line from the DKC basin showing the main stratigraphic intervals and a number of features of interest for hydrocarbon exploration. The well on the section penetrated Upper Cretaceous good-quality reservoir sands as can be seen in the gamma ray (GR) log.




A close-up of a canyon - a seismic pseudo-relief cross section overlaid by velocities. Velocity variations follow geological features, and the velocity model is able to account for higher velocities within the fill.




Location map showing CGG's 3D seismic coverage in the DKC basin, well locations and hydrocarbon fields in the DKC and RDR basins.

# Cameroon: leveraging three vital drivers for near-term high-impact exploration

**A proven petroleum system and strong government support are two of the key drivers for hydrocarbon exploration. Now, newly reprocessed PSDM seismic data using CGG's latest technology provides the third vital driver for near-term high-impact exploration**

**MISHA ISAKOV, PAOLO GABRIELLI, EMMANUEL NFORMI, SHONA CULWICK, CGG, AND BLANCHE MAHAMAT ACHTA BOUBAKAR, CHRISTOPHE ATANGANA NDENDE, SOCIÉTÉ NATIONALE DES HYDROCARBURES**

CAMEROON HAS established itself as a hydrocarbon-rich region, with production occurring in both the Rio Del Rey (RDR) and Douala/Kribi-Campo (DKC) basins. Located at the eastern extension of the Niger Delta, RDR is a basin with existing infrastructure and ongoing production. In contrast, the DKC basin is poorly explored, despite discoveries confirming active petroleum systems.

Petroleum exploration began onshore in the DKC basin in the 1950s, but it wasn't until the first offshore discovery in 1979, Sanaga Sud A-1, that exploration accelerated, initially targeting Cretaceous tilted fault blocks. Subsequently, younger reservoirs were drilled in the offshore portion of the DKC basin, resulting in just a couple of commercial discoveries (Yoyo and Yolanda) and producing fields (Alen and Aseng) from Miocene channel sands.

CGG, working in association with SNH, previously evaluated the region by examining well results and legacy seismic data. With strong evidence for the existence of regional source rock and reservoir, likely reasons for well failure are charge-access, trap and seal integrity. These are common challenges in passive margins where prospects have a strong stratigraphic trap component.

The limitation of the legacy seismic dataset was undoubtedly another factor for well failure. Many of the prospects drilled on the slope are situated below a complicated overburden with an equally complicated velocity field. As such, even small errors can have a large impact on these prospects due to the subtlety of traps. In addition, the legacy seismic data is not optimised for examining the finer details of fault systems nor for delineating the architecture of the target reservoirs. Therefore, better seismic imaging was required.

## USING ADVANCED TECHNOLOGIES FOR BETTER IMAGING

Recognising the need for depth-processed data to enable seamless analysis of the geological prospectivity, CGG reimaged a multi-client 3D PSDM seismic volume of approximately 6,800 square km from ten legacy surveys. High-end proprietary imaging technologies were subsequently used to overcome reservoir-imaging challenges posed by the vintage data. Figure 1 demonstrates the clear improvements in reflector continuity and noise attenuation.

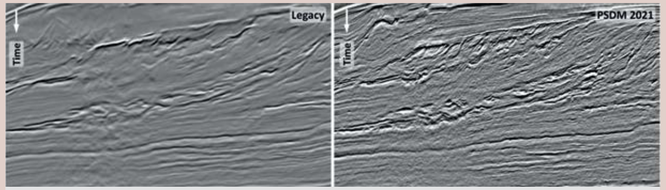



Figure 1. A comparison of the legacy data (left) and CGG's newly reimaged PSDM seismic (right). The new data shows better defined stratigraphic features, and clearer details within the slope depositional system and faults, and improved reflector continuity, all of which provide more precise understandings, especially around the subtleties of the petroleum system.





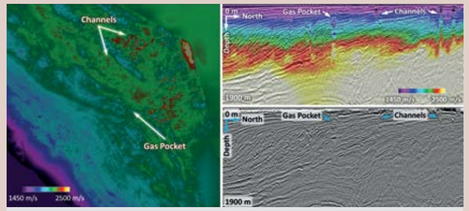



Figure 2. Shallow details revealed by FWI and incorporated into the velocity model, such as a gas pocket and buried channels, visible on the 600m depth slice (a) and on the model overlaid on the north-south line (b), helped to focus energy and minimized distortion on the stack section underneath the anomalies (c). Facies-related velocity variations in the clinoforms at the top of the section are also reflected in the model.

Joint source and receiver 3D Ghost Wavefield Elimination helped achieve higher quality data in terms of both frequency bandwidth and signal-to-noise ratio, enhancing the geological details, particularly in deeper seismic events where low frequencies have been restored. This is especially apparent in the southern deep-water DKC blocks, as shown in the foldout.

Wave-equation deconvolution, together with model-based water-layer demultiple and surface-related multiple elimination, was applied to remove the multiples in the shallow water area. Adjacent surveys were used to ensure consistency and model accuracy at the edges. This improved the imaging down to depths greater than 3,000 m and increased confidence in the seismic facies where reservoirs, such as the oil-filled Paleocene channel in Coco Marine-1, can be expected.

Multiple tomography passes were performed using a multi-layer approach to build an accurate regional velocity model. Subsequently, Full Waveform Inversion (FWI) was applied to reveal the shallow lateral velocity variations and distortions. Small-scale gas pockets and channels were identified and incorporated into the model, along with facies changes in the clinoforms (Figure 2). The velocity model was also constrained by well data to provide a robust subsurface image.

In the Tilapia block, where well data indicate stacked high-velocity channel sands, the original seismic suffered from significant pull-up, generating artificial structural closures. The new data improves the positioning of these events and demonstrates that the PSDM reprocessing over a time stretch to depth approach was needed.

Seismic attributes extracted from the PSDM dataset using stratal slices were interpreted to map the distribution of submarine fan and channels, as these provide multiple opportunities, often as stacked plays. The Bamboo-1 well penetrated a number of such stacked reservoir features but, as shown in Figure 3, significant channels were missed. As such, opportunities clearly remain and by solving the challenges of legacy seismic data, the PSDM reimaging will undoubtedly help de-risk future drilling.

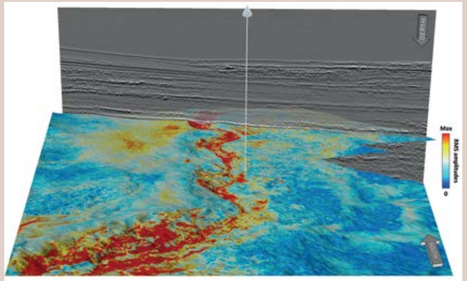



Figure 3. RMS amplitudes extracted along a Palaeocene stratal slice, where key reservoir intervals exist. A major confined channel that was missed during drilling of the well shown can be seen on both the slice and the seismic section.

## ADVANTAGEOUS ABOVE-GROUND ASPECTS

Cameroon offers a supportive environment for hydrocarbon exploration, with the government increasingly keen to leverage Cameroon's oil and gas resources. For example, the 2019 Petroleum Code offers improved regionally competitive fiscal terms and flexibility when negotiating production sharing contracts.

On a regional scale, the new bilateral cooperation agreement between Cameroon and Equatorial Guinea for the exploitation of cross-border oil and gas fields paves the way not only for the commercialisation of Yoyo and Yolanda but also for future discoveries. Gas from these, and presumably all future discoveries, will be used as a feedstock to Equatorial Guinea's Gas Mega Hub.

For the first time, the three vital drivers for near-term high-impact exploration in Cameroon are in place: a proven petroleum system, government support for exploration and now the tools to accurately interpret the subsurface thanks to the newly re-imaged PSDM volume by CGG.





# Unlocking the Power of Data: Katalyst Data Management and Virtual Data Room Web Platform

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**CHRISTIANO LOPES, KATALYST**

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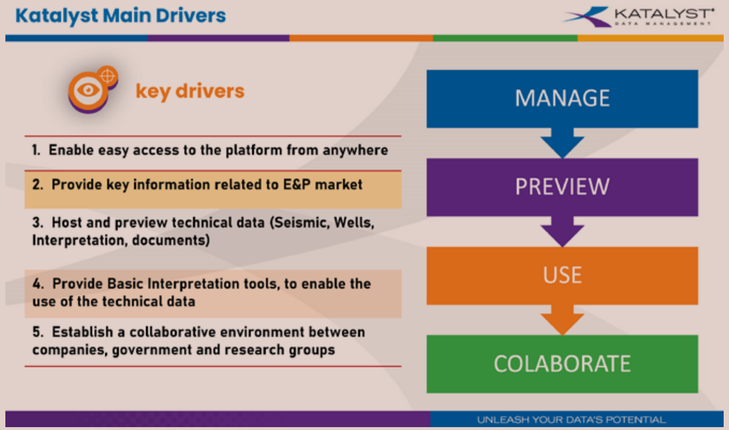
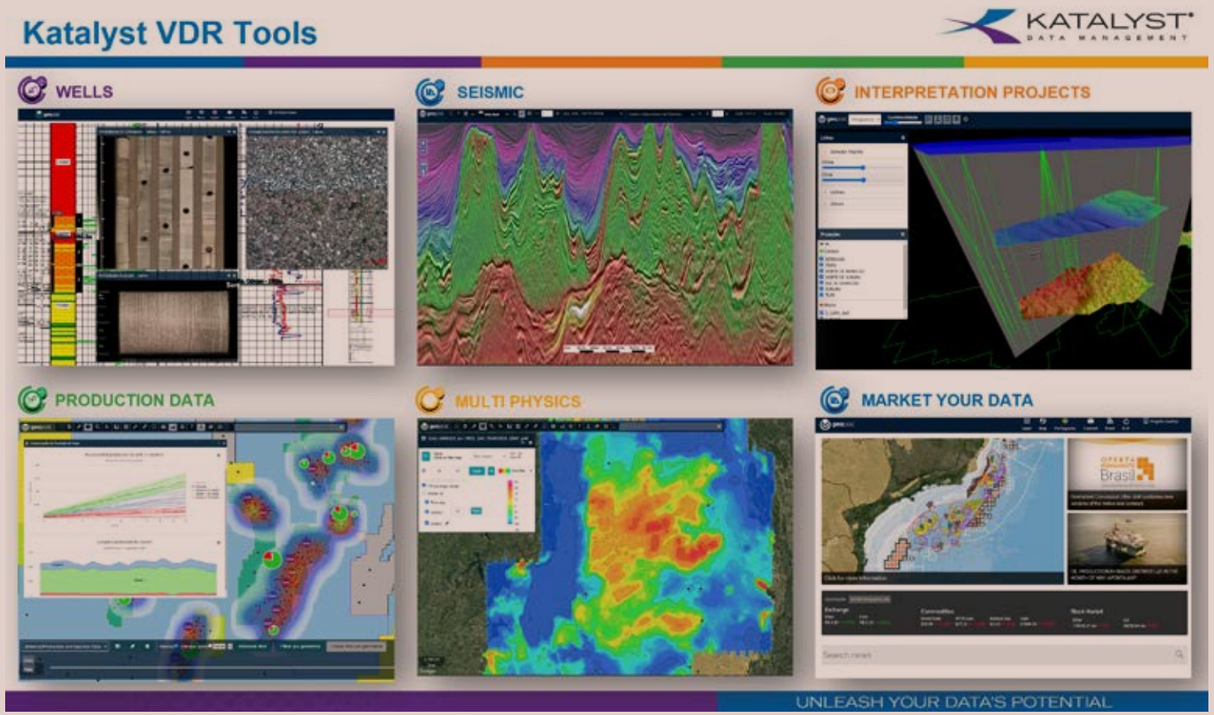
Data Room Excellence: Katalyst Virtual Data Room Tools are designed to support the seamless management, preview, and interpretation of your datasets. External users, such as partners and potential investors, can conduct a comprehensive evaluation of your assets, all within a ▸



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National Data Repository (NDR): When it comes to managing and hosting your National Data Repository, Katalyst offers the ideal solution. Our suite of solutions ensures data quality, integrity, and the seamless delivery of data, products, and reports. You can host web maps, production data, seismic volumes and profiles, wells, cores, interpretation, and Multiphysics data, allowing end-users to draw their own conclusions about potential investments in Blocks, Basins, or entire countries.

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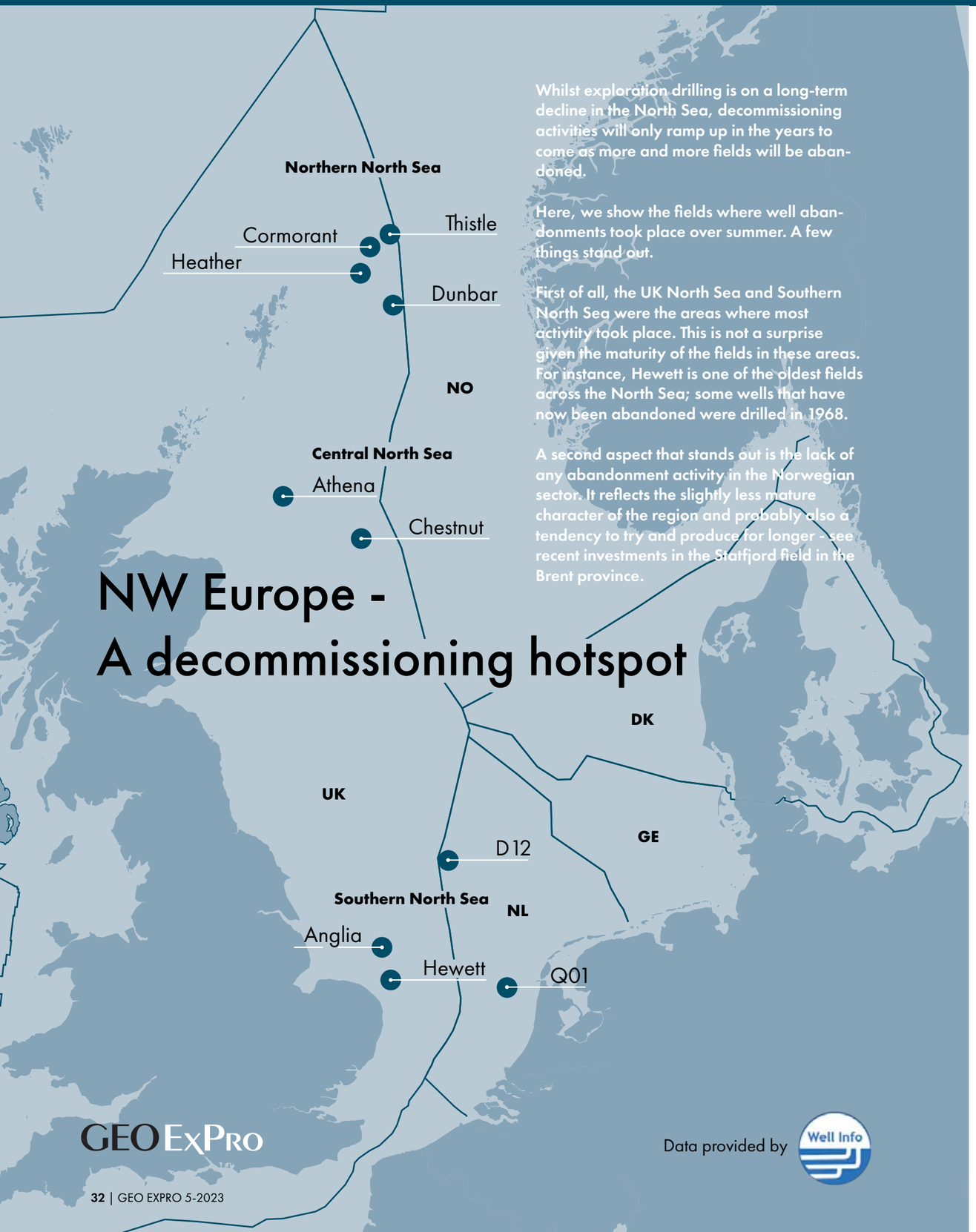
# NORTHWEST EUROPE

"Before the COP26 Conference in Glasgow, new oil and gas developments could not be discussed in the UK. Only a few months later, especially after Russia's invasion of Ukraine, the narrative changed dramatically with all the emphasis placed on security of supply. What will the talk of the town be in half a year?"

*Prof. Paul de Leeuw – Robert Gordon University Aberdeen*




# NW Europe - A decommissioning hotspot

Whilst exploration drilling is on a long-term decline in the North Sea, decommissioning activities will only ramp up in the years to come as more and more fields will be abandoned.

Here, we show the fields where well abandonments took place over summer. A few things stand out.

First of all, the UK North Sea and Southern North Sea were the areas where most activtity took place. This is not a surprise given the maturity of the fields in these areas. For instance, Hewett is one of the oldest fields across the North Sea; some wells that have now been abandoned were drilled in 1968.

A second aspect that stands out is the lack of any abandonment activity in the Norwegian sector. It reflects the slightly less mature character of the region and probably also a tendency to try and produce for longer - see recent investments in the Statfjord field in the Brent province.





# Dynamic model giant Groningen field publicly released

## This comes in addition to a large collection of core photos and the static reservoir model made available at earlier dates already

WITH THE IMMINENT cessation of production from the giant Groningen gas field in the north of the Netherlands, the operator NAM – a joint venture between Shell and Exxon Mobil – decided to make available key datasets of the biggest gas field in Northwest Europe.

Earlier, the static model and a large collection of core photos were released via the EPOS-NL website, but now the Dynamic Reservoir Model has been added to this as well. EPOS-NL is a Dutch initiative that makes data available to national and international researchers, with the goal of addressing key geo-societal challenges.

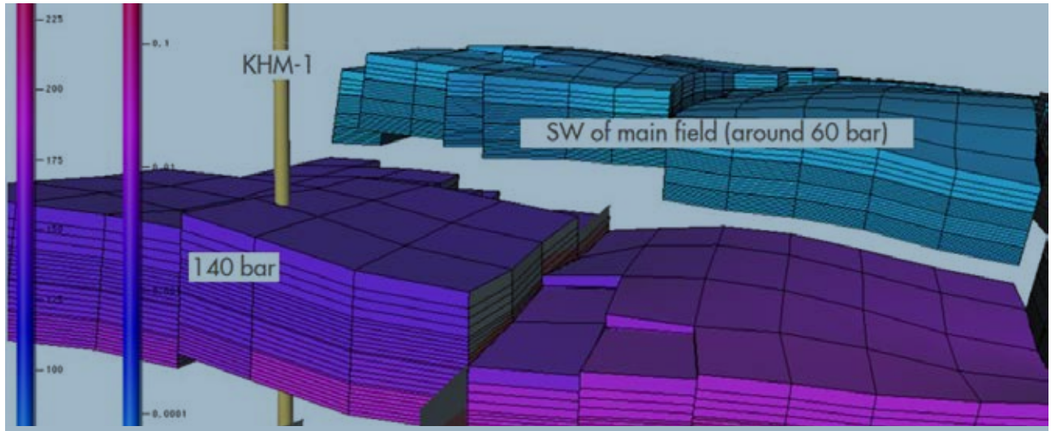
Those who are interested in downloading the model should be aware that it comes in Eclipse format, which is licensed software. An EPOS-NL LinkedIn post says the following about it: "The authors are not aware of open-source software packages with similar functionality, or software that is able to efficiently run a model with the size and complexity of the present model for the Groningen gas field." If you happen to know an open-source platform that could host a model of this kind, please get in touch with us, or with the people from EPOS-NL.

The dynamic model of the Groningen field was built in 2011 and 2012. Special attention was paid to the faults in the field to support studies into induced earthquakes. The latest update of the reservoir model focused on improvements for forecasting pressure development after gas production from the field ceases. Initially, intra-field pressure equilibration will dominate whilst the response of lateral aquifers will play a more important role later.

The Groningen gas field was discovered in 1959 and kickstarted exploration in the North Sea as companies soon realised that the Permian Rotliegend reservoir could extend further north from where it was found in the Netherlands. That concept proved correct, but Groningen remained the biggest Rotliegend find across the entire Southern Permian Basin. That in itself is quite remarkable, even though in this case it is more likely a matter of luck than of being a smart exploration strategy. ■

### THE HUIZINGE EARTHQUAKE

In August 2012, a 3.6 magnitude earthquake occurred near the village of Huizinge in the northern part of the field. This triggered a national debate that ultimately resulted in the decision to cease production from the field, despite the significant reserves that will be left in the ground. It is estimated that the field still contains around 450 Bcm of gas from a total of 2,800 Bcm at production start.




SOURCE: GRONINGEN DYNAMIC MODEL UPDATE, 2023

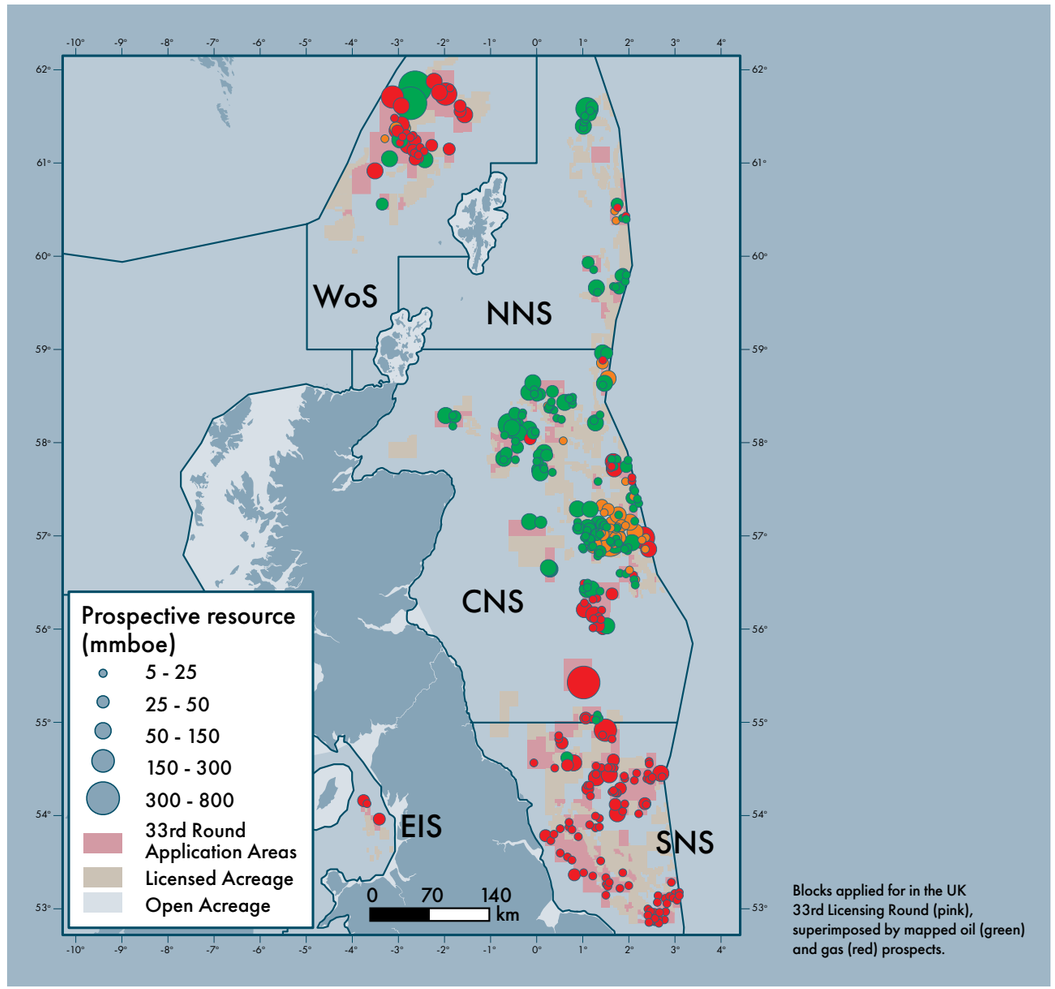
A snapshot of the Groningen Dynamic Model near the Kolham-01 well.

# Applications for the current UK licensing round reveal a focus on gas

**But based on drilling results and wells to be spudded soon, 2023 has the potential to become a bumper year for oil**

As Paul de Leeuw from Robert Gordon University noted during the panel session at a Westwood Energy event in Aberdeen last week: "Before the COP26 Conference in Glasgow, new oil and gas developments could not be discussed in the UK. Only a few months later, especially after Russia's invasion of Ukraine, the narrative changed dramatically with all the emphasis placed on security of supply."

What will the talk of the town be in half a year? Nobody knows, but what is apparent is that the applications NSTA received for the latest and 33rd petroleum exploration licensing round would probably have looked very differently ▸




Blocks applied for in the UK 33rd Licensing Round (pink), superimposed by mapped oil (green) and gas (red) prospects.

MAP KINDLY SUPPLIED BY WESTWOOD ENERGY GLOBAL

if recent historic events had unfolded in another way.

Documents made available by the UK government show that the main areas where applications were filed are the West of Shetlands (WOS) and the Southern North Sea (SNS). If one would only look at which part of the UK Continental Shelf holds the most prospective resources, the focus on WOS and SNS seems odd at first.

Namely, Westwood estimates that it is the Central North Sea that holds the most potential by far - around 5 billion barrels of risked potential resources. However, the Central North Sea is dominated by oil prospects, whilst the SNS is mostly gas, and it is probably for that reason that companies are flocking to the very part of the continental shelf that only a few years ago seemed to be amongst the quietest on the UKCS.

Even though the West of Shetland does hold more oil than gas prospective volumes, there is a good number of sizeable gas prospects in this relatively unexplored part of the UKCS, and that is probably the reason why so many applications were filed there.

The infrastructure setting in the West of Shetland is entirely different from the SNS though, with the latter still having a relatively dense network of pipelines in shallow water whilst the West of Shetland is in deeper water – beyond jack-up territory – and has less infrastructure, especially for gas. Hence the need for bigger finds in the north.

## A BUMPER YEAR?

But how has exploration fared so far this year in the UK? Looking back over the past 10 years, results for 2023 have been quite good, bearing in mind that the reserve replacement ratio is still very poor in the best of times at around 15%.

In two ways, 2013 and 2023 are the most contrasting years of the last decade, as technical manager Alyson Harding showed. Ten years ago, 21 exploration wells were drilled on the UKCS. However, none of these resulted in a commercial discovery, meaning that not a single barrel was added to the resource base.

This year, even with a few months and a few well results still to be announced, the discovered resources stands at 130 MMboe thanks to success at Pensacola (99 MMboe) and Orlov (30 MMboe). This means that 2023 is surely the most successful year for exploration across the UKCS in the last decade.

And, 2023 even has the potential to become a real bumper year if the Devil's Hole Horst well comes in as anticipated. Unfortunately, the driver behind drilling this potentially massive Zechstein prospect is not with us anymore – Niels Arveschoug passed away earlier this year – but the 584 MMboe prospect has the potential to shake up the UK's replacement ratio once more and also ensure that it is oil that dominates the charts and not the gas that seems so much in favour at the moment. ■





# FEATURES

"Hesitance to embrace uncertainty often derives from time, data and budget constraints, limited interdisciplinary understanding, accompanied by claims of 'black box' algorithms and software solutions."

*James Mullins – Rock Flow Dynamics*

# Somalia: The final frontier?

**Like the crew of the Starship Enterprise, explorers in the deepwater acreage offshore Somalia must Go Boldly, and largely where None have Gone Before…but as was proven over and again in Star Trek, the rewards of taking those bold steps could be socially, scientifically and financially significant**

KEVIN SCHOFIELD, KATYA CASEY AND MAREL SANCHEZ, COASTLINE EXPLORATION

AT THE OUTSET of a project in the area, one has to ask "Why does offshore Somalia remain unexplored?" It is one of the last undrilled frontier basins in the world, and is physically one of the more accessible. It has a regional database of good-quality sparse 2D seismic data which has been the basis of a number of publications pointing out that it is a margin with significant potential, albeit one with more "above-ground issues" than many.

The technical team at Coastline Exploration set out to analyse the margin, where Coastline holds 7 PSA licences (Figure 1), with a skeptical mindset. Our question: "Can a fresh look at the basin reduce the technical uncertainties to a degree that will counterbalance the socio-political and "sanctity of contact" risks for potential partners?"

## SOURCE ROCK BIGGEST UNCERTAINTY

The greatest subsurface uncertainty has always been considered to be the presence of a source interval, as none have been penetrated in the basin. However, there is indirect evidence for a working petroleum system: Gas and liquids have been tested in onshore coastal wells which, given the basin geometry, can only have migrated from the offshore. In addition, gas chimneys and shallow gas accumulations are observed on 2D seismic data. Our first step therefore was to re-examine the evolution of the basin to see when and if appropriate conditions may have been present for source rock deposition.

Most prior work has emphasised basin evolution through Late Triassic to Early Jurassic via a mechanism of "transtensional" rifting, with the subsequent development of a Middle Jurassic transform margin, and does not make a particularly persuasive case for extensive source deposition under restricted conditions other than during early continental rifting.

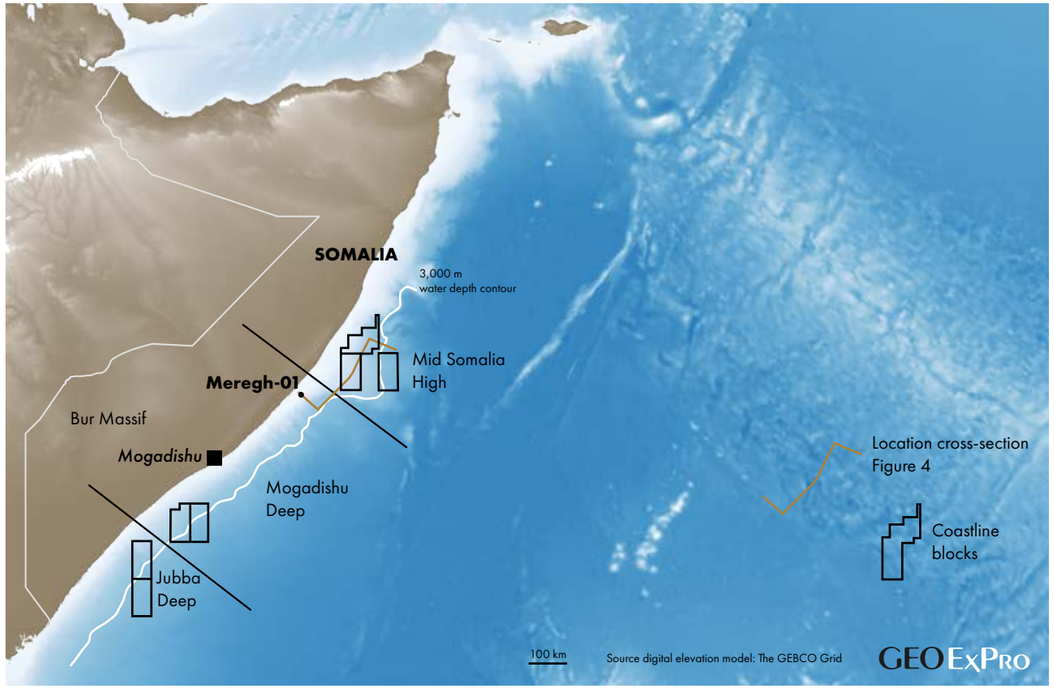



Figure 1: Map showing the main structural elements discussed in the text along with the location of Coastline's blocks.

Leveraging a prior working relationship, Coastline worked closely with the University of Texas "Plates" consortium to develop a model that produced a better local fit, utilising the constraints provided by our interpretation of the 2D dataset and regional magnetic anomaly data (Figure 2). The seismic interpretation of rifting and accommodation space development in the Mogadishu Deep and contemporary continental extension in the Mid-Somalia High, combined with the integration of the earliest dated anomalies (145 Ma) marking the locus of initial organised oceanic spreading, permitted recognition of orthogonal rifting for a period of at least 30 million years. Rift initiation in the Early Jurassic (175 Ma), was followed by a sag phase in the Middle Jurassic (161 Ma), and the drift phase, lasting through to the end of the Jurassic (145 Ma) when oceanic spreading was established (Figure 3).

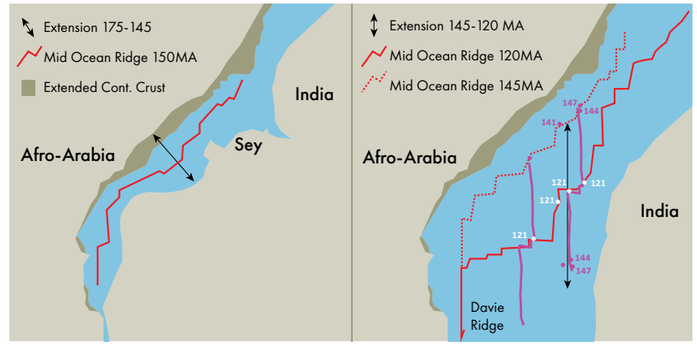



Figure 2: Reconstruction of Somalia's rifting history, as constrained by ages of magnetic anomalies. This has allowed the recognition of an orthogonal rift phase during the 175-145 Ma period that helped create the circumstances for source rock deposition.

The model predicts a basin closed off to the south with restricted connection to the open Tethyan ocean to the north as a result of the "buttress" of the Mid-Somalia High: in short, ideal circumstances for source-rock deposition over a prolonged period until the establishment of the transtensional margin as the Davie Ridge developed and Madagascar moved away to the south.

## 50 TO 70% CHANCE OF SUCCESS

The counterpart basin to the southern sector of the Somalian offshore, the Majunga Basin in Madagascar, provides a compelling analogue for source deposition, with documented high-quality Early to Middle Jurassic source rocks being the demonstrable source for hydrocarbons in the basin.

Given the modelled early basin evolution, mapped basin geometries of rift, sag and drift intervals, evidence of migrated fluids on the ▸

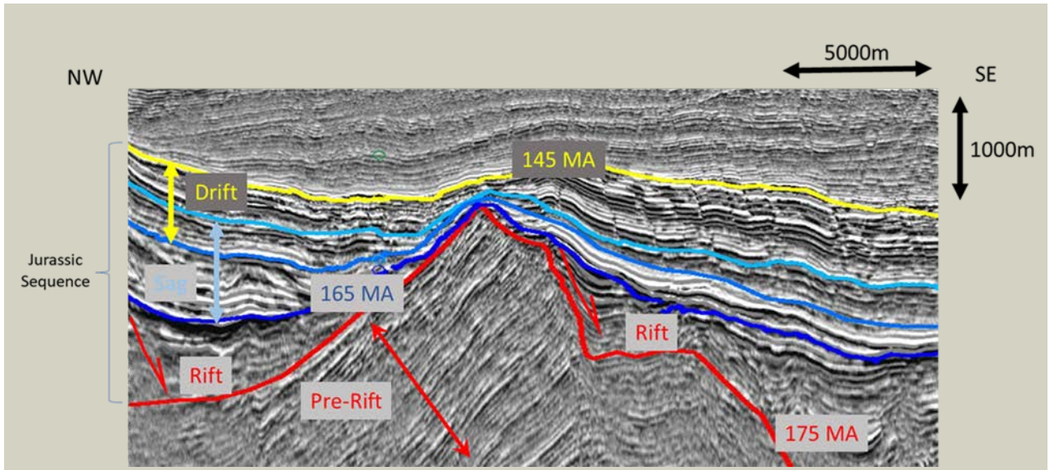



Figure 3: The potential Jurassic source interval was mapped around the Mid-Somalia High and Mogadishu Deep on the basis of the classical Rift (wedge), Sag (lunate) and Drift (approaching isopachous) geometries as observed in rift basins worldwide. Note that there is significant vertical exaggeration on this seismic depth line from the Mid-Somalia High.

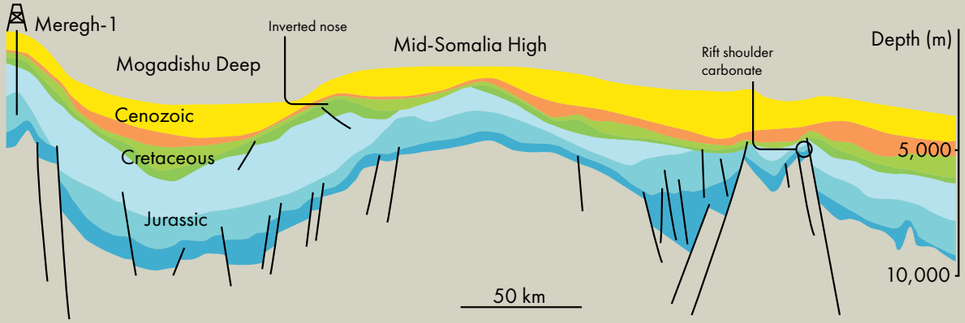



Figure 4: A composite line ties the Middle and Upper Jurassic carbonates penetrated in Meregh-1 on the inverted margin to the mid-Somalia high where carbonate reservoir plays have been defined in both the aggrading platform (centre) and on the crests of fault blocks in the coeval rift (right).

basin margin, and the evidence for source-rock deposition along the counterpart margin, we assess the likelihood of source presence in the basin using a Sherman-Kent methodology, as "more likely than not", with a 50 to 70% chance of success.

## TRILLIONS OF BARRELS

The Jurassic rift-sag-drift sequences were mapped on the depth-converted 2D seismic lines as having thicknesses in the range 0.75 to 1.5 km. A stochastic modelling approach utilised Zetaware Trinity® software to test the basin potential for "total fluids generated". With conservative assumptions for viable source-rock thickness, HI, TOC, source kinetics and geothermal gradient, output ranges demonstrate that the basin has the potential to have generated multiple trillions of barrels of oil-equivalent. Present-day, the Mogadishu Deep models as mature for gas, and the northern Mid-Somalia High as oil-mature.

The next question to be answered was that of volumetric materiality. Although the counterpart Majunga basin has a prolific proven source rock, there are no discoveries of sufficient materiality to "open" the basin. However, there is a significant "tar belt" onshore where migrating hydrocarbons migrated updip without encountering volumetrically-significant trapping structures.

## A SIGNIFICANT DIFFERENCE

One significant difference between deepwater Somalia and offshore Madagascar is a phase of inversion tectonism beginning in the Early to Middle Cretaceous, and culminating in the Early Paleogene. In its earliest incarnation, it is seen as the uplift and erosion of rift shoulders in the Mid-Somalia High. It manifests as a large inverted nose in Cretaceous sediments of the Mogadishu Deep, and in the Early Paleogene as major uplift of the Bur Massif, inboard of the Mogadishu Deep basin (Figure 4).

The sparse seismic grid makes it difficult to pinpoint the lineaments upon which the inversion was centred, but they clearly run perpendicular to the basin margin, so are likely to be either reactivated transfer zones from the original rift and/or reactivated transforms from the early oceanic spreading. Inversion was driven by compressional forces generated as first India and then The Seychelles separated and drifted to the northeast. Madagascar did not experience these bouts of compression. These episodes of inversion created large migration-focusing structures in the Mogadishu Deep in particular.

## A WORKING PETROLEUM SYSTEM

Our conclusion is that the long-standing concerns over the presence of a working petroleum system in deepwater offshore Somalia are, within the bounds of uncertainty that would be expected in any frontier basin, unfounded. Furthermore, the rift to passive margin sequence in the basin was perturbed by several phases of inversion in the Cretaceous and Paleogene, resulting in the development of large, migration-focusing structures where reservoir fairways have been recognised in thick Jurassic carbonates in the Mid-Somalia High, and in Middle/Upper Cretaceous and Paleogene intervals in the Mogadishu Deep Basin.

Revisiting the question we posed at the beginning of this article, we have concluded that offshore Somalia has all of the characteristics of a prolific, multi-billion barrel province. As a result, Coastline Exploration is on the cusp of authorising a 14,000 km$^2$ 3D seismic survey in the Mid-Somalia High to allow us to define drillable prospects, with plans to follow up in the Mogadishu Deep. We are seeking partners to join with us to test those prospects with the drill-bit in 2025. ■

# Progress on the UKCS online National Data Repository

**The drive to re-use old seismic data is nothing new, but it has certainly gathered pace over the last five years. It was a subject rarely out of the limelight at Seismic2023 earlier this year, so we thought it time to provide an update on what is being achieved with UKCS data**

NEVIL HALL, MOVEOUT DATA

THE NEED FOR GOOD quality data is self-evident – oil and gas exploration continues, at least for the moment, wind farms must be securely and economically sited, potential carbon and nuclear waste storage sites fully understood.

Inevitably, the cost of new data acquisition in financial, time and environmental terms has encouraged the re-use of existing datasets.

Access to legacy data received a major boost in 2021 when the UK North Sea Transition Authority (NSTA) awarded contracts to build and populate a revised, cloud-based version of their National Data Repository (NDR) for seismic and well data. The NSTA's aim was clear; to stimulate collaboration within the UKCS through the reporting of both legacy and current seismic and well data in a cloud-based, high-quality and easily accessible data resource.

The project replaced an existing NDR run by Common Data Access Limited, built upon the service they had operated in various guises for over 20 years.

Cloud-based subsurface data management company Osokey was awarded the contract to develop the NDR cloud environment and online solution, with close collaborators Moveout Data responsible for all media-based seismic data handling, conditioning, and quality control. Andy Thompson, NDR Manager at the NSTA, is pleased with the choice. "We knew combining flexibility and speed of response with a high-quality service was going to be key, and the Osokey/Moveout bid showed a clear focus on being able to quickly cater for many differing scenarios. I am happy to say this has been borne out in practice."

Although the NDR's oldest data originates in the '70s, the bulk comes from the past 20 years or so, and UKCS operators are legally obliged to make this available to the NSTA on request as part of their licence conditions.

The NSTA requires seismic data to be reported at a licence event, such as transfer of an asset, or when another NDR user request is validated. In addition, new reporting regulations introduced by the Energy Act 2016 require seismic surveys shot since 2018 to be uploaded in full to the NDR.

Moveout carries a broad range of tape drives, to be able to read legacy data on a variety of media.

PHOTOGRAPHY: MOVEOUT

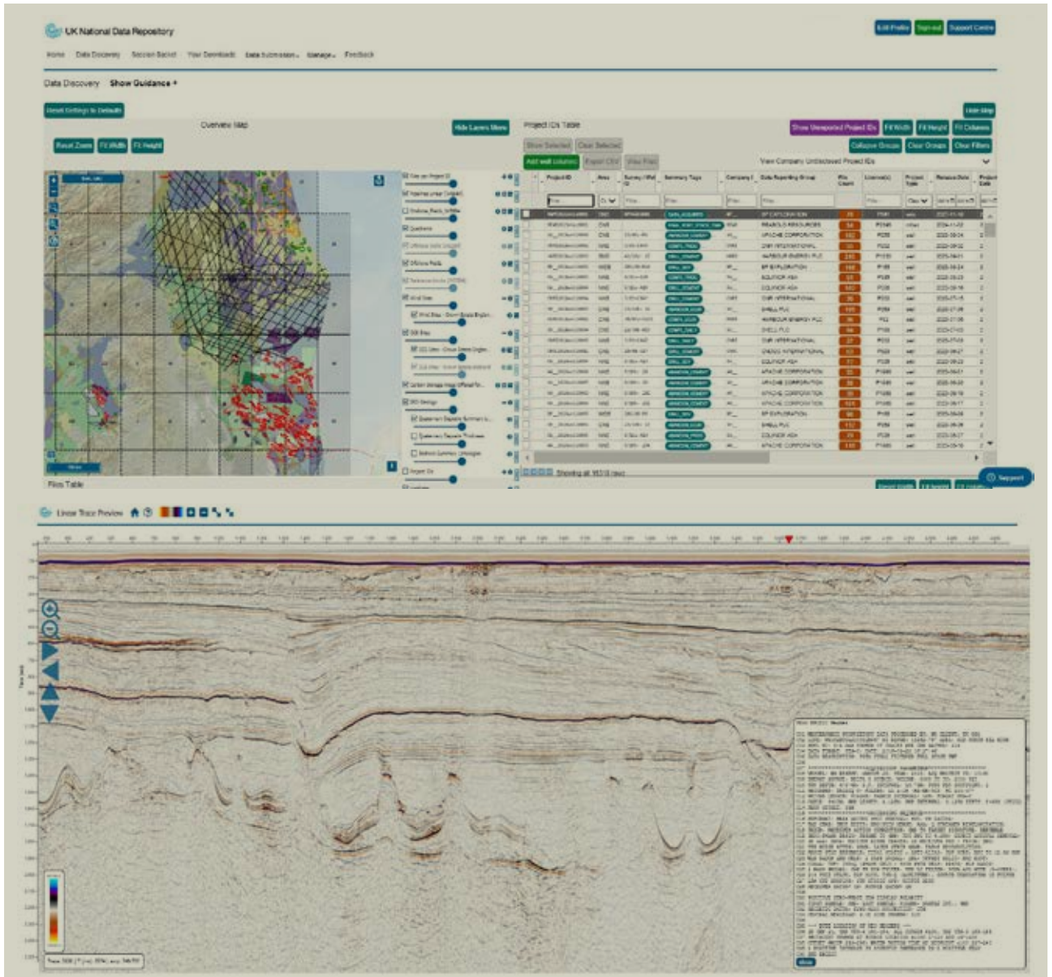



Figure 1 Top: The NSTA's online NDR has an intuitive, visual interface to help users discover data easily and quickly both spatially and using metadata.
Figure 2 Bottom: NDR information including seismic data is available for preview prior to download.

This means legacy data is being presented for NDR upload in a variety of formats, media types and states of completeness, and is required to meet defined reporting standards to ensure data in the NDR is of consistent quality.

From the outset, Moveout was confident it could meet this challenge. "The company has been built around Metaseis, our own in-house software, designed with ultimate flexibility to handle and repair any formatting and quality issues with seismic data," says Moveout Data's managing director, Darren McDonald. "Our team of geophysicists can react quickly to rectify the trickiest of data inconsistencies. One example that stays with me is a client which had seismic but no navigation data. We reverse engineered a pseudo P1/90 file and nav-merged it. While not perfect, it was certainly good enough to meet most needs, and rescued a significant amount of otherwise valueless data."

McDonald values the relationship with Osokey. "We knew that in Osokey we had a very responsive technology lead - one which could react to the data challenges we knew we would encounter. And we were not wrong, on either count." Founded in 2014, Moveout has developed an expert team with over 300 years' experience. Now established leaders in data preservation, Moveout specialises in the audit, analysis, and remastering of geoscience data. ▸

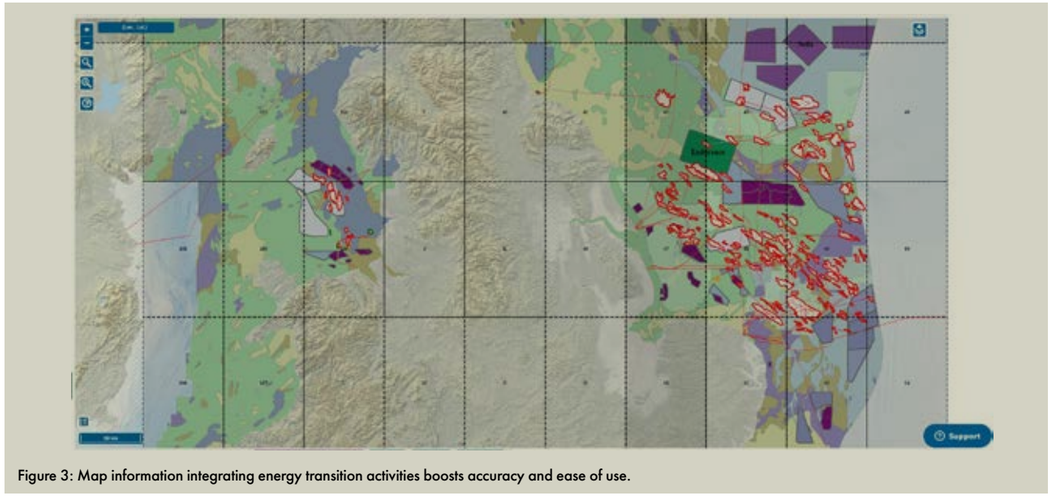


Figure 3: Map information integrating energy transition activities boosts accuracy and ease of use.

Osokey, founded in 2016, has progressed rapidly with its innovative approach to cloud-based subsurface data management. Joseph Nicholson, Osokey's chief operating officer, has always viewed an NDR as an ideal use of its technology: "It is a perfect fit – the presentation of complex and varied data to a wide, multi-sector audience. We continually focus Osokey's technology upon easy access to subsurface data - anytime, anywhere. It is extremely rewarding to see previously inaccessible data being analysed for new-use cases, at a fraction of traditional cost models.

"Two years in, the NDR is a vastly bigger data resource with broad-based user interest. It is already bringing valuable insight to new UKCS opportunities. For example, at the start of the 33rd Offshore Licensing Round, 70Tb of data were downloaded and re-used to aid decision making by users."

How have users reacted to this new resource? One little-known aspect of Moveout's role is the operation of the NDR Support Desk. Moveout's Mat Kelley says that while initially some users found the new environment strange, most have quickly adjusted. "While we do still get regular queries, they tend to be about more advanced features, extending their existing knowledge. There have certainly been questions which have driven change in the way the NDR works – this is new territory, so all constructive conversations are welcome. But wherever possible, Osokey's speed of response when implementing user feedback has been truly impressive."

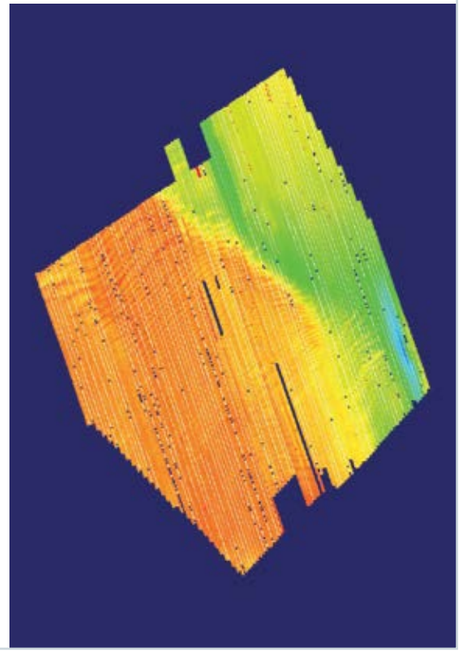
One early beneficiary of the NDR is Rockwave, a seismic data processing specialist involved in a wide range of energy projects, including for offshore wind. Matt Swan, Rockwave's managing director, told us that access to the NDR has provided a vital tool. "The NDR has allowed us to access existing seismic survey data, initially acquired for the oil & gas industry, and re-purpose it to optimise the near surface. This provides valuable subsurface information, providing our clients with enhanced understanding of their site early in the scoping or application phases and prior to the acquisition of UHRS data."

After two years of development and ongoing data upload and download, Andy Thompson is very happy with the NDR's progress. "From an initial 15Tb, there is now over 600Tb of seismic and well data loaded to the NDR. Licensees have uploaded over 135Tb themselves in the first half of this year alone. Alternatively, Moveout has the capability to quickly and efficiently assist users, such as successfully nav merging legacy 3D field data from the NDR's offline archive for the NSTA.

"Our decision to partner with Osokey and Moveout has resulted in fast development and high-quality data, presented in a cogent visual environment. The acid test will be the collaboration which this enables, and the results to come from that. Early indications are that this will be a very valuable asset for the UK energy industry for decades to come – which is exactly what we planned." ■

| Current UK NDR Volumes by decade | |
|---|---|
| | TB |
| 1970s and earlier | 0,2 |
| 1980s | 1,4 |
| 1990s | 37,8 |
| 2000s | 103,2 |
| 2010s | 305,3 |
| 2020s | 148,6 |
| **Total** | **596,4** |







# Can we get more comfortable with uncertainty?

**Hydrocarbon and emerging new energy subsurface developments are typically characterised by high degrees of complexity and uncertainty, with low margins for error. Consequently, the demand for robust and fit-for-purpose reservoir modelling solutions that capture key uncertainties to inform management decisions and to help avoid substantial financial losses is high**

JAMES MULLINS AND BASTIAN STEFFENS, ROCK FLOW DYNAMICS

UNFORTUNATELY, DILIGENT and scientific handling of subsurface uncertainty is rarely undertaken. Hesitance to embrace uncertainty often derives from time, data and budget constraints, limited interdisciplinary understanding, accompanied by claims of 'black box' algorithms and software solutions. Nevertheless, failing to address uncertainty impacts not only model accuracy and performance but can also culminate in the loss of valuable time and resources.

Traditionally, management decisions hinge on a deterministic (base-case) three-dimensional numerical representation of the subsurface. This model encompasses the best knowledge of all subsurface disciplines calibrated to the actual production response through history matching.

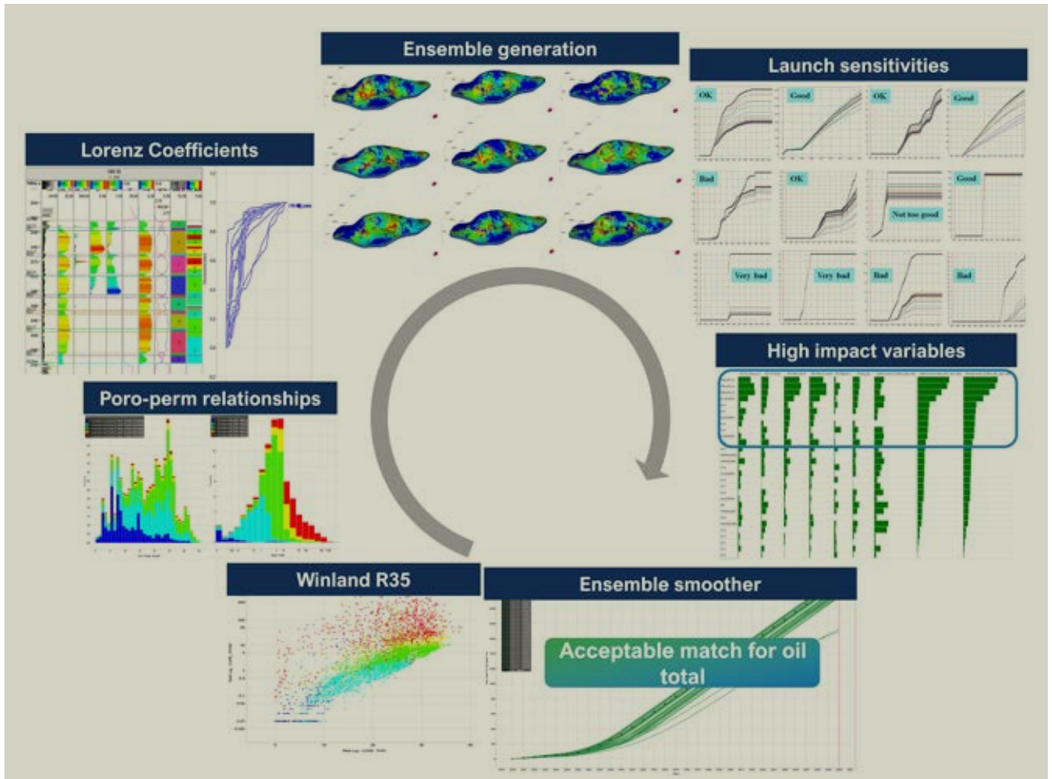



Figure 1: Fully integrated workflow using geologic ensemble-based modelling and the ensemble smoothing algorithm to explore uncertainties in a synthetic carbonate field.

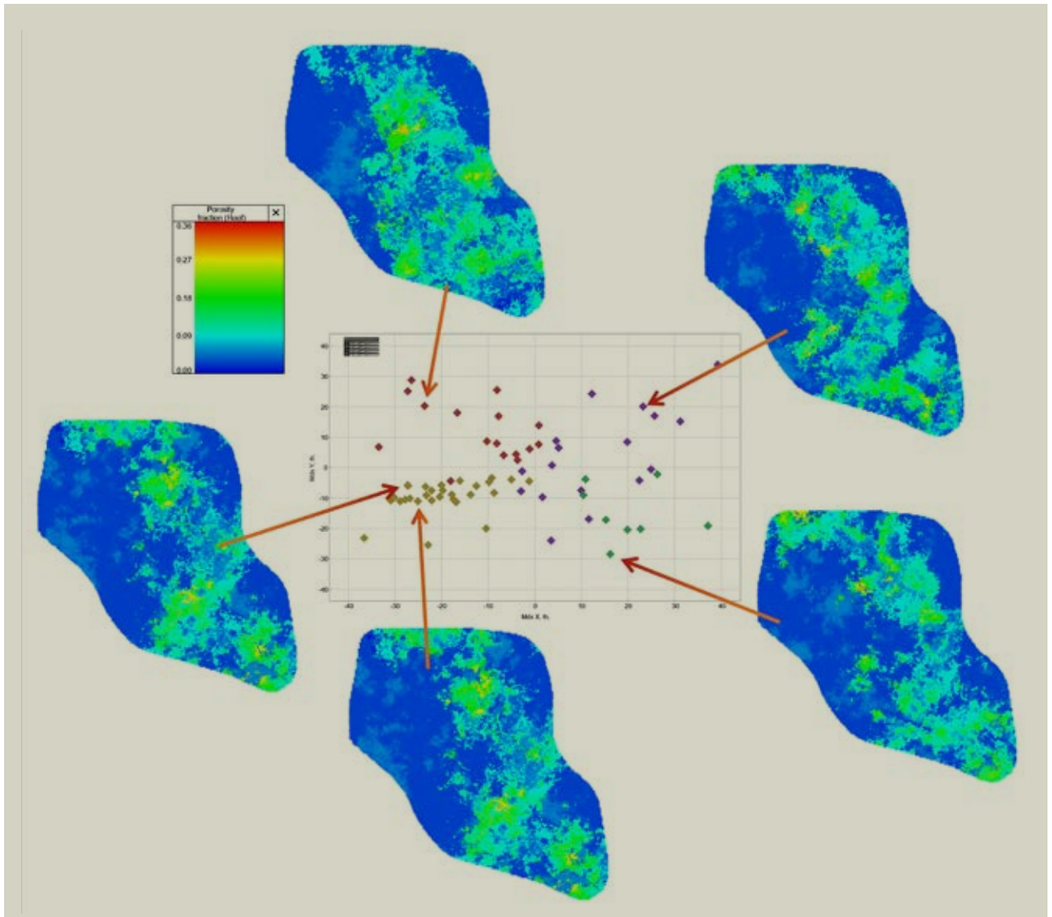


Figure 2: Projection of model ensemble into a reduced parameter space with the help of Multi-Dimensional Scaling, where each reservoir model is represented by a dot. Color-coding of dots represents grouping results from k-means clustering. Exemplarily visualized is also the top view of subset of models, showcasing model diversity.

However, subsequent model modifications to approximate geological heterogeneity, accompanied by high and low case sensitivities, enter a trial-and-error loop to match the reservoir model to dynamic data. This phase invariably results in an underrepresentation of subsurface uncertainty.

Such approaches are no longer valid for complex, marginal and new energy assets under the current volatile economic climate, where uncertainties associated with projects and assets need to be identified, quantified, mitigated, and clearly communicated to decision makers.

Rock Flow Dynamics have deployed an ensemble-based approach inside of their tNavigator suite to manage uncertainty. The intuitive approach promotes the seamless integration of uncertainties of geological and reservoir parameters across all subsurface disciplines.

## EXPLORING THE UNCERTAINTY ENVELOPE

Ensemble-based modelling offers a method to generate a large range of initial reservoir models, an ensemble, that covers an array of possible static reservoir properties. Dynamic information can be seamlessly integrated to create a variety of probabilistic forecasts. In this manner, more ▸

time can be dedicated to understanding the reservoir and its inherent uncertainties, rather than building and forcing the single base case model to match historic production. This enables model diversity and widens the range for possible forecast scenarios that honor the input data; ultimately facilitating more informed reservoir management decisions.

One significant challenge in this context revolves around effectively managing a suite of reservoir models. The sheer volume of models makes it impractical to meticulously assess each one in isolation and conduct thorough comparisons with the rest. However, the concept of integration holds paramount importance. This applies not only to the seamless integration of geological, reservoir engineering, and surface-related elements, but extends to minimising barriers that hinder a comprehensive setup and analysis of simulation and modeling outcomes. Through the utilisation of uncertainty analysis and machine learning tools such as unsupervised dimension reduction and clustering techniques, this setup permits an easy overview of the reservoir model ensemble.

## HARNESSING NEW APPROACHES

In the following section, we provide a concise overview of an integrated workflow. Rebuilding the COSTA model, an open-source synthetic carbonate case study based on the prolific Rub Al Khali Basin, UAE, a fully integrated workflow encompassing both static and dynamic uncertainties including facies, petrophysics and Corey exponents for oil and water relative permeabilities was developed.

First, a Latin Hypercube experiment, a statistical technique that efficiently samples multi-dimensional parameter spaces, was run to generate an initial ensemble of models. It permits an adequate coverage of subsurface uncertainties with a limited amount of generated reservoir models.

With the help of unsupervised dimension reduction techniques, such as Multi-Dimensional Scaling (MDS), the ensemble of models can be projected into a lower dimensional parameter space, where each model is represented by a single point (Figure 2). Points that are situated closely together represent models of greater similarity.

To optimise model selection while maintaining model diversity, it is sensible to only take models forward that are far apart from each other, i.e. the ones that are more dissimilar. This step can also be assisted through various unsupervised clustering or grouping algorithms, such as k-means clustering, to group together similar models and select a representative model of each cluster.

The initial ensemble was subsequently taken forward into an ensemble Kalman smoother to iteratively update the models to match the historical production data. Eventually, this leads to an updated ensemble that represents a weighted blend of existing models with a better match to the historic production data (Figure 1). It should be noted that the aforementioned dimension reduction and clustering techniques could now again be applied to the ensemble of matching models to ensure that a sensible tradeoff between maximising model diversity and simulation runtime is taken forward into the forecasting step.

## DELIVERING VALUE

Ensemble-based methods offer a novel way to explore uncertainties typified in the complex, more marginal and new energy assets that the industry now increasingly deals with. Fully identifying, exploring, and mitigating these uncertainties is crucial for informing successful asset management decisions. Ensemble-based modelling is fully integrated and spans a range of technical subsurface disciplines.

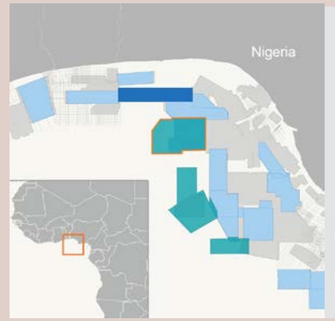
Due to easy parameterisation, ensemble runs can be generated throughout the lifespan of the asset and can be readily updated when new information is available. Moreover, they permit greater understanding of the reservoir as significant time is saved, rather than invested in matching large and unwieldy base case models that do not capture the full range of uncertainty in the subsurface. ■

# Deepwater Niger Delta:

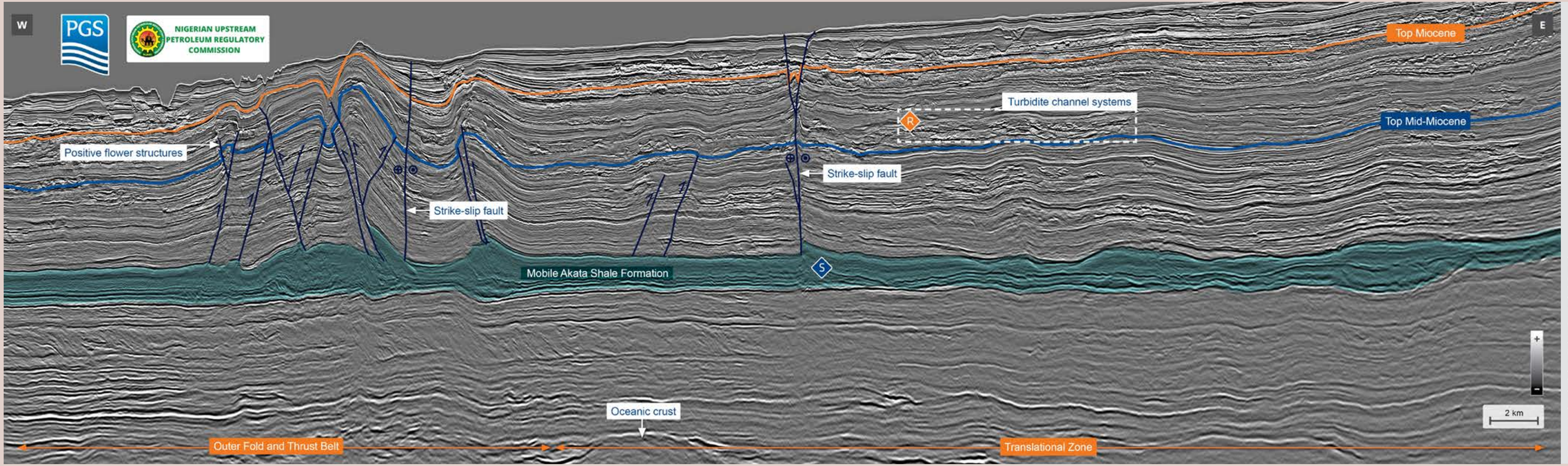
## Revealing the structural influence on reservoir channel deposition to highlight remaining prospectivity

The Niger Delta Basin is a classic example of a passive margin delta that has experienced extensive gravity-driven deformation facilitated by detachment on an under-compacted, over-pressured shale sequence. The offshore area can be divided into the Western and Eastern Deltaic Lobes which are separated by a remnant basement high related to the underlying Cretaceous-aged Charcot Fracture Zone. The Western Lobe has produced significant volumes of hydrocarbons throughout its prolific exploration history with large discoveries found in the offshore Bosi-1 Field and larger Bonga cluster.

Exploration in the basin has historically focused on the inboard, shallow water extensional province where hydrocarbons are found trapped against major growth faults and in associated rollovers. This leaves the deeper water area comprising the Outer Fold and Thrust Belt relatively untested. Understanding the complex interplay between the occurrence of fold-thrusts derived from the detachment of the Akata Shale Formation and turbidite channel deposition is key to unlocking prospectivity in this area. Using newly reprocessed PGS MegaSurveyPlus 3D seismic data, this closely interlinked relationship between structural development and reservoir distribution can be uncovered, highlighting the significant remaining potential in the area.




PGS MultiClient data library, offshore Nigeria. Location of the MegaSurveyPlus 3D data is shown in teal, with the area of interest highlighted in orange.




This West-East full-stack PSTM (prestack time migrated) seismic line is taken from the northern area of the Nigeria MegaSurveyPlus and shows the transition from the proximal Translational Zone in the east to the distal Outer Fold and Thrust Belt in the west. Post-Akata Miocene aged turbidite channel systems provide the main reservoir in the Akata-Agbada petroleum system, and these are visible as high amplitude chaotic seismic facies. A variety of structural and combination structural/stratigraphic trapping configurations are illustrated.

# Nigeria MegaSurveyPlus:
## Reprocessing delivers excellent resolution of complex structure, de-risking prospectivity in underexplored areas

**AVRIL BURRELL AND WOLE OYETORAN , PGS, AND AHMAD ABDULLAHI, NUPRC**

THE NIGER Delta Basin contains up to 12 km of Upper Cretaceous to Quaternary clastics deposited in an overall upward-coarsening regressive deltaic sequence. The Tertiary section is composed of three main diachronous units. At the base is the Akata Formation, comprising pro-delta shales deposited in a deep marine, anoxic environment. As the Niger Delta is one of the largest deltas in the world, extensive progradation has resulted in Akata Formation deposition directly over oceanic crust in distal areas. Overlying this are the paralic siliciclastics of the Agbada Formation, representing the main deltaic sequence. Finally, the Benin Formation completes the section and is dominated by continentally sourced sands.

The Niger Delta Basin is renowned for the highly prospective Akata-Agbada Petroleum system. The main source rocks are thought to be the Akata Formation marine shales and the Lower Agbada Formation paralic shales. Proven reservoirs in the basin are found in sandstones of the Agbada Formation deposited as stacked turbidite channel and fan complexes. Interbedded transgressional marine shales provide excellent seals. The largest hydrocarbon accumulations are trapped in roll-over anticlines in the hanging-walls of growth faults, but hydrocarbons may also be found in fault closures and subtle stratigraphic traps.

The area of focus for this article is a 4700 sq. km area in the northwestern Nigerian offshore. The area of interest (AOI) is located across two main structural provinces directly linked to the gravity-driven detachment of the Akata Shale Formation. The eastern part is in the Transitional Zone and contains subtle faulting along with long wavelength detachment folds of Eocene to Quaternary stratigraphy. The west of the area, situated in the Outer Fold and Thrust Belt, is structurally controlled by closely spaced fold-thrusts and oblique transpressional strike-slip faults.

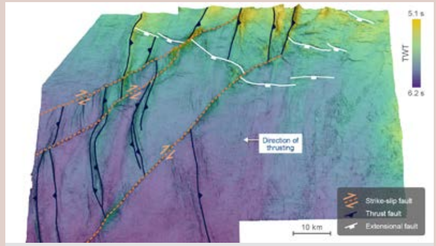



Figure 1: Top Akata TWT surface with a minimum similarity attribute overlain highlighting the main structures within the AOI. Reprocessing results in a better image of the structural complexity in the Outer Fold and Thrust Belt, uncovering the three main structural trends in this area of the deepwater Niger Delta.

### MEGASURVEYPLUS: DATA LIBRARY REJUVENATION

MegaSurveyPlus 3D seismic data is used here to show unparalleled imaging of the complex interplay between shale tectonics and the deposition of turbidite channel systems. The MegaSurveyPlus concept aims to revitalize the PGS MultiClient data library in Nigeria by applying a modern broadband reprocessing sequence to vintage 3D data. Contemporary techniques including optimized denoising algorithms and a full deghosting sequence have improved data bandwidth and signal-to-noise ratio. Application of a multiple attenuation process also leads to enhanced image integrity by eliminating complex multiples.

The extensive MegaSurveyPlus 3D data delivers an expanded and consistent regional geological perspective. The resulting full-stack PSTM data can be used for regional interpretation, providing a greater understanding of plays and migration pathways across open acreage. Improved imaging of the reflectivity within and around the Akata Shale Formation gives a clearer image of the deformation of surrounding stratigraphy. Pre-stack PSTM products also allow for AVO analysis to be undertaken, helping to derisk exploration.

### COMPLEX STRUCTURE UNVEILED BY REPROCESSING

The AOI is dominated by three main structural trends which are most easily observed by overlaying a minimum similarity attribute on the top Akata Shale TWT surface (Figure 1). The Akata Shale imbricate toe-thrusts and anticlinal folds are trending in a north-south direction, correlating with thrusting propagating from the east, towards the west. This compression is created by the progradational sediment loading of the Niger Delta and the detachment-driven, down-slope gravitational movement of the shale.

Cross-cutting this, in a northeast to southwest orientation, are a series of dextral strike-slip faults which transect the northwestern deepwater area of the dataset. These faults could be linked to underlying crustal fracture zones and occur at an oblique angle to the dip of slope and as shown in the seismic foldout line. The faults are observed to be long-lived, propagating from the top of the Akata Shale through to the present-day seabed. The strike-slip faults appear to accommodate and compartmentalize the compressional strain of the Akata Shale thrusting, demonstrated by the occasional termination of shale thrusts at these lineaments. The lateral movement on the faults is however relatively minor, indicated by the minimal offset of the Akata Shale thrusts. Unsurprisingly in an area undergoing transpression, positive flower structures are observed to occur in between the strike-slip faults.

Finally, a series of en-echelon extensional faults can be observed in the northern portion of the AOI, which form small pull-apart basins off-stepping in an east-west direction. These tear faults occur at the northeastern termination of the strike-slip lineaments and are interpreted to accommodate extensional stress.

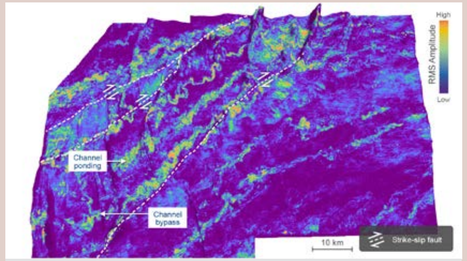



Figure 2: RMS amplitude extraction generated 100 ms above and below the Top Mid-Miocene TWT surface. This indicates the main reservoir sands were deposited as turbidite channel systems and highlights their interaction with strike-slip faults and Akata Shale thrusts.

### STRUCTURAL CONTROLS ON CHANNEL DEPOSITION

From around the Mid-Miocene, we can observe thickening of stratigraphy between the shale thrusts, indicating the syn-kinematic deposition of sediments at this level. Turbidite channel complexes progress down-slope in a northeast to southwest orientation, transferring sediment to the base of slope beyond the Outer Fold and Thrust Belt. These channels flow into topographic lows, following the path of least resistance.

In Figure 2, an RMS Amplitude extraction at a 100 ms window around the Top Mid-Miocene horizon demonstrates how the channels have interacted with the complex structure in the Outer Fold and Thrust Belt. Where active Akata Shale thrusting and folding has created significant topography during Agbada Formation deposition, the channels are seen to pond behind the thrusts, unable to overcome the topographic highs as thrusting out-paced the rate of channel sedimentation. In some locations where the rate of structural deformation is slower, channels are observed to incise the hanging wall anticlines and continue downslope without having to re-route.

In the areas adjacent to the strike-slip faulting, channels are seen to have bypassed the thrusts and folds by exploiting these zones. In these cases, we observe the continued vertical stacking of channel complexes through the section indicating these areas were key incision points for turbidites.

### DERISKING THE UNDEREXPLORED DEEPWATER

Miocene aged Agbada Formation channel systems are demonstrated to have been consistently deposited along or adjacent to strike-slip faults in the AOI. These prolonged corridors of channel deposition could result in favorable sand body connectivity within key reservoir facies. Potential reservoirs may also benefit from being advantageously located near hydrocarbon migration pathways, with strike-slip faults providing routes for fluids to charge from deeper Akata-Agbada Formation source kitchens into shallower sands. The Nigeria MegaSurveyPlus reprocessing has provided better images to enable explorers to de-risk the complex interplay between channel deposition and structure in the underexplored deepwater Niger Delta Basin.







# PORTRAITS AND INTERVIEWS

"Geoscientists have scientific mathematical-naturalist expertise, the ability to understand geological processes and to create models for both prospectivity and risk. These are skills that can be leveraged across many industries."

*Keryn Tsimitakopoulos – S&P Global Upstream Solutions*

PORTRAITS AND INTERVIEWS

# EXPLORING THE MANY FACETS OF AFRICA'S GEOLOGY ON THE BACK OF WORLD EVENTS

From counting foraminifera in a modern-day estuary to mapping faults in chrome mines, exploring for onshore oil and offshore diamonds, Keryn Tsimitakopoulos's career in South Africa and beyond has proven to be closely tied to global trends in commodity prices. With an open mind and a can-do attitude, she's been able to navigate this seamlessly and learn a lot about Africa's geology along the way

Standing on Chapmans Peak Drive where the southern Atlantic Ocean meets the tip of the African continent, Keryn Tsimitakopoulos oversees the Cambro-Silurian Table Mountain Sandstones overlying the Cape Granite basement below the road.

"You are not going to play around here for a month and do nothing", said Keryn's father when she returned home to Oranjemund (Namibia) from High School for the summer holidays. He had asked the geologist at the Orange River diamond mine where he worked if his daughters could help log core samples. "It turned out that I quickly became distracted from logging, wondering off to find exotic pebbles, while my sister meticulously inspected every sample. At the end of the day, my sister did a degree in business, and I was the one pursuing a career in geoscience. My parents did not see that coming!" laughs Keryn.

## COLLECTING CRYSTALS

Maybe Keryn's parents could have known, though. It was at the Koffiefontein mine, one of the oldest in South Africa, dating back to 1870, that Keryn realised how fascinating geology can be. "We moved there as a family in 1987 when my father accepted an engineering position as the mine reopened."

"As children we were always playing outdoors. One day we were making a tree house close to some historical tailings dumps, and I noticed red and green crystals sparkling in the sunshine. I collected as many as I could and spent hours washing and polishing at home. I then asked my father if he could please have them identified and valued at the mine sorthouse. The bad news was that they were not the 'rubies and emeralds' as I had hoped, but pyroxene and garnets instead. The note from the sorthouse explained that together with spinel and ilmenite, these crystals represent indicator minerals for kimberlite intrusions and hence for diamonds! That very real awareness of indicator minerals had me hooked!"


**"Geoscientists have scientific-mathematical-naturalist expertise, the ability to understand geological processes and to create models for both prospectivity and risk. These are skills that can be leveraged across many industries."**

## PICKING FORAMS

Even though Keryn's later career would revolve around mining and petroleum exploration, her honors and master's research focused on environmental geology instead. "I studied the microfauna (foraminifera specifically) and sediment dynamics of the Knysna Estuary, which is South Africa's most important estuary in terms of biodiversity and conservation", Keryn explains.

"Thesen Island had been the site of a timber factory for a long time. Developers of an exclusive marina development needed a baseline study on the water quality and flow dynamics surrounding the island. This study evolved into my master's project, encompassing the entire 18 km long estuarine system, including the fluvial, marine and saltmarsh environments."

## INTO THE STOPES

"In order to work off my bursary grant, my first job after university was in the Western Chrome Mines in the North West Province of South Africa", Keryn continues. "The Bushveld hosts around 70% of the world's chromium ore reserves, so while it was daunting to work underground, I appreciated the importance of the mines that are leading the global supply of this metal."

"My main responsibility was to map the quality and thickness of the chromite layers and the distribution of faults and fracture zones so as to advise on mining operations."

"In the year I was there, one of the mines progressed into an increasingly faulted zone. There were several occasions when I was called out at 6:00 am to map and secure a fall-of-ground (FOG), which is an incident involving a collapse of the hanging wall. You surely feel the responsibility of understanding the geology when you are accountable for the safety of all who enter the mine following a FOG."

## OFFSHORE DIAMONDS

Diamonds were first discovered on the Namibian coast in the early 1900s. Marine diamond mining barges were operating by the 1960s and Namibia emerged as a leader in marine diamond mining from the late 1980s.

De Beers Marine started exploring the South African coastline in 2004. "An initiative motivated by favorable market conditions and paleogeographic studies of Southern Africa", Keryn says.

"Pre 90 Ma, a paleo-Karoo River transported diamonds eroded from Kimberlite pipes further inland towards the present-day Olifants River outlet. From around 90 Ma, this drainage system was captured by the 'paleo-Kalahari' River, a precursor to the modern Orange River system, shifting the diamond depocenter northwards. A combination of a northward flowing longshore current and the observation that the Early Cretaceous diamond deposits have a smaller average stone size, means that the South African Sea Areas (SASA) are more marginal than the Atlantic-1 marine mining area offshore Namibia", explains Keryn.

"Embarking on an exploration campaign of this nature was a very exciting experience in my career", continues Keryn. "We were looking for channels, gullies and coarser-grained deposits at water depths of around 120 m. Drillship sampling locations were planned by combining interpretation of swathe-bathymetry, chirp seismic and side-scan sonar."

"The room on the ship where we viewed the sample product from the x-ray machine, to assess the number and size of diamonds recovered (grade), was secured to the highest standards. Only three of us were allowed to enter and all three had be to there to gain access. You are surrounded by cameras, and because we were not allowed to fidget, I always felt like my nose started to itch!", laughs Keryn.

PHOTOGRAPHY: ANGELA AND ANDREW GORMAN

PORTRAITS AND INTERVIEWS

**"You are surrounded by cameras, and because we were not allowed to fidget, I always felt like my nose started to itch!"**

An important part of the mining operation is the monitoring of tool efficiency, and the impact on the marine environment. This was done by survey and ground truthing with a two-person submarine.

"Fortunately, there was no direct overlap between commercial fishing grounds or marine mammal breeding areas and 99% of the sediment mined settled back to the seabed. I was fortunate to be able to join a Jago submarine dive to the seabed. We saw that deepwater species quickly migrate back. In a way, we almost created a better environment, with the boulders reshuffling to create a sheltered habitat", recalls Keryn.

## RISING OIL PRICES

As both oil and steel prices continued to climb from 2006 to 2008, the economic model for diamond mining offshore South Africa became harder to justify. "The most optimal pockets were mined first and as a result, cost-cutting meas- ▸

ures were being applied everywhere", says Keryn. It marked another turn in her career. Where offshore diamond mining was under pressure because of high oil and steel prices, another possibility opened up, and that was in the oil industry itself.

## EXPLORING THE EAST AFRICAN RIFT

At the time, Tullow Oil had discovered the Lake Albert oil fields in Uganda and was awarded frontier exploration licenses within the rift basins of Kenya and southern Ethiopia. As a result, the company was looking for exploration geologists to work up the newly obtained acreage. "All we had at the time were just a few vintage 2D seismic lines; we used those to target the very first discovery wells, Ngamia and Twiga."

Having another opportunity to join a frontier exploration project right from the start, and to work with what were considered relatively new technologies to the upstream industry such as Full Tensor Gradiometry (FTG) and Passive Seismic was a very exciting phase of my career", Keryn says, "and Tullow being marked as 'most admired explorer' also added to that."

"The key geological challenge in the East African Rift (EAR) was the presence of volcanics. This contrasts the western arm of the EAR in the Albertine Graben, where volcanics are missing altogether. Volcanics impact seismic acquisition and imagery, drilling operations and reservoir quality. There are some basins where thick volcanic successions deter exploration for potential petroleum plays."

## TRANSFERABLE SKILLS

On joining Tullow, Keryn was tasked with creating paleogeographic reconstructions for the East African Rift basins. "Even though I did not have oil experience on my CV, I had transferable skills from previous work experience, such as basin modelling, fluvio-deltaic sedimentology, geophysical data interpretation and working in sensitive areas. The bottom line is that no matter what you are looking for in the subsurface, many skills are transferable from one industry to the other", says Keryn.

Planning new seismic surveys was another aspect of Keryn's job. "The Turkana, Lokichar, Omo and Chew Bahir basins are essentially a desert environment around freshwater lakes and rivers. The shores of Lake Turkana and the Turkwel River are renowned for archeological finds, which many consider the 'Cradle of Mankind'. Every planned seismic line was first walked by a team that included archeological and environmental experts. This resulted in some findings, which is testament to the fact that seismic acquisition can also go hand in hand with other types of research."

"When a big move seemed overwhelming, my father would ask us to give it 6 months. I adopted this mantra throughout my career, and it certainly helped as I took on new roles and responsibilities."

## THE PERFECT STORM

Experience Keryn gained while working in the East African Rift basins led to new onshore projects in the Zambian rift basins and thereafter the Ivorian Basin of the West African Transform Margin. It was around this time that Tullow Oil suffered some disappointing operational and exploration results. Mounting financial concerns ultimately led to an announcement in February 2020 to close the Cape Town exploration office as part of a drastic move to cut costs across the business. "A month later we went into full lockdown as the COVID pandemic hit, the oil price collapsed, and most new hire opportunities were frozen as global upstream companies cut budgets. It was a double whammy for sure", Keryn says.

"Then, a former manager at Tullow Oil informed me that IHS Markit's Plays and Basin's team was looking for an EMEA-focused upstream research analyst and that he would be happy to refer me for the role. A number of interviews later, I was ecstatic to receive the call that my application was successful!

## WHEN THE TIME IS RIGHT

Since then, Keryn has worked for what is now S&P Global, reporting on upstream exploration and production trends and insights, considering the opportunities and challenges associated with mature, emerging and frontier basins from different regions, and how operators, investors and host nations are responding to targets towards energy sustainability, security and affordability. "Since joining S&P Global's Upstream Solutions, Plays and Basins team, I've led research on several African, Eastern Mediterranean, Caspian and North Sea basins. The Cape Town team has grown as well, which I am very happy about", Keryn says.

"Looking back", concludes Keryn, "I would say that a career is much more than the numbers on a paycheck, it's about feeling valued and inspired. By promoting your transferable skills, focusing on what you enjoy, and leveraging esteemed connections as referrals, geoscientists have no reason to be concerned about making a move when the time is right!" ■

### "GIVE IT SIX MONTHS"

Born in the far south of Namibia, on the South African border, Keryn's family moved to many places as her father worked on a range of mining projects while employed by De Beers. As such, it was always a challenge to move schools and build up a new life. "My parents' advice was to "give it your best and allow yourself some time to find your feet". When a big move seemed overwhelming, my father would ask us to give it 6 months and then reassess. I adopted this mantra throughout my career, and it certainly helped as I took on new roles and responsibilities."

# GEOTHERMAL ENERGY

"It sometimes feels as if there is a second gold rush going on."

*Neil Farquharson, Erdwerk*

# Drilling twice as fast in basement rocks

**To make deep geothermal energy economic, drilling rates have to increase. GA Drilling has developed a way to achieve that**

JOHN GIBB'S Aberdonian accent is noticeable even though he has spent many years in Houston. "I drilled many wells throughout my career", he says, "including highly deviated development wells on Alwyn and Dunbar in the North Sea. At the time, the Northern North Sea looked like a city during the night because of the flares, platform lights and the semi-subs drilling appraisal and development wells in the many newly discovered Brent fields."

As the lights have gradually gone out in the Northern North Sea, John has now focused his career towards geothermal. He helps GA Drilling bring a new piece of drilling technology to the market. Interestingly, the company is based in Slovakia, and are expanding with offices in Houston, the UK and Brazil. GA stands for Geothermal Anywhere – its strategy does not need further explanation.

The people behind the so-called ANCHORBIT® technology are aware that drilling costs and speed need to come down and up respectively to make deep geothermal drilling competitive, especially when deeper basement targets are looked at. John explains: "When drilling a well, torque can be a big issue, especially when reaching higher depths. This leads not only to a loss of energy and slower drilling rates, but also more wear and tear and hence the need to pull out of the hole and replace the bit."

The GA Drilling team developed a methodology to clamp the drill string situated just behind the bit to the bedrock through a series of pistons. "This causes all torque to concentrate onto the drill bit rather than in the drill string, making sure that the energy is used where it needs to be", explains John.

Whilst one section of the drill string is clamped to the formation, the bit drills deeper into the formation, at a speed that is estimated to be twice the rate of penetration as conventional bits. "Then, the lower set of clamps is activated, the upper one released, and the telescope is sliding in again. In that way, the drill bit "crawls" down the borehole.

John Gibb

"We have tested the tool with our partner Nabors at a site in Houston and have had very positive results", says John. "We are now ready to commercialise the tool and can't wait until the first wells are drilled using this promising technology." ■

**"torque can be a big issue, especially when reaching higher depths. This leads not only to a loss of energy and slower drilling rates, but also more wear and tear and hence the need to pull out of the hole and replace the bit."**

ANCHORBIT®, developed by GA Drilling, was designed to improve drilling economics and make more geothermal projects economically feasible by bringing enhanced performance and consistency to existing drilling technologies.

### ENABLING A NEW TYPE OF LOOP

"Our technology could be applied to a new well pair system that could be developed today – one being the producer and one the injector. These wells connect with each other at TD, which then allows fluids to be circulated through the loop. It is a straightforward concept, and it does not require fracking. Pairing these innovations with our technology means that the holes in geothermal loop systems can be drilled much faster and more economically than what is now deemed possible. It's the ideal solution for accessing geothermal basically anywhere!", concludes John.

PHOTOGRAPHY: GA DRILLING





# Heating a block of houses rather than a single one

**Rossingh Drilling and Geophysics and WKO Nederland are working on a deeper closed-loop geothermal system than the more conventional ones**

CLOSED LOOP geothermal systems, with a heat pump superimposed, form a new and promising way of domestic heating systems. Hundreds of small rigs are actively drilling these loops across many countries, enabling the decoupling from gas-fired heating.

Most of these closed-loop systems are designed to provide energy to one building and are normally drilled to between 100 and 200 m depth. The power that such a system provides ranges between 2 and 20 kW, which is sufficient for a single house. But what if you would drill a little deeper and be able to provide power for a block of houses instead?

Jan Rossingh, director at Rossingh Drilling and Geophysics, is always looking for ways to improve on currently used methodologies. Therefore, he decided to drill a borehole in his own back garden in the north of the Netherlands, more than twice as deep as the conventional ones.

The end result? A borehole that successfully terminated at 500 m, the desired depth, in just two days of drilling. "On the third day, we carried out borehole measurements", says Jan. "We always run a gamma-ray to have a better grip on the lithological variation, but of course, the geothermal gradient and conductivity are the most important things for us." The temperature at the depth of 500 m did not disappoint. "Rather than an expected 16/17°C, we are looking around the 21.5°C here", explains Jan.

The challenge with these deeper loops is to minimise the energy with which the fluids need to be pumped around the closed system. "The deeper you get, the more friction along the tubes is to be overcome. For that reason, the company developed a new concentric heat exchanger that is fitted in the borehole and maximises the power output whilst keeping friction to a minimum.

Using the experience gained through this project, Jan thinks there will be a market for these deeper closed-loop systems. "We can provide energy for an entire block of houses with one borehole rather than many smaller ones. This is not only a solution for existing housing blocks, but also for new developments and high-rise buildings where the spatial footprint is small but the power demand significant." ■

Drilling ongoing in Jan Rossingh's back yard.

PHOTOGRAPHY: ROSSINGH DRILLING AND GEOPHYSICS

# The economics of geothermal pumped well power projects

**This is the third and final contribution in a series on geothermal pumped well power projects. The first instalment provided a global overview of operating projects and subsurface characteristics. The second instalment covered downhole pump hydraulics and energy conversion. This piece will provide an overview of the economics of operating projects and a brief description of emerging technologies**

**ELLIOT YEARSLEY (enyearsley@gmail.com)**

GEOTHERMAL PUMPED well projects provide power to the grid at a contract price and terms negotiated with the power off-taker. This can vary significantly from country to country, but as the state of Nevada in the US represents the largest single market for power from geothermal pumped wells, power pricing in Nevada is presented here.

The Nevada Bureau of Mines publishes an annual report on mining, geothermal, and oil and gas statistics that includes price and production information, as shown in here.

The price of geothermal power in Nevada has varied from 5-9 cents/kWh over the period shown (1986-2021), with prices given in US cents per kilowatt-hour (kWh). This offtake price has been profitable for the geothermal operators in the long term, as shown by the growth in production from less than 0.5 million MWh to 4.0 million MWh. Production levelled off and slightly declined when prices fell below 6 cents in 2001 but recovered again as prices increased above that threshold in 2008.

The largest geothermal operator in Nevada during this period has been Ormat Technologies Inc., whose annual reports demonstrate a long period of growth and profitability, primarily based around geothermal pumped well projects in Nevada. In 2021 for example, Ormat's annual report shows electricity revenues $585 million versus costs of $337 million.

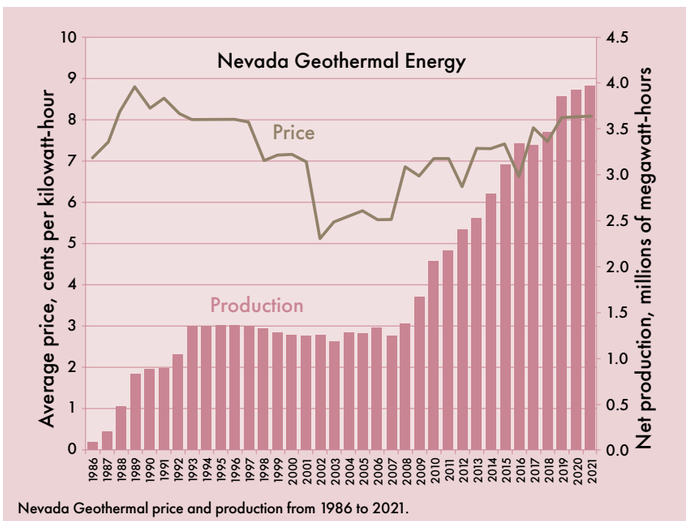
Data listed in a publication from researchers at University of Wisconsin-Madison in 2016 document long-term contracts for geothermal power, predominately pumped well projects, priced at 5-10 cents/kWh for contracts starting in the period from 2006-2018.

## THE ROLE OF SUBSIDIES

Subsidies for geothermal power in the US have mostly been in the form of tax credits. Geothermal power qualified for a 2.5 cents/kWh tax credit from 1992 to 2021 under various forms of the Production Tax Credit (PTC) legislation. This has been replaced recently by the so-called Inflation Reduction Act (IRA), which provides similar tax credits across a broad spectrum of renewable energy.

In Europe, subsidies have mostly taken the form of government-subsidised power prices available to the producer. In Germany for example, the Renewable Energy Sources Act (EEG) enacted in 2000 guaranteed a "feed-in tariff" to producers of 25 cents/kWh for 20 years. The original subsidy has recently been replaced by new EEG legislation.

This subsidy has facilitated the growth of the geothermal pumped well power industry, notwithstanding the higher development costs in Germany compared to the Western US where power prices of 6-10 cents/kWh have been sufficient to sustain a profitable industry - assisted by the 2.5 cents/kWh tax credit.




Nevada Geothermal price and production from 1986 to 2021.

SOURCE: NEVADA BUREAU OF MINES

## EMERGING TECHNOLOGIES

As summarised in the previous instalments in this series, well-established geothermal pumped well power projects utilise production wells with downhole pumps, fed from highly permeable reservoirs capable of average production rates in the range of 1,500 - 2,500 gallons or 6,800 - 11,000 litres per minute of 100-190C fluid. Re-injection wells are used primarily for the purpose of disposing of the produced fluid after it has been through the surface heat exchangers. In addition, re-injection also serves as reservoir pressure support.

Where sufficient subsurface permeability does not naturally exist, production wells must be hydraulically fractured to create this permeability, which is referred to as "enhanced geothermal systems" (EGS). In these systems, the pump is usually located at the surface and fluid is pumped at high pressures down an injection well and produced by an adjacent production well. Average production rates for EGS to date have been in the range of 100 -600 gallons or 450 - 2,700 litres per minute. Efforts to increase flow rates from hydraulically fractured production and injection well pairs are ongoing, and by some accounts promising, but to date, there are no continuously operated commercial EGS projects.

Another type of emerging geothermal power intended to utilize similar temperatures and surface pumps is referred to as "closed loop", which relies on heat exchange from the rock to the circulating fluid within the well, as opposed to direct production of the subsurface fluids. To date, there are currently no continuously operating commercial power projects of this type.

## ONGOING EFFORTS

Geothermal pumped well power projects are widespread and economically viable. Nevada has the largest concentration of pumped well projects in the world. Power prices in Nevada have ranged from 5-10 cents/kWh over the past 35 years and the US geothermal industry has been supported by a 2.5 cents/kWh production tax credit. Subsidised power prices in Germany and Europe in general have historically supported the geothermal power industry.

Emerging technologies for geothermal power projects that are intended to utilise a similar temperature range to pumped well projects (100-190C) include EGS and closed loop. Efforts to commercialise these technologies are ongoing, however to the author's knowledge there are currently no continuously operating commercial EGS or closed-loop geothermal power projects. ■

PHOTOGRAPHY: THINKGEOENERGY VIA FLICKR

Steamboat geothermal power plant complex by Ormat Technologies near Reno/ Nevada, October 2018.

GEOTHERMAL ENERGY

# An order of magnitude more energy for drilling twice as deep

## QUAISE is developing a new drilling technique to tap into energy deep into basement rocks

WHAT ATTRACTED me to geothermal is the fact that there are still a host of technical challenges to be addressed in order to unlock it as the ideal complement to wind and solar", said Matt Houde from QUAISE during a recent interview.

With his background in geology and engineering, the co-founder is now trying to commercialise a totally new technique of tapping into the earth's heat. All with the idea to make geothermal a viable option in more areas.

To realise this, the company has embarked on a research project that includes developing a new way of drilling. "We call it millimetre wave drilling", says Matt. "It means that we are drilling with electromagnetic radiation using wavelengths of between 1 and 10 millimetres. This is the high-frequency end of the microwave spectrum, and it will essentially vaporise the rocks we are drilling through."

The reason to use this high frequency is that it can be transmitted through pipe for a long distance with very high efficiencies. "This was actually looked at in the 1960's to enable long-distance communication, only to be taken over by fibre optics later. It shows that transmitting energy this way is not new. The new aspect is that we now use this energy to drill deep into basement rocks", Matt continues.

### FUSION TECHNOLOGY

In order to generate the energy to vaporize the rocks deep down – the company envisages drilling projects to 10-20 kilometres deep – a gyrotron is being used. "These devices were developed for the nuclear fusion industry to heat plasma, now we use it to heat rocks", Matt says. "We envisage we need between 100 kW and 1 MW of microwave power to drill a geothermal borehole to our target depths."

Even though the rocks are being vaporized, it does not mean that there is no material to be taken care of. "The gas will quickly recondense back to a very fine ash, which will then be taken up to surface by a purge gas. In our case, we will use nitrogen", Matt explains.

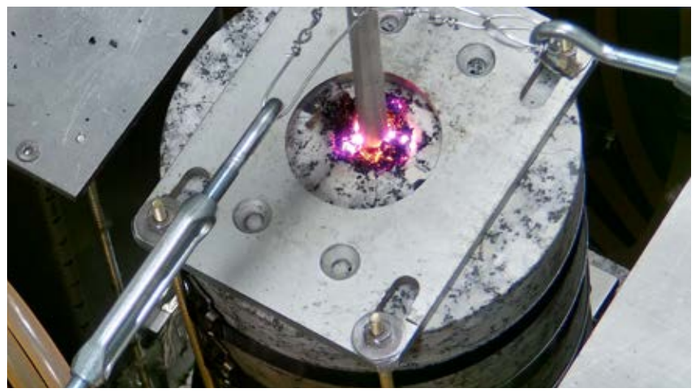
Drilling a QUAISE borehole will still involve conventional drilling though, as the millimetre wave technique only commences at the top of basement. "Our aim is to drill into basement faster and more efficiently with millimetre wave drilling, but conventional drilling is still our best alternative for drilling through the shallower, sedimentary overburden."

### SUPERCRITICAL FLUIDS

But how to produce the energy from deeper down? Matt continues: "We are aware that basement rocks can be tight. Faulted and fractured zones are mostly a very limited part of the succession, so if we do not find naturally occurring permeability, we create it through hydraulic fracturing and other stimulation techniques deployed in oil and gas and geothermal."

Using the millimetre drilling technique, QUAISE aims to target depths where the water reaches temperatures in excess of 374° C. This means that it is present as a supercritical fluid. "At those temperatures, the equivalent electrical power output can be more than 5 to 10 times the amount produced from a more "conventional" geothermal well producing a 200° C fluid", Matt says. "We think we can reach between 20 and 50 MWe per well."

At the moment, the company is still running lab tests to fine-tune the drilling technique, but the aim is to do the first pilot demonstration project in the next couple of years. "We are targeting an area with a relatively shallow basement and high heat flows, so the western part of the US will be a good candidate. We are very much looking forward to further maturing our technology this way and hope that we are on track to deliver a scalable, baseload energy resource to the renewable energy mix!" ■



PHOTOGRAPHY: QUAISE

Laboratory test facility where the millimetre wave drilling technology is being tested.

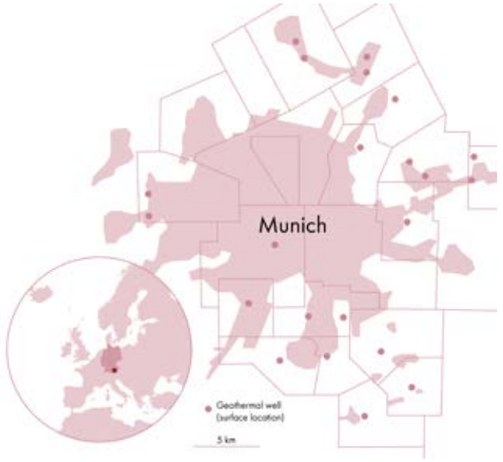
# A geothermal gold rush

**Thanks to a combination of favourable geological factors, the Greater Munich Region in Southern Germany has made a successful transition to geothermal energy production. And the neighbours are watching**

WHEN IT COMES to producing geothermal energy, Munich is without a doubt the place to be in Germany. As the map here clearly shows, the city is dotted by wells producing hot water and wells injecting the cooled liquids. But why is it Munich? Is there something special about this place? The answer is yes, there is. To learn a little more about that, we caught up with Neil Farquharson from Erdwerk, a consultancy firm based in the capital of Bavaria that has been involved with most if not all geothermal projects in the area, over the last 20+ years.

"Our city just happens to be situated in the heart of a geological sweet spot", Neil confirmed during our meeting. "There are in fact two things that make geothermal energy production from this place so attractive. First of all, there is a good reservoir. This is an Upper Jurassic platform carbonate succession with reefs developed in places. "It is especially these reefs that form targets of the wells, as these often show karstification and hence very favourable properties when it comes to producing water", he adds.

The second aspect of the geology that makes Munich such an attractive place is the water chemistry. "Current thinking is that the reservoir experienced a phase of complete flushing in Tertiary times", Neil explains. "Because of that, the produced water is close to the quality of fresh drinking water in places, which is very positive when it comes to scaling and corrosion issues. We still need scale inhibitors in some projects, or routine acidisation to remove carbonate buildup - typically around the pump - but it is much more manageable than in many other regions."




Given the number of geothermal projects now active in the Munich area, there is another way to ensure that energy delivery can continue at times of pump failures, and that is through connecting up neighbouring projects. "This could greatly reduce the reliance on oil or gas as contingency fuels, so the feasibility of connecting different heating networks is currently being investigated", Neil explains.

> "Our city just happens to be situated in the heart of a geological sweet spot"

## SECURITY OF SUPPLY

Producing geothermal energy for district heating, as is the case in Munich, must take place where the demand is, given that hot water cannot be transported over long distances. However, even the production of energy from a source so close by does not mean that there are no risks of interruption.

"The weakest link in some deeper and hotter projects is the submersible pump", says Neil. These pumps break down sometimes, which means that a workover is required to lift the old pump out of the well and install a new one. For that reason, most projects have a spare pump on-site. This is also the reason why there is always pressure and questions from project developers and investors regarding measures taken to ensure an as long as possible pump life.

## GOLD RUSH

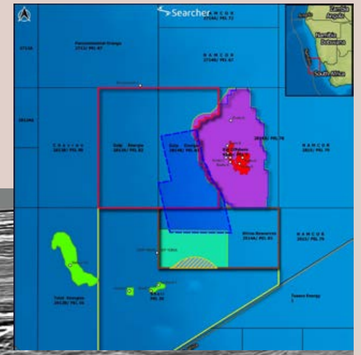
With the success in the Greater Munich Region and the political pressure to move away from gas-fired heating, more villages and towns near Munich have now also started to investigate geothermal potential of the same Upper Jurassic carbonate succession. "It sometimes feels as if there is a second gold rush going on", says Neil, following the one that took place between 2005 and 2010.

However, when moving further east of the Greater Munich Region, temperatures in the same carbonate reservoir are on average 5 degrees lower. "A negative thermal anomaly is known to exist, why this is the case is a matter of debate", Neil said, "but the fact is that Munich is just in the right place when it comes to the successful production of geothermal energy!" ■

# A big beast makes a big point

Rhino Resources led the way in the Orange basin in 2022 and 2023, allowing Searcher to acquire a 1,700 km² Multi-client 3D over PEL 85, using the Shearwater Empress vessel, adjacent to and up dip from Shell's Graff and La Rona discoveries. Within one month of last shot, Rhino were working on PSTM fast track data which was of extraordinary quality, defining new prospectivity both below (Graff style) and within the Gravity Driven Fold and Thrust Belt (GDFTB). Here, we take a quick look at the early imaging from this groundbreaking MC survey in the Orange Basin, opening the way for great exploration drilling results in the near future.

Searcher



PSTM Final Full Stack
TVDSS (SEG +ve)
W ⟷ E

TVDSS (m)
2,000
3,000
4,000
5,000
6,000
7,000
8,000

Pliocene Pockmark Trails
Post-GDFTB MTS
Extensional GDFTB
Compressional GDFTB
Post-Aptian Sand Play
Pre-GDFTB Cretaceous Turbidite Channels onlapping outer high
Aptian Source Rock
Volcanic SDRs of Eastern Outer High
Kudu-like SDRs

SHEARWATER Searcher

0 (km) 7

# 3D that is fast, good, cheap and over the hottest exploration on Earth

**So far this year, approximately 18,000 km² of new 3D was acquired in the white-hot Orange Basin of Namibia, aiming to delineate the Venus and Graff plays and constrain similar related plays and development opportunities in the basin**

**NEIL HODGSON, KARYNA RODRIGUEZ AND LAUREN FOUND, SEARCHER**

6,700 KM² of the new 3D in the Orange Basin was multi-client, the first of which was acquired over PEL85, operated by Rhino Resources. The Shearwater Empress towed 12 streamers each 8.1 km long and 150 m apart, commonly known as a wide tow configuration, in late 2022 to early 2023.

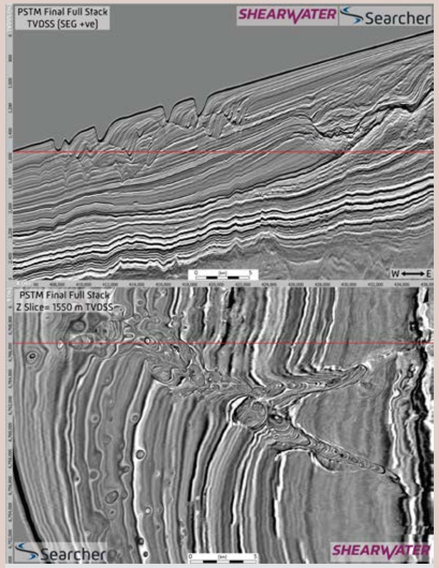



Figure 1: Tertiary indications of migrating fluids. a) W-E seismic section through pockmarks at seabed. b) horizontal depth slice at 1550m through narrow downward prograding pockmark trail. Pipes and cone structure also visible.

Shearwater are processing the data and yet only one month after the last shot delivered a depth converted PostSTM 3D volume, with a full set of angle stacks. Some seven months later a full PSTM was delivered, see example in fold out, and final PSDM will be delivered by November 2023. The processing results even from the fast track are superb, giving rapid access to data where a steady stream of discoveries and drilling activity is constantly changing the prospectivity story.

## THE JOURNEY BEGINS: THE FRAMEWORK

PEL85 is located updip of the Graff and La Rona discoveries. The lowest part of the section shown in the foldout line is comprised of Seaward Dipping Reflectors (SDRs), both mixed clastic and volcanic in the east with "Kudu Field" type set of lithologies, and purely volcanic in the west.

Above the unconformity at the top of the SDRs lies a thick Lower Cretaceous section at the top of which is a decollement surface marking the base of the Orange Basin's famous Gravity Driven Fold and Thrust Belt (GDFTB). As we will see, substantial targets lie below the GDFTB. However, a variety of prospects are mapped in the compressional, translational and extensional sections of the GDFTB too. Above this is a thin but significant Mass Transport Complex (MTC) which is significant as it provides topseal to buried topology plays.

Above the GDFTB and the MTC, the Tertiary sequence marks a transition from the "collapse-a-thon" of the unstable Late Cretaceous Orange shelf to a period of stability. This is related to a dynamic topography effect on the basin as South Africa rotated over a mantle upwelling. Elliptical seabed depressions at seabed are formed as trails of pockmarks migrating down slope related to the presence of oil in deeper reservoirs, as seen on figures 1a and b. They are associated with narrow fluid flow pipes and vents and small sections of Bottom Simulating Reflectors (BSRs), indicating near surface gas hydrate accumulations.

## WE NEED TO TALK ABOUT THE EARLY CRETACEOUS

Lower Cretaceous Aptian source rock lies on top of the SDR packages.

The Aptian source rock reflector is low frequency, low amplitude, almost isopachous across the section with only some thinning towards the western high. In age, we suspect it is similar to the Aptian source rock penetrated by the Wingat-1 well and may be equivalent to the upper part of the Aptian source under Venus deposited in-board of the outer high as drift subsidence in the Aptian allowed flooding, peneplanation and then deposition of source rock over the volcanic-SDR, and clastic SDR units of the early post rift and late syn-rift respectively.

Early analysis of this unit shows it is thick, omnipresent and displays a strong negative far angle minus near angle times far angle response (F-N*F) indicating a Type IV AVO anomaly which is also identified on the gradient versus intercept plot and is associated, especially in Namibia, with an oil generative source rock.

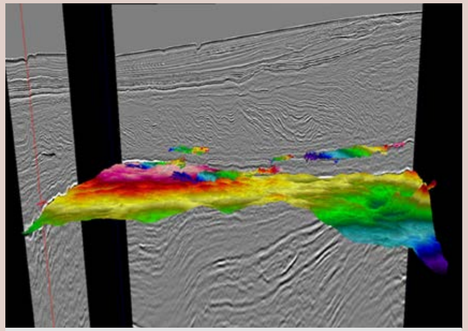


Figure 2: Depth converted volume with mapped surface at top Aptian Source Rock and a number of the Early Cretaceous channel anomalies either onlapping onto the Outer high or in the punctuated channels system running South and West towards the Graff discovery.

Between the Aptian source rock and the overlying GDFTB lies a conformable section, within which we map a number of high amplitude channels running broadly NE to SW across the block. The amplitude anomalies in these channel systems map out over 30 to 90 square km in extent, and we suggest that these channels would be similar to those feeding sand into the Graff and La Rona discoveries. Graff is reported to have complex trapping, including sub-GDFTB thrusting and mixed system interaction between slope channels and contourite drifts/current.

Some sub-GDFTB structuration is apparent on the data here, and some contourite current influence on turbidite flow, in particular the ability to winnow turbidites to improve net/gross, would not be unwelcome. On this dataset these onlapping, counter-regional dipping traps are associated with very strong positive F-N*F attribute responses indicating the presence of hydrocarbons. Sitting as they do over Aptian source rock, buried sufficiently to be well in the oil generative window, these features look attractive already, and no doubt the diligent geoscience from the Rhino Resources team will find that they are even more irresistible in the near future.

## BRING ON MORE DATA!

These extraordinary results will soon be added to by another 20,000 square km more multi-client 3D being collected in the 2023-2024 season in this basin. These 3D's across the basin will allow the industry to map, understand and make investment decisions with a knowledge of how the whole basin is working, and for once, being able to see all the cards in play rather than just the data in their own hands.

That Rhino Resources took the first step to get this new data to redefine the hydrocarbon story is a great credit to them, and together with spectacular seismic acquisition and processing from Shearwater, this has paved the way for the industry to explore this exciting play fairway. This makes the point; early multi-client seismic plays a key role in re-writing the future exploration story.

*References provided online.*

# Carbon storage in Leman – how feasible is that?

## What does it mean to store $CO_2$ in the oldest and biggest gas field on the UK Continental Shelf?

A CARBON STORAGE licence covering the Leman field was recently awarded to Perenco and Carbon Catalyst. The gas field has had 120 wells drilled in total, with some of the early ones completed about 60 years ago.

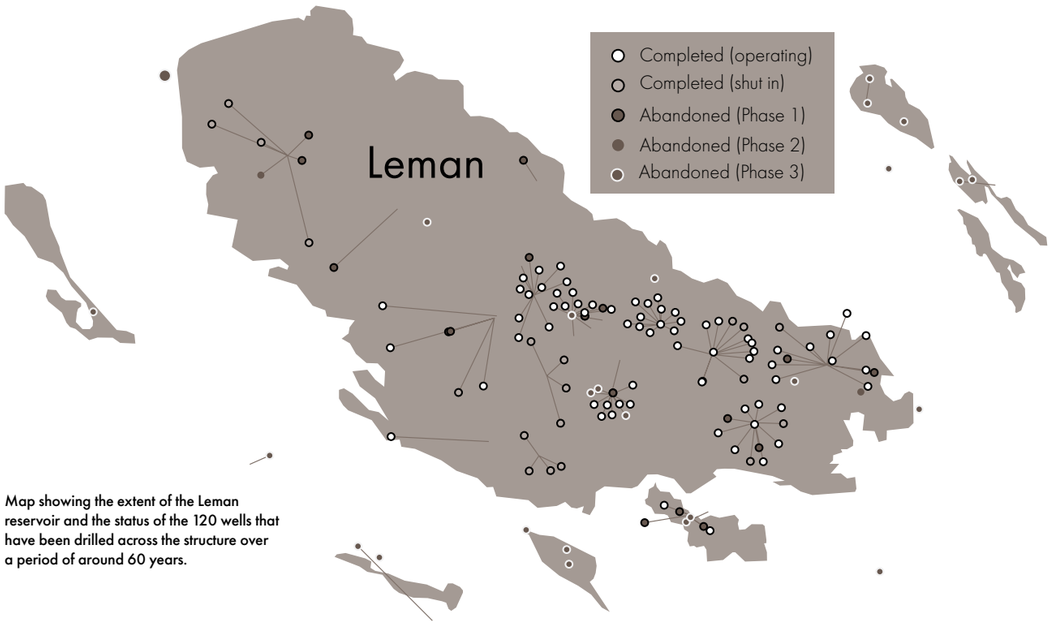
All the wells that will not be used for injecting $CO_2$ will need to be completed in such a way to comply with the standards for $CO_2$ capture, which means that the cement sheath between the steel casing and the borehole must be corrosion resistant and of sufficient thickness. As the map here shows, which is based on information from the UK National Data Repository, most of the wells have not been abandoned yet (92), which should mean that access to these wells is relatively straightforward given that the platforms are still in place.

But the key is, with such an old field where there are still 28 wells at various stages of abandonment, some of which were drilled and plugged in the 1960's, what is the subsurface situation with regards to the cement and how easy is it to find the documentation to prove that they were plugged correctly? There only needs to be one that does not comply to put the entire project at risk if leakage is still seen as something that cannot happen.

When injection can start, the rates have to be depressed first, as the operator already wrote in one of their press releases. "The depleted nature of the reservoir means that the pressure is now so low that injection of dense phase $CO_2$ cannot happen straight away", says reservoir engineer Bob Harrison from Sustainable Ideas Ltd in a message to us. "Transporting $CO_2$ in its dense phase requires high pressure, which must be lowered to inject it safely into a depleted gas reservoir. The pressure drop may induce a phase change and will cause Joule-Thomson cooling that risks hydrates forming in the well and thermal induced fracturing of the reservoir".

One way of managing $CO_2$ phase behaviour is to inject in its gaseous form first, meaning that injected volumes will be depressed for quite a long time before the reservoir pressure is up at a level where dense phase $CO_2$ can be injected without a phase change occurring.

It does help that operator Perenco is already injecting water into Leman. This not only increases reservoir pressure, but also means that there is a medium for the future $CO_2$ to dissolve in and thereby be captured properly. But it is the legacy of some of the wells and obviously the status of the transporting pipelines that will form the biggest concerns for a project of this kind. ■




Map showing the extent of the Leman reservoir and the status of the 120 wells that have been drilled across the structure over a period of around 60 years.

DATA SOURCED FROM THE NATIONAL DATA REPOSITORY (NDR)

# Exploring $CO_2$ storage efficiency: striving for clarity

**The Conference on $CO_2$ Storage Efficiency, held at the Geological Society of London's Burlington House this September, brought together experts from industry, academia and governments to tackle the complex topic of storage capacity calculations**

TINA LOHR AND ELLEN MITCHELL, ERCE

PRIOR TO BUILDING a full 3D model of a carbon store, the mass of $CO_2$ that can be stored in a reservoir can be calculated by multiplying the pore volume by the $CO_2$ density and a Storage Efficiency. The "efficiency factor" accounts for the portion of the pore volume that could be occupied by $CO_2$. This sounds straightforward, but the calculation of Storage Efficiency is complicated as it does not have a consistent definition.

In some cases, the Storage Efficiency factor is applied to the total pore volume within a slab or cylinder, while in others it is applied to the net effective pore volume above a spill point.

Furthermore, the constraints that feed into the Storage Efficiency are not well defined. For instance, some estimates include pressure while others do not. Other controls that may or may not be included are lithological heterogeneity, trapping structures, injection rates, well spacing and fluid properties like $CO_2$ density and mobility.

Due to this complexity, there is much controversy on how to estimate Storage Efficiency, with some arguing it should not be used at all and that reservoir simulation is a better path.

At the same time, estimates of Storage Efficiency are being used in many regional mapping studies, which are demanded by regulators and government bodies to base new policies on. Companies use Storage Efficiency at the early stages of project screening, and when determining which licence area to bid for. In turn, for US landowners the Storage Efficiency factor dictates how much money they can make by allowing $CO_2$ to be stored in reservoirs situated under their land.

Based on these examples, it is easy to see that it is critical for an appropriate definition of Storage Efficiency to be developed, as the number of active storage sites is going to increase rapidly. The discussions and talks at the conference will hopefully have helped to get a step closer to establishing a consistent, multidisciplinary approach for estimating Storage Efficiency. The convenors are now planning to distil the conference's insights into a comprehensive paper, providing a roadmap for calculating and applying Storage Efficiency. ■

The convenors of the conference, from left to right: Florian Doster (Hariot Watt University), Clare Glover (ExxonMobil), Ellen Mitchell (ERC Evolution) Tina Lohr (ERCE), Philip Ringrose (Equinor/NTNU) and Adrian Topham (The Crown Estate).

PHOTOGRAPHY: HOLLY-MARIE OWEN, ERCE

> "...there is much controversy on how to estimate Storage Efficiency, with some arguing it should not be used at all and that reservoir simulation is a better path."

### STORAGE AND VOIDAGE

Storage Efficiency is generally discussed in relation to both open and closed saline aquifers, while voidage replacement is used to calculate the mass of CO2 that can be stored in a depleted gas field.





# Dutch flagship CCS project given the go-ahead in court

**Court rules in favour of construction Porthos CCS project despite concerns raised about nitrogen emissions**

ON WEDNESDAY 16 August, more than 1000 people listened to the online broadcast of a hearing that lasted for about 3 minutes. There was something important at stake; the future of carbon storage in the Dutch offshore.

The most advanced carbon storage project in the Netherlands, Porthos, was put on hold more than a year ago when activist organization MOB challenged plans to construct the pipeline that will carry $CO_2$ from the Rotterdam Harbour to the offshore platform P18-A. The issue? Nitrogen emissions as a result of the construction work. Nitrogen emission and deposition are a big issue in the Netherlands at the moment, which has put a break on many projects and caused havoc amongst the agricultural community.

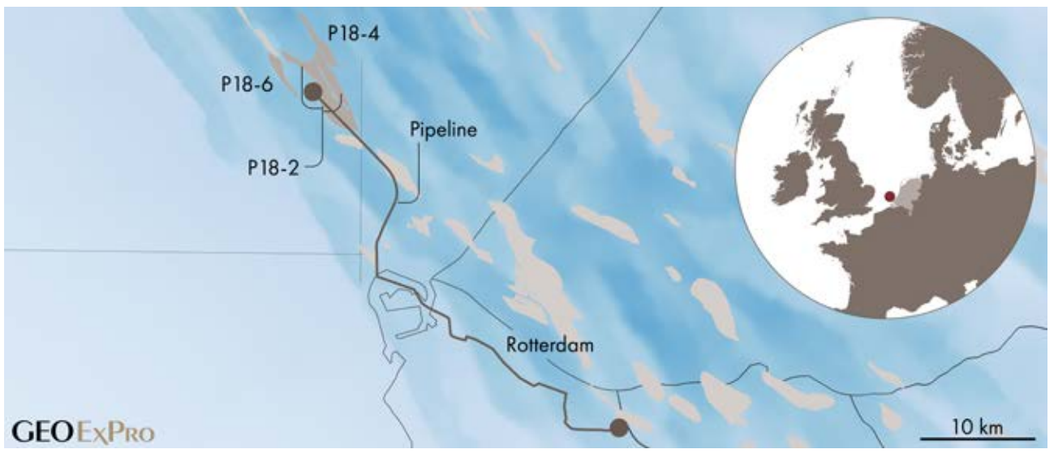
However, in the Porthos case the judge has now ruled that even though the emission of nitrogen will temporarily increase, the surrounding nature reserves will not be affected significantly. The fear that this will lead to more projects being given the go-ahead was rebutted. Every project will need to be assessed individually, even in the case of a temporary increase in nitrogen deposition.

What would have happened if Porthos was not given the go-ahead? It would certainly have put a huge damper on the prospect of any carbon storage projects going ahead in the Netherlands. Also, a lot of energy already went into realising Porthos. An entire team is dedicated to the project at Energie Beheer Nederland (EBN). Also, offshore, extensive work has already been carried out to prepare the P18-A depleted gas field for injection $CO_2$. For example, as we reported on last year, a complex well intervention operation was required to properly abandon one of the side-tracks because access to the well had to be gained through fishing a whipstock.

### A SMALL DENT BUT IT IS A BEGINNING

The three reservoir compartments, consisting of Triassic sandstones, that make up the Porthos carbon storage project in the P18-A field (P18-2, P18-4 and P18-6) are together capable of storing around 41 million tonnes of $CO_2$. Whilst the facilities will be able to transport and store up to 5 million tonnes a year, the plan is to initially inject 2.5 million tonnes a year.

With an annual emission of around 170 million tonnes (2020) in the Netherlands, Porthos will only make a very small dent in the country's carbon emissions. But, with other CCS projects on the table and a trend of declining emissions altogether, CCS is still seen as a way to get to Net Zero much quicker than without. It is therefore a positive signal that Porthos can now go ahead and hopefully it provides momentum for other projects currently on the agenda. ■




Map showing the three compartments of the P18-A field that comprise the Porthos carbon storage project.

# TECHNOLOGY

"The industry has always innovated, those who complain don't understand!"

*Miles Leggett – Geophysical advisor*

# Your digital search assistant

**Before the summer, the Norwegian Petroleum Directorate (NPD) launched a new tool on its website that is freely available to anyone who wants to learn more about exploration through the use of artificial intelligence**

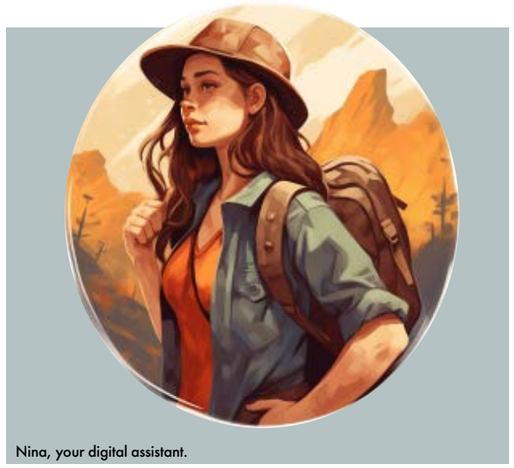
THE COINED FABRIQ tool allows you to talk to a digital assistant about a selection of the Norwegian Petroleum Directorate's publicly available status reports, well histories and news articles. You can ask questions about wells, discoveries, geology, prospects and more.

"You can choose between four personalities to assist with your questions", says Jesse Lord, founder and Lead - Product Strategy at Kadme. Jesse developed the search tool earlier this year, around the time many people became familiar with ChatGPT and the concept of Large Language Models (LLM'S). The tool is based on the same digital language models as the popular chatbot.

"We wanted to launch this quickly so that those working with the applications for this year's APA Round could test it out. We believe the artificial intelligence assistant has helped them do research, as it understands the context of questions and sits on a lot of valuable information", explains Petter Dischington, geologist at the NPD.

"In addition, we wanted to explore how we can use this type of technology internally. We wanted to see if, with few resources, we could make available useful information for internal work processes and for those who use our data, using language models and user-friendly interfaces", adds NPD geologist Maria Juul.

It is Petter and Maria who have been the driving force behind the initiative at the NPD.



Nina, your digital assistant.

SOURCE: NPD.FABRIQ.COM

**"We wanted to see if, with few resources, we could make available useful information for internal work processes and for those who use our data.."**

## A FRIENDLY FACE

The assistants you meet at the platform on the NPD website, Nina and Neil, are based on the latest language models GPT 3.5 and GPT 4. The language models have been developed by OpenAI and are based on so-called neural networks. It is the tremendous increase in available computing power and quantity that has contributed to such models becoming possible in the past year.

"The tool we have developed at Fabriq is based on OpenAI's language models, but is specifically designed for the oil and gas industry. The knowledge base for the digital assistants is, as of today, publicly available data from the NPD. Based on the users' questions, the most relevant data is fed into the language model, which makes sure to provide an understandable answer in a natural language form", explains Jesse.

## BUILDING TRUST

Many of those who have tried ChatGPT have painfully learned that you cannot fully trust the information that is presented. First, the chatbot does not tell you where it got its information from. Secondly, it just so happens that it gives you information that is not rooted in reality.

ChatGPT is primarily developed to be able to give a well-formulated and relevant answer. Facts come second. "The first feedback we gave Fabriq was that all information presented by the assistant must be able to be documented", says Petter.

A large part of the work on the development of the tool has actually been to give users the answer they don't want: "Sorry, but I have no information about...". "It was absolutely necessary for us to ensure that the assistant does not fabricate an answer", points out Jesse.

The tool, which is still in a pilot phase, can be used until October this year. ■





# Is new technology being used to squeeze more barrels from maturing assets?

**Results of a poll on social media suggest that most people agree, with a vocal minority arguing that this is not the case at all**

OFTEN, PEOPLE complain about the oil industry being slow in adapting new technology. However, with more and more fields maturing, the need to innovate to get more barrels from existing fields is clear. In your experience, is this now happening? That's the question we asked our followers on LinkedIn the other day.

**"the industry has always innovated, those who complain don't understand!"**

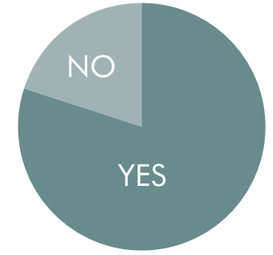
*Miles Leggett – Geophysical advisor*

In total, 69 people cast their vote on the poll, with the majority of 44 agreeing with the statement. Geophysical advisor Miles Leggett commented on the poll saying that "the industry has always innovated, those who complain don't understand!" We asked Miles for some further insights on the matter, and he responded by saying that there are numerous examples where new technology is being applied. As an example, he mentioned the development of new umbilicals that cater to $CO_2$-rich oil and gas.

Miles also reminded us about the fact that ANP rules on pre-salt production in Brazil dictate that a fixed percentage of the revenues have to be reinvested in research and development, which should make its way into innovations fueling the production of hydrocarbons from these assets in particular.

However, not for everyone in the industry it is obvious that new technology finds its way to produce more barrels from mature fields. A geologist from a major global operator told us that beyond the application of 4D, he does not see so much new technology being deployed into the further development of brown fields. Instead, he sees that the focus is on discovering new volumes and developing those once they have been proven.

How much does a poll mean? Of course, it is just a snapshot of what people think and the number of voters is small, but even though most of those who voted do see that technology plays a role in the further development of existing fields, there are people from within the industry who do not really see this happening at the moment. Maybe it is time to dedicate some more content to this for the magazine! ■




VOTES: 69 (44 Y - 11 N)
New technology is increasingly being applied in the drive to squeeze more barrels from mature assets.

PHOTOGRAPHY: ZBYNEK BURIVAL VIA UNSPLASH

# The Netflix of geoscience

**Claudia Ruiz-Graham tells the story of how she launched a virtual reality company without knowing much about virtual reality in the first place**

WHEN I LEFT bp in 2016, I didn't know anything about virtual reality, but what I did know is that I wanted to do something with it", says Claudia Ruiz-Graham when we meet on Teams in August. Her company Imaged Reality, which now employs ten people based in the UK, Japan, France, Colombia and Bolivia, has surely tapped into a market.

A geologist herself, Claudia has had the benefit of attending numerous field trips throughout her long spell at bp. "The more outcrops we saw, the better our ability to translate depositional and structural complexities into our subsurface models", Claudia says.

"During the downturn of 2015, many experienced people left the organisation without having enough time to transfer their knowledge to the younger generations. Field trips were also cancelled. I came across virtual reality and drone technology, and thought, maybe I can put the two together and create field trips in virtual reality. This was the original idea."

Claudia Ruiz-Graham.

**"I will never forget the moment I first put on the headset and saw the first version of the platform; I got goosebumps."**

"I benefitted from a redundancy package", Claudia continues, "and with that, I invested some seed capital to get started. I knew I needed to get up to speed with the latest VR and drone technology, so I started attending conferences to learn about the opportunities out there. I quickly met the first developer at one of these events. He happened to come from the gaming industry and was able to bring his expertise of visualisation to our geoscience expertise."

"I will never forget the moment I first put on the headset and saw the first version of the platform; I got goosebumps. It was like being able to touch the outcrops myself! We were pioneering virtual reality in Geoscience."

Claudia continues: "We launched the first prototype quickly and as we continued to develop the platform we managed to secure our first sales. To get to the next level of development, we then secured investment, which enabled us to really scale up. Now, we run projects for a range of large and small companies, universities and research institutes."

## FINALLY I UNDERSTAND WHAT THE GEOLOGISTS MEAN!

"Our mantra is reducing subsurface uncertainty through data integration from basin scale to pore scale, while enabling team collaboration in an immersive environment. Not only do we work with outcrop models, we also integrate these with all other subsurface data types such as thin sections, cores and well logs into a virtual data room", Claudia explains.

Whilst going to the core store or on a field trip is mostly only possible for a select group of specialists from these companies, the Imaged Reality platform can now be used by entire teams simultaneously, enabling a much better transfer of information from one expert to the another. "I have heard engineers say that they now finally get what these geoscientists are on about", laughs Claudia.

## DIGITAL TWINS

Viewing outcrops is one thing, but the Imaged Reality team has also put a lot of effort into enabling people to interpret data in the platform and export these for other purposes, in addition to creating digital twins for entire core collections. And with on-demand cloud-based access to 3D outcrop collections from a catalogue, I like to call ourselves the "Netflix of Geoscience." ■

# Japan eyes production from REE-rich muds

**Far from mainland Japan, at depths reaching 6,000 meters, lies a deposit that holds vast quantities of rare earth elements. The island nation is targeting trial extraction next year in an effort to reduce its dependence on China**

THE UNUSUAL DEPOSIT was first discovered by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in 2013 and is located in an area off the Minami-Torishima Island (Marcus Island) in the Pacific Ocean, some 1,900 kilometers southeast of Tokyo.

A ten-meter interval of highly enriched rare earth elements (REE) muds may help Japan reduce its dependence on China for its industrial metal needs.

According to a story in Nikkei Asia, published late last year, the Japanese Diet (the national legislature) approved to allocate 44 million USD to a project dedicated to developing and testing technologies for extracting mud from depths reaching 6,000 meters.

"Japan will curb excessive dependence on specific countries, carry forward next-generation semiconductor development and manufacturing bases, and secure stable supply for critical goods, including rare earths", stated the Japanese National Security Strategy, announced in December 2022.

In essence, the technologies required for the trial extraction, which may occur in 2024, are strong pumps and a 6,000-meter-long pipe. Although a rather simple concept, the task may prove challenging, as a previous trial in 2022 was done at depths of only 2,470 meters.

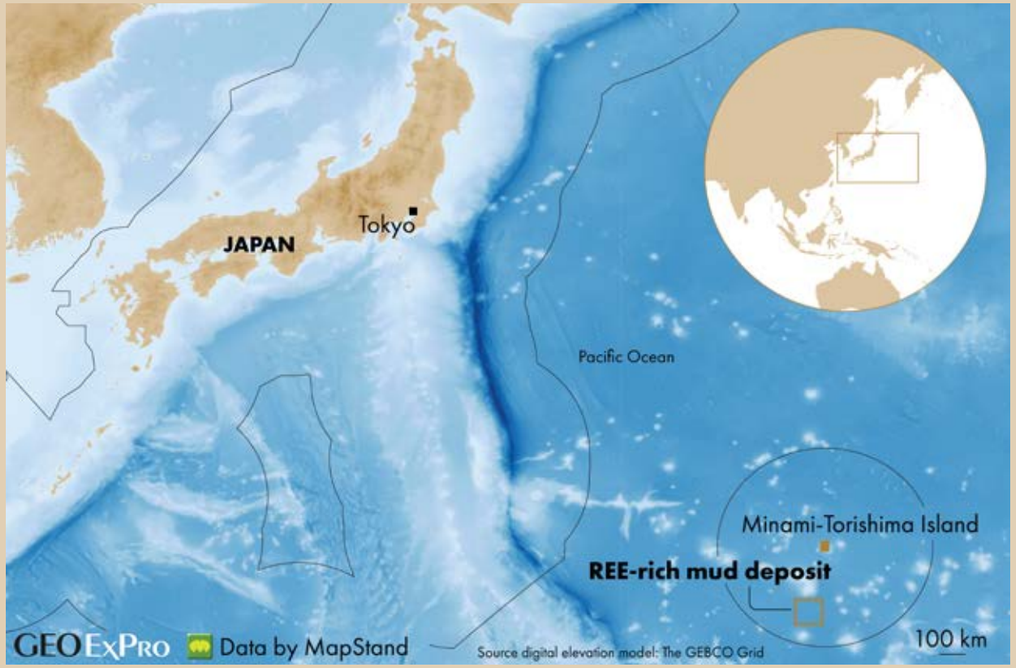
The deposit may be worth the effort though. According to a 2018 Nature Scientific Reports article, the cores revealed grades of up to 5,000 ppm (0,5 percent) REE and Yttrium. That is on par with many other known deposits globally. Further, optimal mineral processing procedures may enhance the economic value of the resource.

The researchers tested the sampled material in a laboratory to gain additional insights into potential future processing methods. They discovered that the mud was amenable to hydrocyclone separation, which is a rather straightforward technology that can be applied on an industrial scale.

By separating and then selectively processing the heavier components of the mud, the researchers effectively increased the deposit grade. They explained that by decreasing the mud weight and volume by only bringing high-grade mud to onshore processing facilities, they could decrease the smelting costs. Further reductions in costs may be achieved if a hydrocyclone separator can be operated in-situ on the sea floor, thus reducing the amount of material to be lifted.

The most promising area (102 km$^2$) and the uppermost ten meters of the mud may yield 1,2 million tons of REE oxide. That could account for the world's current annual demand for yttrium, europium, terbium, and dysprosium for decades. For the total research area, we could be talking centuries.

These metals are essential components in a wide range of high-technology applications and processes, including superconductors, lasers, magnets, data storage, nuclear power, light bulbs, and medicine, to name a few. ■




When the boundaries of Japan's maritime zones were confirmed, was it already known that REE-rich muds were present at a depth of around 6,000 m? The island of Minami-Torishima must certainly have been of key importance in drawing up the boundaries, as it is located in the center of this particular area of Japan's maritime zone.

### A NEW TYPE OF DEPOSIT

A research article from 1990 explains that REE-enriched muds in the Pacific Ocean, such as the deposit found near Minami-Torishima Island, contain fish-bone debris. Fish bones are composed of biogenic calcium phosphate, which readily accumulates REE from the seawater. The researchers concluded that low sedimentation rates in combination with high biological productivity have contributed to the formation of REE-rich muds in certain parts of the Pacific Ocean. These muds represent a lesser-known, fourth type of deep-sea mineral deposits. More common are nodules, massive sulphides, and polymetallic crust deposits.

# Hot debate about deep sea minerals

**Is it right for Norway to open up marine mining, and do we have sufficient knowledge of the conditions and resources in the deep seas?**

THIS WAS the topic of a debate during Arendal Week in Norway this summer. On stage were senior advisor in WWF, Kaja Lønne Fjærtoft, parliamentary representative in AP, Sverre Myrli, parliamentary representative in MDG, Rasmus Hansson, senior geologist in NGU/Mareano, Terje Thorsnes, general secretary of the Norwegian Forum for Marine Minerals, Egil Tjåland, and information manager in Fiskebåt - the sea fishing fleet organisation, Odd Kristian Dahle.

Fjærtoft began the afternoon discussion by saying that opening mineral extraction on the Norwegian continental shelf could potentially be the biggest environmental intervention Norway has ever made, and without knowing what the consequences might be. She was supported by Hansson, who reiterated the need to invest more in recycling.

"We all agree that the energy transition will include more recycling, but it must be accelerated - it requires more minerals than what can be recycled. It is what the International Energy Agency, among others, tells us", said Tjåland.

## MAPPING AND EXPLORATION

Thorsnes expressed the wish that we must take the time for much more thorough mapping of the deep sea areas before we can assess exploration and extraction, and that it should be Mareano who does that work.

Tjåland maintained that a smarter way to acquire an increased knowledge base would be precisely to open up exploration: "It is a golden opportunity if the exploration companies are required to carry out environmental surveys at the same time as they conduct exploration. Then we can map the areas we need more knowledge about. Environmental investigations in connection with exploration are beneficial for both the environment and fisheries. Alternatively, we risk that the areas will remain unknown for many years to come."

## HOW PROFITABLE IS IT?

The profitability of the potential new seabed mineral industry was also discussed. Fjærtoft pointed out that we have too little knowledge of the resources, and that the Norwegian Petroleum Directorate's resource assessment is based on a few spot samples and a lot of extrapolation.

Thorsnes thought it would be more correct to look at increased extraction on land, where Norway has great potential in terms of mineral deposits. Hansson was also more positive about more mining on land.


Rasmus Hansson, Egil Tjåland and Odd Kristian Dahle.

> "I meet opposition to mining everywhere I travel. It is easiest to say no, but the fact is that in some places we have to extract minerals..."

"I meet opposition to mining everywhere I travel. It is easiest to say no, but the fact is that in some places we have to extract minerals. Let's therefore investigate the possibilities, and see if there are deposits worth driving in the deep sea", said Myrli.

"We don't really know if this can be profitable, but the Norwegian Petroleum Directorate has worked over several years to map the resources. We need to take the next steps to find out more. We must give the companies the chance to do research and find out if this can be profitable", concluded Tjåland. ■

PHOTOGRAPHY: ESPEN LUNDBERG SIMONSTAD





# Environmentally responsible mining: Not so impossible

**Impossible Metals is developing autonomous underwater robotic vehicles that can collect polymetallic nodules off the ocean floor while leaving the marine ecosystem intact. A successful shallow water demonstration was performed in May**

A KEY MILESTONE was met in May this year. Impossible Metals demonstrated the capabilities of their autonomous underwater vehicle (AUV) Eureka 1. The successful test in shallow water has brought the technology developer one step closer to their vision of a fleet of AUVs that can mine polymetallic nodules efficiently and with a "softer touch" than competing solutions.

**The opportunity:** Vast areas on the sea floor in certain oceans around the world are covered in nodules – potato-sized rocks that contain metals that are in particular demand for the energy transition, mainly copper, nickel, and cobalt. The Clarion-Clipperton Zone in the Pacific Ocean is considered to be the richest nodule field globally.

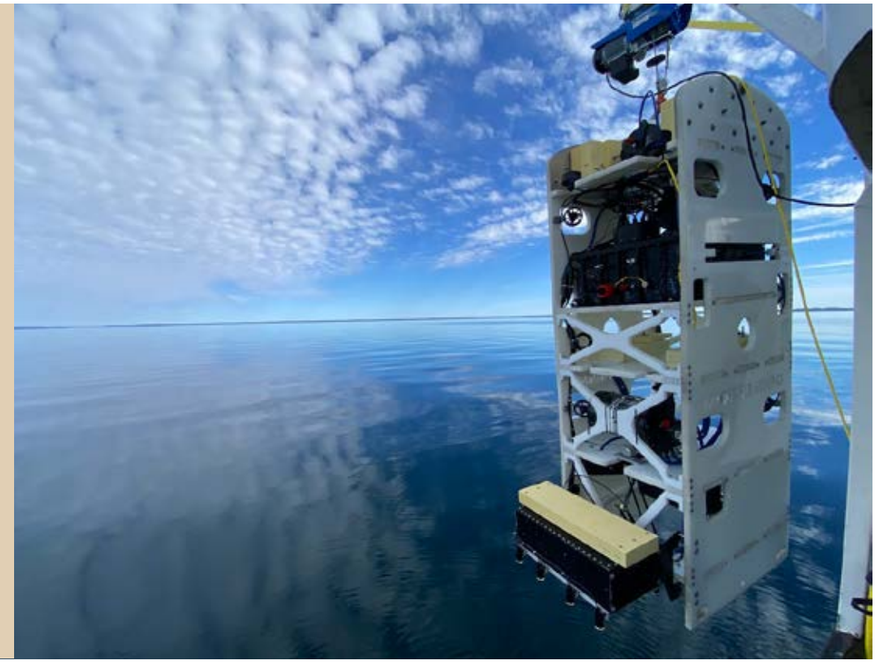
**The challenge:** Dredging (vacuuming) the ocean floor leaves long-lasting scars, generates sediment plumes that may affect ecosystems over large areas, and it destroys the ecosystem at the dredging site.

**The solution:** Don't dredge.

The AUVs designed by Impossible Metals will float above the seafloor. Instead of indiscriminate vacuuming, a set of mechanical arms will pick up the individual nodules. In combination, these features will minimise plume generation and disturbance of benthic organisms.

Further, the AUVs will have an AI-driven computer vision system that recognises collectible nodules and avoids other types of rocks or nodules with marine life. The AUVs can also be algorithmically programmed to leave behind a certain percentage of nodules as habitat corridors to ensure the ecosystem and habitat remain intact.

Additionally, using a fleet of AUVs for mining and transporting nodules to surface will result in less noise generation compared to using riser pumps. The latter option is also more expensive, according to the company. ▸



Impossible Metals demonstrated their first-generation nodule harvester in May 2023.

PHOTOGRAPHY: IMPOSSIBLE METALS


"Our goal is to have the lowest environmental impacts and the lowest costs of any deep-sea mining technology. Our economic model shows that our costs per ton of nodules to port are forecast to be half of competing dredging solutions".

## KEEPING BUOYANCY

The demonstration in May was the company's first proof of concept for an AUV with full autonomous operation. Specifically, Impossible Metals showed that Eureka 1 could avoid contact with the seafloor and that its buoyancy system, the harvesting system, and the overall fluid dynamics of the vehicle did not produce any plumes, only minor sediment disturbance, as nodules were picked up.

According to the CEO of Impossible Metals, Oliver Gunasekara, the company's solution for harvesting nodules is not only environmentally friendly, but it may also turn out to be more economical than competing techniques.

"Our goal is to have the lowest environmental impacts and the lowest costs of any deep-sea mining technology. Our economic model shows that our costs per ton of nodules to port are forecast to be half of competing dredging solutions".

The successful demonstration of Eureka 1 is only the first of several milestones on the company's roadmap. The team is already working on developing Eureka 2. The second-generation AUV will be able to operate at depths of up to 6 km and carry a payload of 100 kg (Eureka 1: 25 meters and 5 kg).

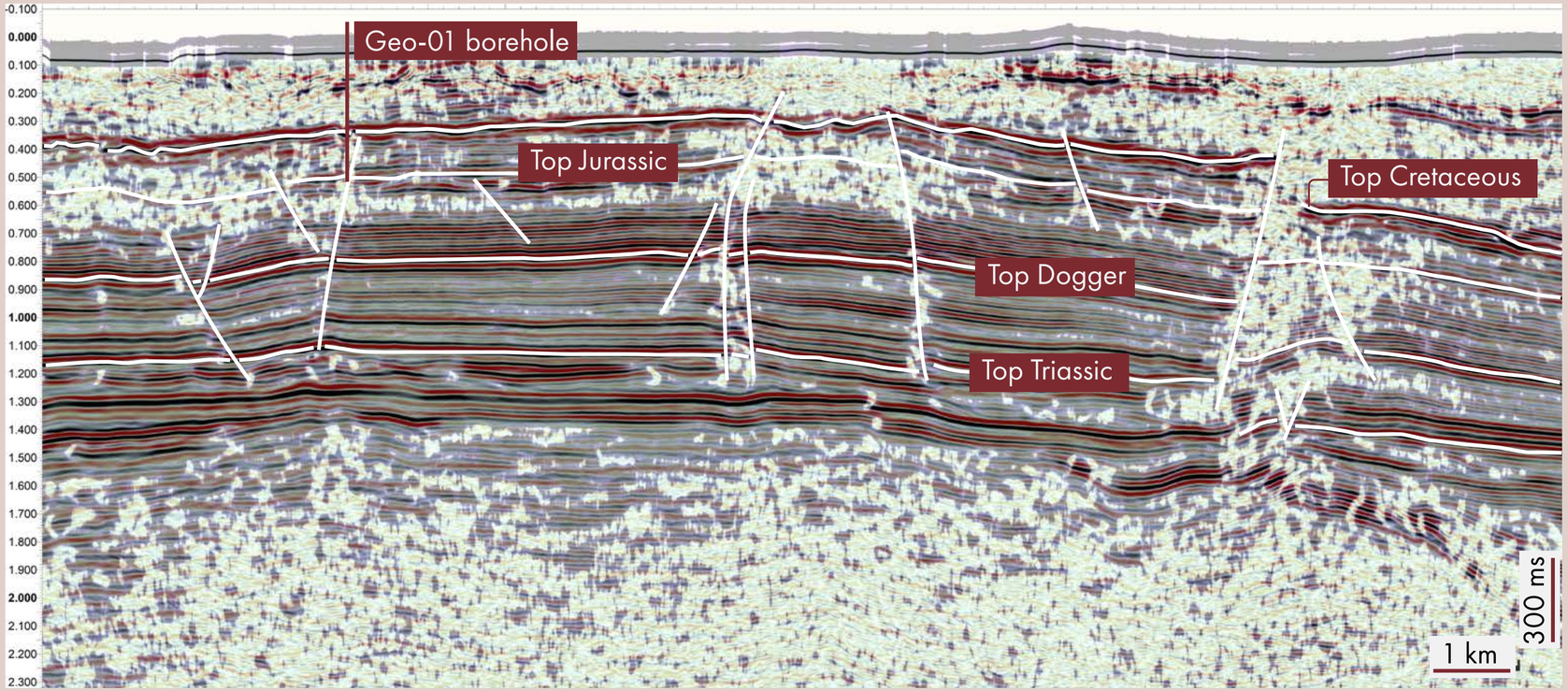
The minibus-sized Eureka 3 is envisioned to be the final prototype model that will pave the way for commercial use of the AUVs in a fleet. Impossible Metals have indicated that these might be ready for operations from 2026. ■

# Geneva: Why 3D seismic is essential for effective geothermal exploration

In a drive to cut its dependence on fossil fuels for heating, the canton of Geneva in Switzerland aims to develop its geothermal resources. But how to find the best places to drill geothermal wells?

Based on recent work that included the drilling of two exploration wells and acquiring 2D seismic lines, it transpired that a full 3D seismic coverage of the city was required in order to better map faults cross-cutting the Jurassic and Lower Cretaceous carbonate succession and the karst features that are associated with the top of the Mesozoic carbonate succession.

Here, we report on the challenging yet successful acquisition of the Geneva 3D survey. A survey that has resulted in a significant de-risking of future drilling sites through the details that have now been made visible for the first time.




Composite line through the 3D seismic survey, showing the location where the Geo-01 well was drilled. The strike-slip nature of the fault that was dissected is apparent through the lack of significant vertical offset at the well location. Image by Services Industriels de Geneve & Pro-Gaia Invest SA.

This timeslice below shows the top of the Cretaceous carbonate succession in the Geneva area. Observe the erosional channels, karst features and sinkholes, plus the major fault zones dissecting the interval. Without the 3D survey, these features would have been much harder to map, as the results of the Geo-01 and Geo-02 boreholes have proven.

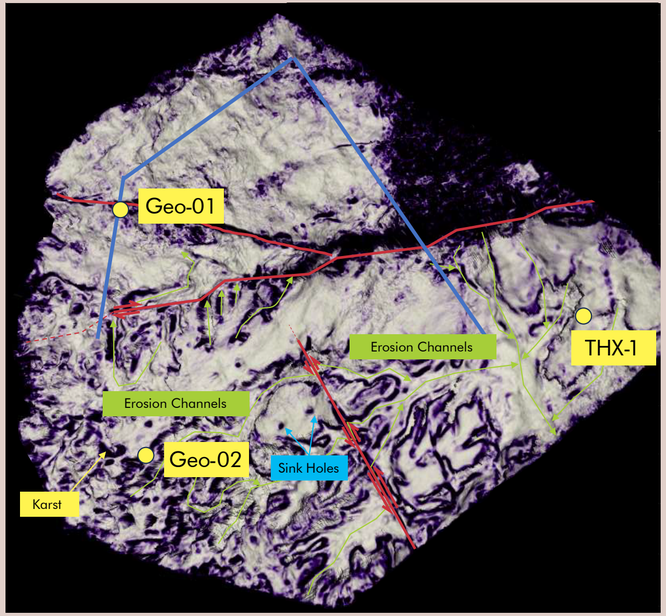
Geo-01 drilled into a fault zone and resulted in high fluid flow on test, but the Geo-02 did not find a similar fault zone. However, it did unexpectedly encounter the sandy and porous infill of a significant karst feature that can be used for seasonal storage of fluids given the porous and confined nature of the infill.

This rapidly led to the conclusion that a 3D seismic survey was required to both map the faults in the Geneva area better, as well as gain more control on the distribution of the karstified zones that can be used for seasonal storage.

With this 3D coverage of sedimentary features and faults now available, the geological model can be refined to an extent that future well planning can be carried much more accurately, minimising the risk of drilling into tight formations.

Two new wells have already been planned in the Malm and Dogger units and if successful these drillings will move directly from the exploration phase to the exploitation phase by 2026.

smart seismic solutions



# Cost-effective 3D seismic acquisition in a dense urban environment

**Covering an entire Swiss city, including its surrounding vineyards, neighbourhoods in France, a lake, an international airport and many other restricted places such as ONU, CERN, embassies and a golf course, that is what the Geneva 3D seismic acquisition was about**

THOMAS BIANCHI, PATRICK ROBERT AND JEAN-BAPTISTE CHALVIDAN, SMART SEISMIC SOLUTIONS (S³)

TO PROPERLY IMAGE the shallow targets, a dense survey with 160 m between receiver lines and varying source line spacing, from 160 m to 240 m, was designed. With some narrow streets and exclusion zones due to dense buried networks and sensitive buildings, it would be very challenging to conduct a conventional acquisition with fleets of 2 to 4 vibrators as it would result in an excessively high level of cancelled vibrated points. Therefore, a single vibrator acquisition with denser sampling was chosen.

## A HIGH-PRODUCTIVITY TECHNIQUE

This decision was taken after a 2D test, which demonstrated that dense single-vibrator acquisition can properly image the deepest targets. This kind of acquisition needed to be combined with a high productivity technique in order to be conducted in a limited timeframe for economic reasons and to limit exposure to the local population.

S³ proposed its established high-productivity technique, SRS (Simultaneous Random Sweep), which is very well suited for geothermal seismic acquisition usually conducted in urban environments.

This technique uses dedicated broadband random sweep for each vibrator. One of the advantages of random sweep is that it limits the peak particle velocity and it avoids the resonance phenomena which could result in damaging infrastructure. The acquisition is carried out with up to 10 vibrators working simultaneously, vibrating as soon as they are in position, without classical limitations in space and time.

It avoids any need for real-time synchronisation between the vibrators, which would limit the productivity and add complexity to the operations.

Instead of conventional correlation, Ground-Force deconvolution combined with a deblending algorithm is used in order to retrieve the seismic response of each vibrator free of interferences. This is made possible due to the use of a unique random sweep for each vibrator which weakly correlates with the other vibrator's sweep. The residual interference is then subtracted by the algorithm.

Another advantage of the SRS technique is its ability to strongly attenuate transient noises from cars, trucks and trains, which are the main strong sources of noise in an urban area.

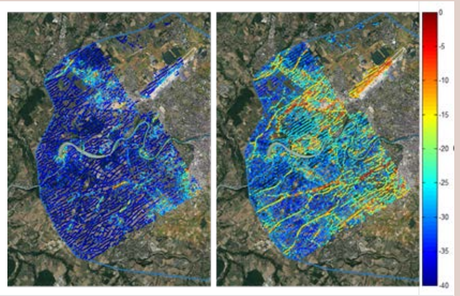

## REAL-TIME TRANSMISSION

On the receiver side, Sercel WiNG nodes were selected. The nodes are equipped with the latest generation low-noise Mems accelerometers. They form a mesh network which has the ability to transmit in near real-time the position, status and tilt of the whole recording spread to one centralized QC office. This feature is of extreme importance in a populated area where nodes may be moved by malicious or just ignoring people. It helps to replace quickly moved or defective units and to find them when they have been thrown away, minimizing the potential losses of data and material.

Finally, in the lake an 840 cubic inch airgun source and 530 cabled hydrophones were selected to avoid a loss of illumination in an important part of the prospect.

## ANTHROPOGENIC NOISE

The survey took place in a populated area with high levels of anthropogenic noise, especially in the centre of the city and along the main transportation axes. After tests showed that noise levels decreased by an average factor of 3 during the night and up to a factor of 10 in the noisiest areas, it was decided to record during night in order to maximise the S/N ratio without using large arrays of heavy vibrators.




The difference in noise level between day and night time in Geneva, Switzerland. This formed the basis for acquiring data during the night.

## OPERATIONS

Four different types of vibrators were mobilised in order to adapt the source to the different terrain conditions. In the city area, small and medium vibrators such as IVI Envirovib and Prakla VVA were used, whereas heavier vibrators, AHV IV and Hemi 48 were reserved for land use or major roads.

The recording operation took place between 13 September and 16 October 2021, with a production reaching up to 2100 Vp's / day. The production was usually limited by receiver layout/pickup. An average spread of 20,000 nodes was maintained on the field with a rotation of 1,500 traces per day.

This high productivity could be reached thanks to simultaneous shooting, strong efforts on the permitting side, and pre-planning, which was done months in advance but had to be reassessed on the fly in some parts of the city.

Careful pre-planning of vibrator displacement was done on a daily basis. Each vibrator was escorted by a traffic control team and a PPV (peak particle velocity) team that stops the vibration if the ground velocity exceeded pre-defined and legal thresholds.

Some VP were acquired in very uncommon areas such as an international airport and a golf course where carpet rotation was put in place in order to preserve the integrity of the fairway.

## DOING IT SMARTLY

With the energy transition progressing, a better understanding of the geology beneath our cities is crucial in order to develop geothermal solutions for heat generation, cooling and heat storage.

These applications have usually lower return on investment than oil and gas and exploration budgets can be more limited.

Therefore, only a smart way of acquiring 3D seismic surveys will result in a cost-effective acquisition with limited disturbance.

PHOTOGRAPHY: S³

A rather unconventional location to acquire seismic data – Geneva International Airport.

HOT SPOT

# Major drilling campaign planned for the new mega-gas trend in Indonesia



**Indonesia is keen to develop new oil and gas basins, against a backdrop of decreasing domestic production and increasing imports**

JONATHAN CRAIG, NVENTURES

GAS RESOURCES play a crucial role in future energy planning, as a transitional fuel and also a path to energy exports, vital to a burgeoning economy. While core areas such as Makassar and Mahakam continue to contribute new gas reserves, the industry has high hopes for a new frontier gas play to the north of Sumatra, in the Andaman Sea.

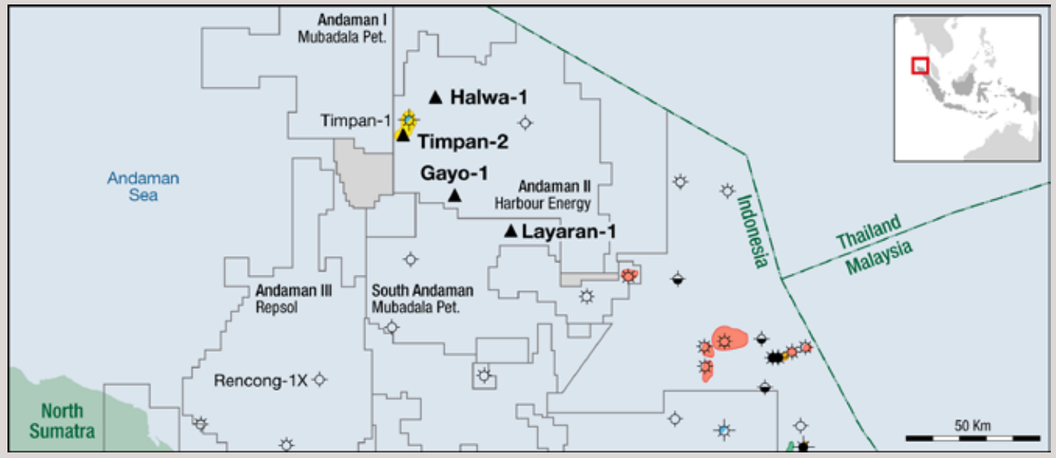
Mubadala, bp, Harbour Energy and Repsol have built a material position in the Andaman Sea, offshore Aceh, with interests in Andaman I, II & III, and South Andaman. In Andaman II specifically, Harbour, bp and Mubadala have successfully drilled a new multi-TCF gas play with success at Timpan 1 in 2022.

Andaman II was awarded to Premier (now Harbour) in 2018, on the back of the 2017 Bid Round. Harbour then joined South Andaman and Andaman I in 2020 along with bp. Mubadala operates Andaman I and South Andaman. Repsol operates Andaman III, on the western flank of the basin.

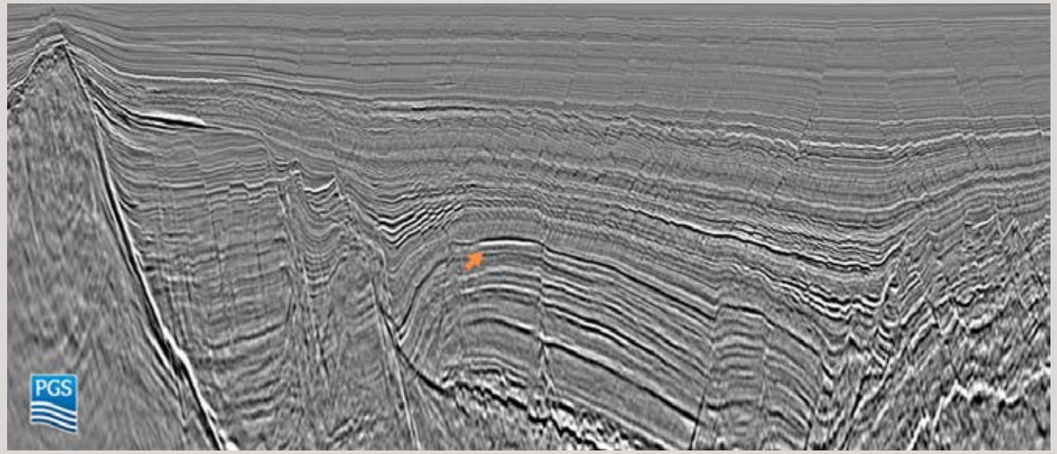
The Andaman South and II groups secured the return of the West Capella drillship to drill the Andaman acreage in 2023 and 2024. This should commence later in 2023, with the drilling of the amplitude-supported Layaran prospect on Mubadala's operated Andaman South licence, followed by the Halwa prospect to the northeast of Timpan and the Gayo prospect to the southeast of Timpan on Andaman II. In the meantime, the group plans to appraise Timpan with Timpan 2 in Q1 2024. The mid-case resource for Timpan is 1 TCF, with a 6-12 TCF target volume across the entire play.

## NOT ONLY FOR THE DOMESTIC MARKET

Success in finding these volumes will lead to a significant development and export scenario. There is of course a strong gas market in Indonesia, but the operators are also considering pipeline offtake to Thailand, Malaysia and Singapore. LNG is also a strong potential market, with offtake being considered at the nearby Arun LNG terminal, which is currently in re-gas/import mode according to reports. First gas could be realised by 2030, depending on the results of this drilling campaign.




Following the successful completion of Timpan 1 in 2022, the months to come will see three more adjacent and high-potential prospects drilled: Lavaran, Halwa and Gayo, in addition to an appraisal well on Timpan itself.




Seismic line through the Andaman II Block in Indonesian waters, clearly illustrating the Timpan flat spot. Kindly provided by PGS.

## TIMPAN

The Timpan 1 exploration well was drilled in July 2022 on the Andaman II licence offshore North Sumatra, Indonesia. The partners in the licence are Premier Oil Andaman Limited, (Harbour Energy Company, 40%), bp (30%) and Mubadala (30%). Water depths are around 1,300 m, with depth to target around 4,200 m in this play. The "play opener" well encountered a 119 m gas column in a high net-to-gross, fine-grained sandstone reservoir with associated permeability of 1-10 mD. A full data acquisition programme was carried out including wireline logging, 73 m of core recovered and a drill stem test. Harbour announced that during testing the well flowed at 27 mmscfgd and 1,884 bpd of associated 58 deg API condensate through a 56/64" choke. Timpan is understood to be a four-way dip closure structure in Upper Oligocene sands in the North Sumatra Basin. 3D was shot here and over adjacent prospects by PGS in Q3 2022.

## TURBIDITES AND CARBONATES

The "Timpan trend" is within the North Sumatra Basin, south of the Mergui Basin, a deeper basin with potential gas source rocks. There are numerous structural depocentres across the area with mainly Oligo-Miocene age deposits. Within these basin-lows are often slope and turbidite clastics, associated with a gas trend that is becoming more understood, and often supported by strong amplitudes and DHIs. Intra-basinal highs are associated with carbonate reefs and build-ups, for example the Arun Limestone. These limestones are more challenging targets but well known to Indonesian explorers. An attempt to extend the carbonate build-up play failed in the southwest of the basin, where Repsol's and Petronas' well Rencong 1X presumably came up dry in July 2022 even though the operator did not confirm this.

## KEEPING AN EYE

The industry will be closely watching the next exploration wells to be drilled on this trend.

Gayo-1 and Halwa-1 on Andaman II are similar four-way dip closures with amplitude support. Harbour do report that Gayo and Halwa may have shallower reservoir targets (Miocene) than those encountered at Timpan (Late Oligocene), which may in turn deliver better reservoir properties. Halwa has a large amplitude response similar to Timpan, along with a pronounced gas chimney. Timpan Utara is a similar feature to Timpan and may well be in the multi-well appraisal programme planned in early 2024. Further south in the Mubadala-operated South Andaman block, Layaran 1 is planned for October 2023 on the amplitude-supported Layaran prospect, between Timpan and the smaller JAU discovery on the Krueng Mane Block by Eni. Lasmo tested this play in 2000 with the Bungong Jeumpa-1, with no discovery reported.

Along with the wildcat drilling, a Timpan appraisal is planned for early 2024. Timpan-2 will be drilled southwest of the Timpan-1 discovery.

With a major multi-TCF gas trend revealed at Timpan, and several exploration and appraisal wells committed on these blocks, the South Andaman region of the North Sumatra basin will be keenly watched, as the long tradition of gas development in Indonesia receives yet another lease of life. ■

# A can-do mentality required

**The change from a big company to a very small team meant a change of approach to getting things done for Iain Brown when he took on the editor role for GEO EXPRO in 2020**

IT'S FUNNY, says Iain Brown, "I had been an avid reader of the magazine for years when I was asked to take over the editor position from Jane Whaley, but until that very moment I had never thought of that being an option!" But, it happened.

It was 2020, the start of the pandemic, and it came at the right time. "I had just finished a consultancy job and the world came to a sudden stop. In such a situation, what is better than working from home and connecting to the world using modern technology to source content for a magazine?" asks Iain rhetorically.

"Being an editor really puts you in the driving seat as to what goes into the magazine, and it makes you communicate with an amazingly diverse group of people from potential writers to designers and marketing managers. Being an editor is surely not the worst job in times of a lockdown, at least if you are a person who likes speaking to people and finding out what they do", laughs Iain.

**"Making sure that authors were meeting their deadlines was probably the most stressful aspect of it all."**

Iain Brown

It was a steep learning curve though. "Luckily, I enjoyed a very good handover from Jane, who had been doing the job for more than a decade. That helped a lot, but ultimately, from the day you start, it's you being the focal point for all the contributing authors and other people involved in the production process. Making sure that authors were meeting their deadlines was probably the most stressful aspect of it all."

"For me", continues Iain, "it was a rather big change from working in a large multinational company with many people having dedicated task portfolios to a very small outfit where there is much more of a can-do-everything attitude. And that is surely what the very small GEO EXPRO team was about. But even though we were all in different places, communication was excellent and we all had the same goal of meeting those six deadlines a year."

The editor may be the only person who reads the magazine from A to Z, more than once. "I particularly enjoyed learning about fascinating aspects of geology that I would never normally have come across. I remember an intriguing article about Lake Kivu in Africa's Western Rift Valley and its associated resources and dangers as well as some great pieces on planetary geology", says Iain.

"The magazine has evolved a fair bit since I left, and it does not offer so much of the broader geological topics anymore. I miss that to a certain extent, but at the same time I do like the new format with the returning sections and the fresher look is more visually appealing too."

Since July 2022, Iain has been back in geophysical surveying business where he was before, but now focused on airborne rather than marine geophysics. "The airborne gravity gradiometry business is a huge growth area and the company is conducting more and more projects exploring for renewables such a geothermal resources, as well as minerals. At the same time, oil and gas remain an important business area too, with gas exploration only likely to grow as demand increases due to the transition." ■





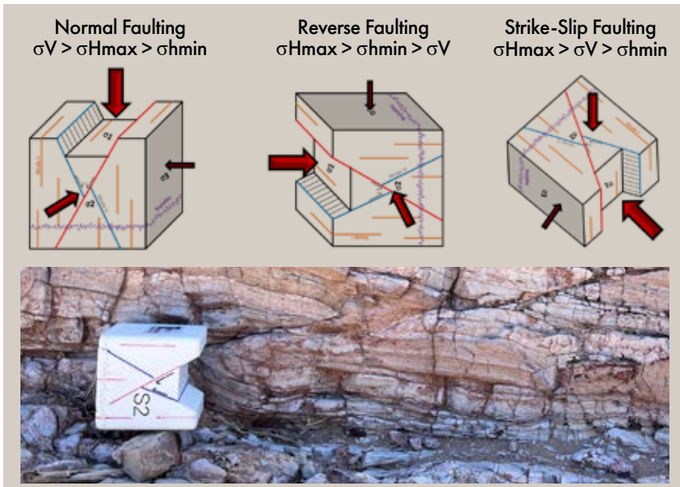
# Who's Andy? And what did he know about faults?

Dr. Molly Turko,
TurkoTectonics@gmail.com

**Scottish geologist Ernest Masson Anderson published "The Dynamics of Faulting and Dyke Formation with Applications to Britain" in 1951. It became a classic paper describing what is commonly called "Andersonian Fault Theory."**

**DR. MOLLY TURKO, DEVON ENERGY**

ANDERSON'S THEORY classified faults based on the orientation and magnitude of the principle stresses. The magnitudes are defined by S1 (maximum stress), S2 (intermediate stress) and S3 (minimum stress). The orientations are defined by SV (vertical stress), SHmax (maximum horizontal stress), and Shmin (minimum horizontal stress). Sigma (σ) is also commonly used in place of the "S". The cubes shows the three basic fault regimes that can be defined using the Andersonian Fault Theory. When S1 is vertical, it is a normal faulting regime. When S1 is horizontal and S3 is vertical, it is a reverse faulting regime, but when S2 is vertical it is a strike-slip regime.




How an Andy cube can be used in the field, in this case to illustrate movement along a reverse fault.

## ANGLES

A general rule of thumb is that the conjugate faults (red and blue lines in the cubes) form at about 60° to each other, which is +/- 30° to S1. This rule remains true for each type of faulting regime as S1 becomes rotated from vertical to horizontal. The strike of the faults (red and blue lines) also remains parallel to S2, and perpendicular to S3. Structural geologists tend to measure the dip of a fault plane from horizontal, therefore a normal fault would form close to 60°, a reverse fault close to 30°, and strike-slip fault close to 90° using the basic Andersonian Fault Theory. However, when measuring fault strike and dip relative to S1, S2, and S3, the relationships remain the same regardless of the faulting regime.

## SHEAR FRACTURES

Faults are also commonly classified as Mode II fractures, "shearing" mode. In contrast, Mode I fractures are known as "opening mode" fractures (orange lines in cubes). These also strike parallel to S2 and open in the direction of S3 since it is the minimum amount of stress to overcome. Mode I fractures can go by many names including tension fractures, extension fractures, joints, and veins. Along with faults, opening mode fractures are great kinematic indicators for paleo-stress orientations.

## PRESSURE DISSOLUTION

Stylolites are also great kinematic indicators for stress directions. These are pressure dissolution features that form perpendicular to S1. These types of fractures are common in carbonate rocks but can also form in other rock types. They are often classified as Mode IV "closing" fractures. The serrated surfaces develop as soluble minerals dissolve under high stress, which can then be deposited elsewhere, leaving behind the geometry seen as purple "squiggles" in the cubes.

By understanding the basic relationships between fault and fracture orientations and stress, a geoscientist can begin to predict the stresses or paleo-stresses that created observable fracture patterns. Alternatively, if the stresses are known, then a geoscientist can predict fracture patterns. ■

*Do you want your own Andy Cube?*
*Visit turkotectonics.com*

NOTHING BEATS THE FIELD

# A famous North Sea unconformity in outcrop

The most important gas fields in the Southern North Sea region are reservoired in Upper Permian Rotliegend aeolian and fluvial sandstones. Thousands of wells have been drilled to test this succession of dryland deposits, only to call TD once the underlying Carboniferous rocks appeared on the shakers. In Germany, near the town of Hettstedt, the boundary between the Carboniferous and overlying Rotliegend sandstones is beautifully exposed (see arrow). Even though the age of the Rotliegend sandstones here may be slightly older than the ones found in the North Sea, the same unconformable contact can be traced across a major area in the basin. It marks a time gap of around 40 million years, a time when this part of Europe migrated from the mostly tropical environments that characterise the Carboniferous succession towards the much drier Late Permian depositional environments in a more northerly position.

Photo: Geert-Jan Vis, TNO – Geological Survey of the Netherlands

**FEATURE YOUR OUTCROP**

In this series, we show a range of outcrops to give more context to what core interpretation typically allows. Do you have a suggestion for an outcrop feature? Get in touch with Henk Kombrink – henk.kombrink@geoexpro.com.

# The northern Perth Basin in a nutshell

## Using core photos, this is the second and final article describing the Permian and Triassic infill of one of Australia's onshore exploration hot spots

AMELY ALLGÖWER, MGPALAEO

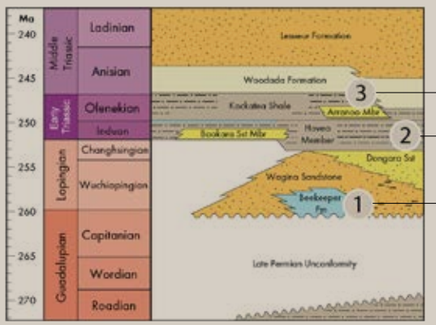
THE NORTHERN Perth Basin forms a large, north-south trending rift basin, extending approximately 150 km wide. The northern Perth Basin is currently one of the most active areas of petroleum exploration in Australia, holding most hydrocarbon accumulations discovered in the Perth Basin thus far, including all the presently operational oil and gas fields. The basin is also piquing interest in Carbon Capture and Storage projects.

Comprising a series of horsts and grabens, the basin was shaped through a long history of rifting episodes that commenced prior to the Early Permian and culminated in the separation of Greater India and Australia during the Early Cretaceous.

One of those rifting events occurred during the Guadalupian and resulted in the widely recognized Late Permian Unconformity. The Upper Permian Beekeeper Formation, Wagina Sandstone and Dongara Sandstone were deposited as the first post-rift sediments in shallow marine environments. The Beekeeper Formation, a limestone to carbonate-rich siltstone, time equivalent to the Wagina Sandstone, forms the gas reservoir in some areas in the southern parts of the basin (Core 1).

Subsequent thermal subsidence resulted in a marine transgression with deposition of the Upper Permian to Lower Triassic Kockatea Shale, contained within which are three distinct members. The lowermost members are the shallow marine "hot" sandstones of the Bookara Member and the coeval Hovea Member, an important oil source rock and regional seal to underlying reservoirs. Initial sediments of the Hovea Member comprise black, carbonaceous and inertinitic shales interbedded with silty sandstones before a sapropelic interval of cryptalgal to stromatolitic limestones and medium to dark grey and dark brown and anoxic shales were deposited (Core 2).

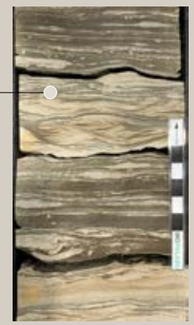
The uppermost member of the Kockatea Shale is the Arranoo Member which consists of generally fine-grained, wave- to tidally-influenced sandstones (Core 3). The Kockatea Shale is conformably overlain by the Woodada Formation, before a second phase of rifting in the Late Triassic and Early Jurassic led to the widespread accumulation of fluvial and deltaic sediments. ■




Northern Perth Basin stratigraphic chart, showing the Permian and Lower/Middle Triassic sedimentary succession.

Siliciclastic expression of the Beekeeper Fm with abundant bioclastic material including solitary corals, bryozoan, crinoids. Well Jurien-1, core 5.

Ammonite within the Early Triassic parts of the Kockatea Shale in well Frankland-2 (2191 m).



Contact between the Upper Permian Wagina and overlying Dongara sandstone reservoirs in well Dongara-24 (1527 m).

SOURCE: MGPALAEO

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